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ORGANIC CHEMISTRY

BY

F. SHERWOOD TAYLOR

Ph.D., M.A., B.Sc.

FOURTH EDITION



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PREFACE

In presenting a new text-book of Organic Chemistry, my object has been to provide a book from which the student may at once easily gain a grasp of the essential principles and logical structure of the subject, and at the same time find, compactly and accessibly collected, all essential significant facts about the commoner organic compounds.

The chief novelty to be found in the matter of the book lies in the treatment of the Carbohydrates as cyclic compounds. This treatment involves a sacrifice of simplicity to truth; but a general adoption of these formulæ in elementary text-books is now overdue. Modern catalytic methods for the preparation of various substances, *e.g.*, methyl alcohol and phthalic anhydride, have also received due mention.

The requirements of the medical student have been given the first place in deciding upon the matter to be treated, and accordingly the treatment of the Carbohydrates, Alkaloids and Proteins is somewhat fuller than is usual in a book of this scope. It will, however, be found that the requirements of the unspecialised student of chemistry have not been neglected.

I wish to acknowledge the assistance I have received from numerous standard works on Organic Chemistry, theoretical and practical.

I also wish to record an especial debt of gratitude to Dr. A. D. Mitchell, assistant editor of the *Journal of the Chemical Society*, for most valuable assistance at every stage of the production of the book.

I am also glad to acknowledge the kindness of Professor W. N. Haworth and Dr. S. M. Reynolds of Birmingham University in assisting me with information and advice as to modern views on the Carbohydrates.

My thanks are also due to the following who have kindly assist me by giving permission to reproduce illustrations:—

Mr. W. B. Randles, of the Technical College, Derby, who was k enough to take the microphotograph of starch grains reproduced Fig. 47; Messrs. Edward Arnold, for Fig. 43, redrawn from Profes Haworth's "Constitution of Sugars"; Messrs. Blackie, for Fig. 4 reproduced from Bernthsen's "Text-book of Organic Chemistry Messrs. W. J. George Ltd., for Fig. 39.

I should also like to take this opportunity of expressing r indebtedness to Mr. H. Wren, who is responsible for the majority the line illustrations, and to that member of my publishers who w responsible for the solution of numerous problems of production a for the checking of the proofs.

F. S. T.

REPTON,
March, 1933.

PREFACE TO THIRD EDITION

IN this, the third edition, a few corrections have been made. Th treatment of fermentation has been brought up to date and notices o certain substances of physiological importance, *e.g.*, ascorbic acid nicotinic acid, mandelic acid, sulphanilamide, have been added.

F. S. T.

MUSEUM OF THE HISTORY OF SCIENCE,
OXFORD, 1940.

PREFACE TO FOURTH EDITION

(SECOND IMPRESSION)

A NUMBER of corrections and additions have been made, to include the industrial and other advances of the last seven years.

F. S. T.

MUSEUM OF THE HISTORY OF SCIENCE,
OXFORD, 1948.

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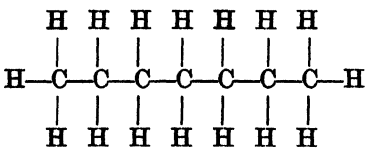
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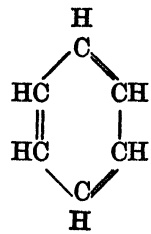
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2. Characteristics of Organic Compounds.—One unique quality of the atom of carbon is the cause of the exceeding complexity of its chemistry. *Molecules containing long chains of carbon atoms linked together are stable.*

Such compounds as heptane or benzene are very stable in spite

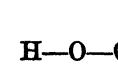


Heptane.

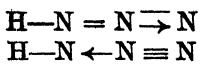


Benzene.

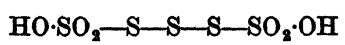
of their having many carbon atoms linked together. In contrast to these, a compound with a chain of more than a few of any other kind of atom is markedly unstable. We may instance hydrogen peroxide, hydrazoic acid, pentathionic acid as compounds with chains of atoms other than carbon. All are relatively unstable.



Hydrogen peroxide.



Hydrazoic acid.



Pentathionic acid.

This characteristic property of carbon accounts for the existence of organic chemistry. Attention will be drawn to other characteristics of organic compounds as and when they are encountered in the course of our study.

DETERMINATION OF THE FORMULA OF AN ORGANIC COMPOUND

In order to discover what elements are present in an organic compound, we employ the following tests:—

3. Detection of Carbon and Hydrogen.—If the subject dealt with is known to be an organic compound, there is little need to test for these elements, and the test is mainly of value in determining whether a substance is or is not organic.

The test depends on the fact that all organic compounds are oxidised and completely broken up by heated copper oxide. If the compound to be tested is a solid the procedure is simple.

Powdered copper oxide is dried by heating it to low redness. It

Let the gain of weight of the sulphuric acid U-tube be x g., that of the potash bulbs and guard-tube be y g., and the weight of the substance taken be w g.

Then w g. of substance form x g. water and y g. carbon dioxide, therefore w g. of substance contain $\frac{x}{9}$ g. hydrogen and $y \times \frac{12}{44} = y \times \frac{3}{11}$ g. carbon;

$$\text{therefore percentage of hydrogen} = \frac{100x}{9w}$$

$$\text{percentage of carbon} = \frac{300y}{11w}$$

The process needs no small degree of skill and experience and is rather tedious and cumbersome. It is now being rapidly replaced by the process of micro-combustion, similar in principle but employing much smaller apparatus. This method is quicker and also requires only very minute quantities of material—a great advantage with a newly discovered substance.

8. Determination of Nitrogen in an Organic Substance. —*Dumas' Method.*—Dumas' method depends on the decomposition of the compound by heated copper oxide and a bright metallic copper spiral, the final products being carbon dioxide, water and gaseous nitrogen. The latter is collected over a solution of caustic potash and measured. The apparatus is shown in Fig. 3.

A combustion tube about a metre long contains (1) a weighed amount of the substance mixed with a con-

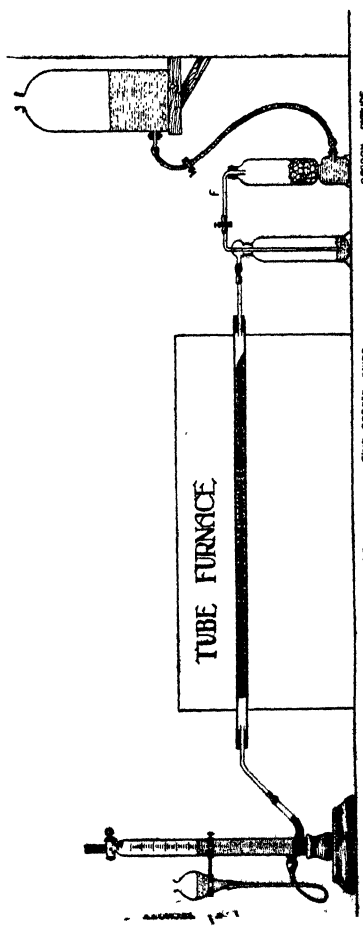


FIG. 3.—Dumas' Method for determination of Nitrogen.

siderable excess of fine copper oxide; (2) a layer of coarse copper oxide; (3) a spiral of bright metallic copper gauze, (to decompose any oxides of nitrogen) prepared by heating the gauze in the flame, plunging it into a tube containing a little methyl alcohol (which reduces any oxide to the metal) and drying at 100° C.

An apparatus for generating carbon dioxide from marble and dilute hydrochloric acid delivers a stream of the gas through a wash bottle into the combustion tube.

To the other end of the combustion tube is attached a 'nitrometer' (Fig. 3) containing a 40 per cent. solution of caustic potash. Caustic soda is unsuitable owing to the local formation of the sparingly soluble sodium bicarbonate which may block the tube.

The carbon dioxide is passed through the tube until all air has been removed and the coarse copper oxide (but *not* the fine oxide containing the substance to be analysed) is made red hot. When a test portion of gas collected in the nitrometer is completely absorbed by the potash all air is known to be displaced. The current of gas is stopped and the nitrometer is filled. The fine copper oxide is now gently and progressively heated and nitrogen collects in the nitrometer, all carbon dioxide and water from the combustion being absorbed or condensed. When no more gas is evolved, the carbon dioxide stream is turned on and the nitrogen in the combustion tube is displaced into the nitrometer. The nitrogen is measured and its volume is read off and corrected for temperature and pressure. (The vapour pressure of water over 40 per cent. KOH is only about half its vapour pressure over pure water.)

If w g. of substance produce x c.c. of nitrogen at N.T.P., the w g. of substance contain $x \times \frac{14}{11200}$ g. of nitrogen and the percentage of nitrogen is $x \times \frac{14 \times 100}{11200w}$ or $\frac{x}{8w}$.

Kjeldahl Method.—A method of determining nitrogen which is much more easily carried out is the Kjeldahl process, which depends on the fact that many organic nitrogen compounds[1] are converted into ammonium sulphate when heated with concentrated sulphuric acid. The liquid is then treated with excess of alkali and the ammonia is distilled into standard acid and the proportion of this neutralised by it is ascertained by titration.

A weighed quantity of the substance (*ca.* 1—5 g.) is placed in a special Kjeldahl flask (Fig 4); 20 c.c. of concentrated sulphuric acid are added, and the flask is loosely stoppered. The liquid is

[1] Certain organic compounds do not give satisfactory results, notably those containing the $-NO_2$ and $-N=N-$ groups. These may be previously reduced with zinc dust to [illegible]nd then give satisfactory results.

heated over the small flame of a micro-burner. After about twenty minutes 10 g. of solid potassium sulphate are added and heating is continued till the contents of the flask are colourless. The

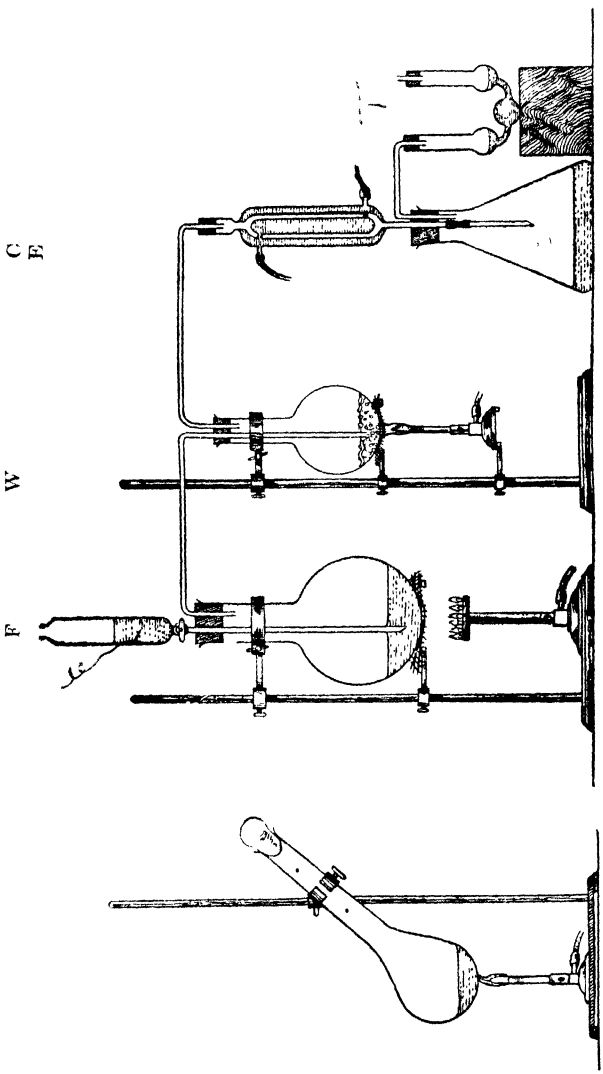


FIG. 4.—Kjeldahl Method for Determination of Nitrogen.

completion of the process is accelerated by the addition of a small crystal of copper sulphate. The nitrogen of the organic compound has now been wholly converted into ammonium sulphate. The cold liquid is then completely rinsed into the flask (F) of a distillation

apparatus such as is shown in Fig. 4. The tap funnel is filled with concentrated (50 per cent.) sodium hydroxide. One or two pieces of pure zinc are placed in the flask to avoid bumping. The flask is connected to a second flask W containing a little water which is vigorously boiled throughout the experiment. This latter flask is connected to a condenser C the lower end of which passes into a flask (E) containing normal acid. An exit tube passes to a ⋃-tube (T) which also contains some standard acid. The flask and ⋃-tube together contain 30 c.c. of *N*-acid.

The sodium hydroxide is slowly run into A with gentle agitation to ensure mixing; it decomposes the ammonium sulphate, liberating ammonia. The liquid is boiled and steam and ammonia pass through the flask W, where any spray of alkali is deposited, into the condenser and flask where the ammonia partly neutralises the standard acid. When a drop of the distillate is no longer alkaline, the acid from E and T is titrated.

If x c.c. of *N*-acid have been used up, $\frac{x}{1000}$ equivalents of NH_3 containing $\frac{x \times 14}{1000}$ g. of nitrogen have been evolved.

If w g. of substance were used then it contains

$$\frac{x \times 14 \times 100}{w \times 1000} = \frac{1{\cdot}4x}{w} \text{ per cent. nitrogen.}$$

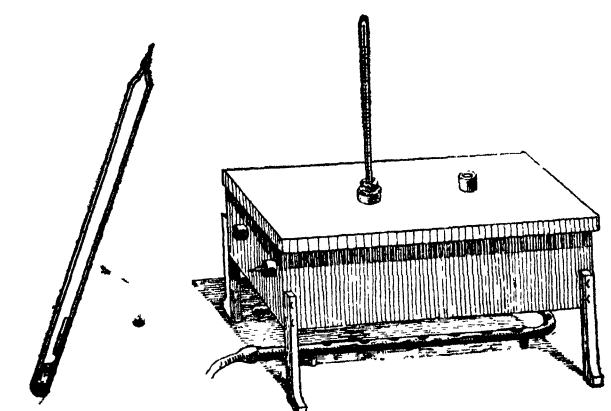


FIG. 5.—Carius' Method for Determination of Sulphur.

9. Estimation of the Halogens and Sulphur.—The usual method for determining sulphur or the halogen elements consists in oxidising the organic compound containing them by means of nitric acid under pressure. Sulphur is oxidised to sulphuric acid which is

estimated as barium sulphate. Halogens are converted into silver halides and weighed as such.

The method of Carius, as it is termed, is carried out as follows:—

Estimation of the Halogens.—A piece of fairly stout hard-glass tubing is closed at one end and somewhat constricted at the other. Some powdered silver nitrate and then a small quantity (*ca.* 1·5 c.c.) of fuming nitric acid (*d.* 1·5), free from halogens, are placed in the tube, and a weighed amount of the substance contained in a small weighing tube is introduced. The tube is then sealed off (Fig. 5) leaving a *stout* capillary at the end.

The tube is now heated in an iron jacket contained in an iron box (Fig. 5) heated by burners from below, and the temperature is allowed to rise slowly to *ca.* 250° C. This method of heating is necessary, as the high pressures developed may lead to a dangerous explosion. After about seven hours the tube is allowed to cool, and the pressure is released by softening the projecting capillary with a Bunsen burner, until a hole is blown in the glass. The tube must not be removed until the pressure, possibly dangerously high, has been released. The end of the tube is cut off, it is removed from the oven, and its contents washed into a beaker. The silver halide is boiled with water, collected in a Gooch crucible, dried and weighed.

Suppose that w g. of the substance are taken and the precipitate consists of x g. of silver bromide.

x g. of silver bromide contain $x \times \frac{80}{108 + 80}$ g. bromine,

$\therefore$ the substance contains $\frac{80x}{1{\cdot}88w}$ per cent. Br.

Estimation of Sulphur.—The procedure is similar, but in place of silver nitrate a little potassium bromide is added to the nitric acid. This liberates bromine which increases the oxidising activity of the nitric acid. The final product is sulphuric acid. The tube is opened with the precautions mentioned above and its contents washed out. The nitric acid is removed by repeated heating with concentrated hydrochloric acid, and the sulphuric acid precipitated as barium sulphate by adding to the boiling solution a hot solution of barium chloride and ammonium chloride. The precipitate is washed by decantation, filtered off, washed, dried, ignited and weighed.

If w g. of the substance yield x g. of barium sulphate, they contain $\frac{32x}{233{\cdot}4}$ g. of sulphur, and the percentage of sulphur is $\frac{3200x}{233{\cdot}4w}$.

Phosphorus may also be estimated by Carius' method. It is oxidised to phosphoric acid and weighed as magnesium pyrophosphate.

Metals are estimated, as a rule, by igniting a known weight of the compound and estimating the metal in the residue by the usual methods of inorganic analysis.

Determination of Oxygen.—There are no simple means of determining the proportion of oxygen in an organic compound. The usual procedure is to determine the percentages of all the other elements present and subtract the sum of these from 100.

This procedure has disadvantages. In the first place the presence of an element has sometimes been overlooked and the proportion of oxygen thus over-estimated. Secondly, the results afford no check on the accuracy of the analysis. Thirdly, the figure for oxygen is inaccurate by an amount equal to the sum of the errors of all the determinations.

Recently a method of determining the oxygen directly has been devised. A known weight of the substance is heated in a current of hydrogen, and the vapours evolved are passed over heated metallic nickel. The oxygen in the compound is wholly converted into water, which is absorbed by calcium chloride and weighed.

10. Calculation of Empirical Formula.—The experimental methods already described have enabled us to find the percentage composition of any organic compound. From these data we can obtain the *empirical formula*, *i.e.*, the simplest formula which corresponds to the percentage composition of the compound. The true formula is either the same as the empirical formula or a multiple of it.

The formula expresses the relative numbers of each kind of atom present. By dividing the total weights of each kind of atom (as given by the percentage composition) by the weight of each atom (given by the atomic weight) we obtain the proportion by number of each kind of atom, and this gives us the simplest formula. An example will make this clear.

The substance chloroform contains 10·05 *per cent. of carbon*, 0·84 *per cent. of hydrogen, and* 89·11 *per cent. of chlorine. What is the simplest formula possible for chloroform?*

The atomic weights of carbon, hydrogen and chlorine, are 12, 1, and 35·5, respectively. In order to find the numbers of atoms in the weights of carbon, hydrogen and chlorine given in the percentage composition, we must divide the weights of these elements by the weight of a single atom.

The relative numbers of atoms are, then:

Carbon . . . . . $\frac{10{\cdot}05}{12}$

Hydrogen . . . . . $\frac{0{\cdot}84}{1}$

Chlorine . . . . . $\frac{89{\cdot}11}{35{\cdot}5}$

The formula is then some multiple of

$$C_{\frac{10{\cdot}05}{12}}\ H_{0{\cdot}84}\ Cl_{\frac{89{\cdot}11}{35{\cdot}5}}$$

$$= C_{0{\cdot}84}\ H_{0{\cdot}84}\ Cl_{2{\cdot}51}$$

Dividing these by 0·84 we obtain

$$C_1H_1Cl_{2{\cdot}99} \text{ or } CHCl_3.$$

$CHCl_3$ is therefore the simplest possible formula for chloroform. But it by no means follows that it is the correct formula, for $C_2H_2Cl_6$, $C_4H_4Cl_{12}$ or $C_nH_nCl_{3n}$ are all equally well in agreement with the figures of the percentage composition. In order to find out which of these formulæ is the true one, we require to know the molecular weight of the substance.

11. Molecular Weight of an Organic Compound.—The molecular weight of a compound is the ratio of the weight of one molecule of it to the weight of an atom of hydrogen. Since the atomic weight of hydrogen is one, the molecular weight is clearly the sum of the atomic weights of all the atoms in the molecule. Accordingly, if the molecular weight is known and also the empirical formula, it is easy to find the true formula, which is the only one which will lead to the molecular weight found.

Example.—The simplest formula of hexane, as calculated from its percentage composition, is C_3H_7. Its molecular weight is 86. *What is its true formula?*

The formula C_3H_7 indicates a molecular weight of $(3 \times 12) + 7 = 43$. A formula of $(C_3H_7)_2$, then, gives the required molecular weight of 86. The true formula of hexane is therefore C_6H_{14}.

The molecular weight of an organic compound can be found (1) from the density of its vapour; (2) from the boiling point or freezing point of its solutions.

The molecular weight of hydrogen is known to be 2, for the atomic weight[1] of hydrogen is known to be 1 and it may be shown to have the formula H_2.[2] The gram-molecular weight of hydrogen must therefore be 2. Now it may be shown by an experimental

[1] If the oxygen standard O = 16·000 is adopted, the figures 1·008 for the atomic weight and relative density of hydrogen and 2·016 for its molecular weight are to be substituted for the above figures.

[2] The arguments for the di-atomic character of hydrogen are detailed in works on inorganic or physical chemistry.

determination of the density of hydrogen that 2 *g.* of hydrogen occupy a volume of 22·412 litres at 0° C. and 760 mm. pressure.

Suppose that 22·412 litres of hydrogen contain n molecules of hydrogen. Then by Avogadro's law 22·412 litres of any other gas contain n molecules of that gas.

Suppose that 22·412 litres of this gas measured at 0° C. and 760 mm. pressure weigh w g. Then each molecule weighs $\frac{w}{n}$ g.

But a molecule of hydrogen weighs $\frac{2}{n}$ g.

$$\therefore \frac{\text{The weight of a molecule of the gas}}{\text{The weight of a molecule of hydrogen}} = \frac{w}{n} \div \frac{2}{n} = \frac{w}{2}$$

$$\therefore \frac{\text{The weight of a molecule of the gas}}{\text{The weight of an atom of hydrogen}} = w$$

It follows then that

the molecular weight of a gas is numerically equal to the weight in grams of 22·412 litres of the gas measured at normal temperature and pressure.

The relative density of a gas vapour referred to hydrogen is the ration of the weight of one volume of gas to the weight of one volume of hydrogen, both measured at N.T.P.

Using the same symbols as above:

$$\text{Gas density} = \frac{\text{Weight of 22·4 litres of gas at N.T.P.}}{\text{Weight of 22·4 litres of hydrogen at N.T.P.}} = \frac{w}{2}.$$

But the molecular weight has been shown to be w, and consequently

the molecular weight of a gas is twice the relative density of the gas at N.T.P. referred to hydrogen as unity.

It follows, then, that if we can find the weight of a given volume of a gas (or of a solid or liquid converted into a gas by heat) under known conditions of temperature and pressure, we can find its molecular weight.

12. Determination of the Molecular Weight of a Gas.—Few organic substances are gases at room temperature and the practical details need not be given. Some form of evacuated container of volume v c.c. is weighed and is then filled with the gas under known pressure p and at a known temperature t. It is then weighed again and the increase of weight w g. gives the weight of the gas.

The volume of the gas at N.T.P. is, then,

$$\frac{v \times 273 \times p}{(273 + t) \times 760} \text{ c.c.}$$

and the weight of 22·4 litres of it at N.T.P. is

$$\frac{w \times 22400 \times (273 + t) \times 760}{v \times 273 \times p} \text{ g.}$$

This quantity is the gram-molecular weight.

An example may be given here.

An evacuated vessel weighed 84·5602 *g. When filled with ethane at* 750 *mm. pressure and* 15° *C., its weight was* 85·1304 *g. Its volume, as ascertained by filling it with water and weighing, was* 455 *c.c. Find the molecular weight of ethane.*

Volume of ethane = 455 c.c. at 750 mm. pressure and 15° C.
∴ at 0° C. and 760 mm. volume of ethane

$$= 455 \times \frac{750}{760} \times \frac{273}{288} \text{ c.c.}$$

This volume of gas weighs 85·1304 − 84·5602 = 0·5702 g.
∴ 22,400 c.c. of ethane at 0° C. and 760 mm. weigh

$$\frac{0{\cdot}5702 \times 22400 \times 760 \times 288}{455 \times 750 \times 273} \text{ g.}$$

$$= 30{\cdot}0 \text{ g.}$$

∴ The molecular weight of ethane is 30.

13. Molecular Weight of Volatile Liquids and Solids.—The principle of the method employed in the last section may be applied also to volatile liquids and solids, in which category a large proportion of organic substances are included. Direct weighing of a fixed volume of gas is a method obviously unsuitable for finding the density of a vapour which condenses at room temperature, and accordingly several other methods have been devised. The method devised by Victor Meyer is the one most commonly used.

Victor Meyer's Method of determining Molecular Weights.—In order to discover the molecular weight of a volatile compound it is necessary to convert it into vapour and measure the weight, volume, temperature and pressure of this vapour. In the Victor Meyer apparatus, the vapour produced by the evaporation of a known weight of liquid is made to displace its own volume of air, which is measured under known conditions. The apparatus is shown in Fig. 6.

A very small (A) bottle holding about 0·2 c.c. is weighed, then filled with the volatile substance, stoppered and weighed again. Alternatively a small glass bulb holding about 0·2 c.c. may be used. The outer jacket of the apparatus is partly filled with water or some liquid boiling 30°—40° C. higher than the boiling point of the substance, the vapour density of which is to be measured.

The inner glass tube, which contains a little glass wool or dry sand to break the fall of the small bottle, is thus heated to a constant temperature, which need not, however, be known. A measuring tube and small pneumatic trough are adjusted to the delivery tube of the inner tube. When the inner glass tube has reached the temperature of the bath, air will cease to issue from the delivery tube and the measuring tube is set over the orifice of the delivery tube. The rubber cork closing the inner tube is removed, the small bottle is dropped in and the cork is instantly replaced. In a few seconds the substance begins to vaporise and the vapour formed expels from the tube its own volume of hot air, which cools in the measuring tube to the volume which the vapour would occupy (if uncondensed) at the temperature and pressure prevailing in the tube. When no more air issues from the delivery tube, the measuring tube is removed, left for a quarter of an hour to attain atmospheric temperature, levelled, and the volume of air (v) read off, and the temperature (t) and atmospheric pressure (p) noted. Then if the vapour pressure of water at the temperature t is p', the volume of the vapour at 0° C. and 760 mm. would be

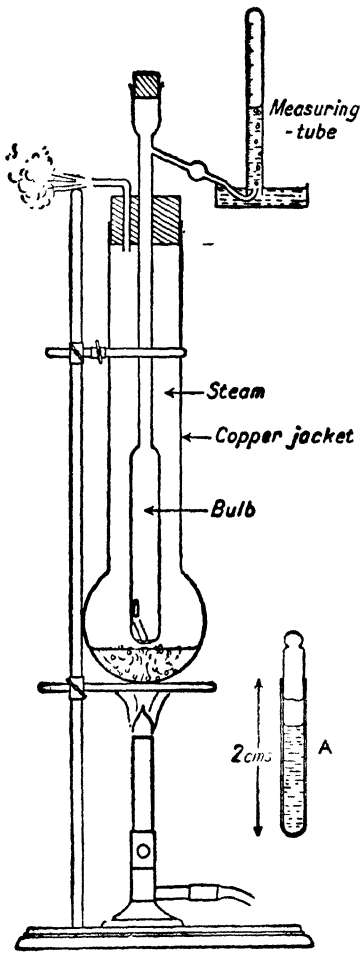


FIG. 6.—Victor Meyer's Method for determining Molecular Weights.

$$\frac{273\,(p - p')\,v}{(273 + t)\,760}\ \text{c.c.}$$

If the weight of the substance taken was w g., then $\frac{273\,(p-p')v}{(273+t)\,760}$ c.c.

of vapour at N.T.P. weigh w g., and 22,400 c.c. weigh $\frac{w \times 22400\,(273 + t)\,760}{273\,(p - p')\,v}$ g. This last number is the molecular weight.

Dumas' Method of determining Molecular Weights.—The principle of this method is the weighing of a volume of vapour measured at an elevated temperature. It is not less accurate than Victor Meyer's method, but requires much more of the liquid to be used. The apparatus is shown in Fig. 7.

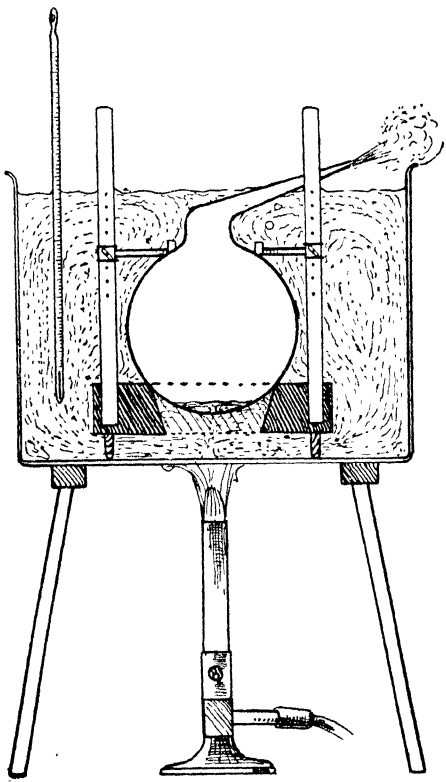


FIG. 7.—Dumas' Method for determining Molecular Weights.

A glass bulb with a narrow pointed neck is weighed (w_1). It is then warmed and the orifice is dipped into the liquid of which the vapour density is to be determined. When some 10—12 c.c. of the latter have been drawn into the bulb, it is removed and clamped under water (or other liquid) so that only the point protrudes. The water is heated until the liquid boils rapidly, and is then kept at a constant temperature (t) measured by a thermometer in the bath. When no liquid remains in the bulb (as shown by vapour ceasing to issue), the orifice is sealed with a blowpipe flame without removing the bulb from the bath. It is now full of vapour at the temperature (t) of the bath and the prevailing atmospheric pressure (p). The bulb is now removed, dried, allowed to cool, and weighed (weight of the bulb full of vapour $= w_2$).

The volume of the bulb is next determined by opening it under water which rushes in and fills it. By weighing the bulb so filled its volume v is readily obtained.

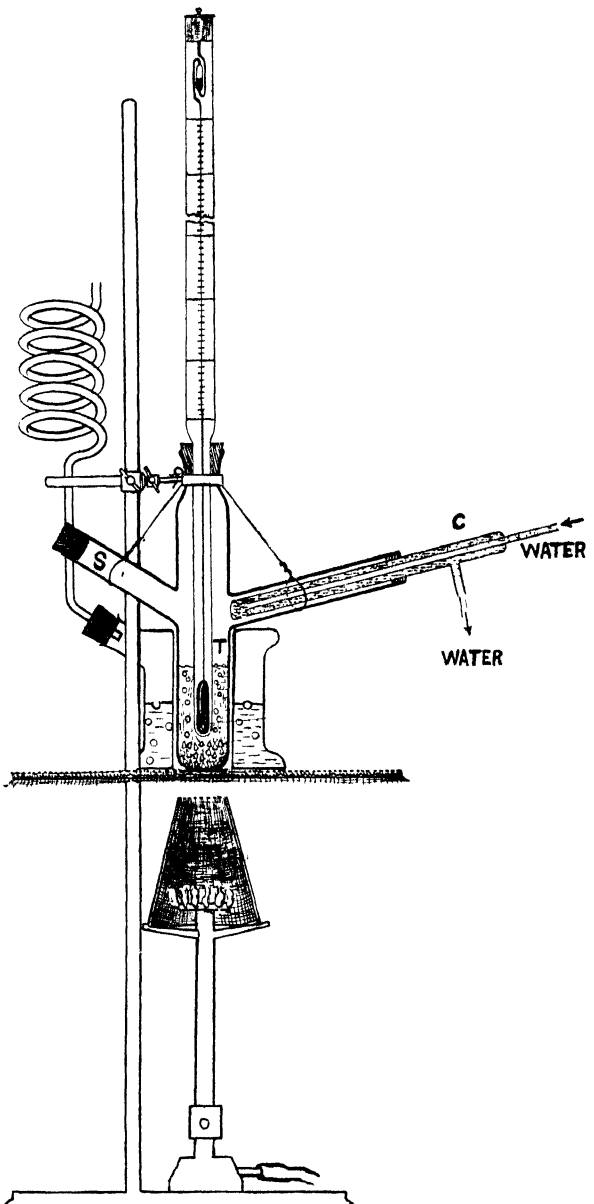


FIG. 8.—Beckmann's Ebullioscopic Method for determining Molecular Weights

amount of solvent (S g.) is placed in the inner tube T which contains tetrahedra of platinum foil, garnets, etc., to ensure regular boiling and thorough mixing of liquid and vapour. A water-cooled tube (C) condenses the vapour and returns the liquid to the central tube. The boiling point (t) is measured by a Beckmann thermometer graduated over a range of 6° C. in hundredths of a degree. The mercury is adjustable to allow of any range of 6° C. being covered. A weighed pellet of the solid (w g.) is then added through the side tube S and the boiling point t' again read. One or two more weighed pellets are added and readings again taken. The molecular weight is given by the formula

$$t' - t = \frac{cw}{SM}.$$

The ebullioscopic constant c is obtained from tables. Some values are:

Water	520
Acetic acid	3,070
Benzene	2,560
Chloroform	3,880
Acetone	1,670

Landsberger Method.—The dynamic method of Landsberger has the advantage that superheating is not possible. The apparatus used is shown in Fig. 9. The solvent is placed in a flask F from which a delivery tube passes to a vessel V graduated in c.c. and provided with a thermometer graduated in tenths of a degree. This vessel has an aperture H through which the vapour can pass through a surrounding jacket J to a condenser.

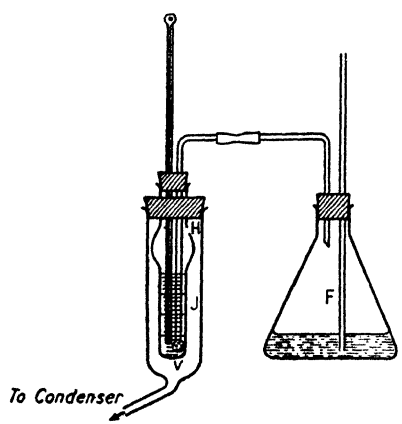


FIG. 9.—Landsberger Apparatus.

About 10 c.c. of solvent are placed in the graduated vessel and the solvent in the flask is boiled so that the solvent in V is raised to its boiling point (t) which is read off on the thermometer. Then a little of the solvent is removed from V, leaving about 5 c.c., and a weighed pellet of the solute—say 0·5—1·0 g. (w g.)—is added. The apparatus is once more connected up; vapour

is passed in, and the temperature t' is noted when the thermometer has become steady once more. The delivery tube and the thermometer are then at once removed, and the volume of solution (S c.c.) is read. This temperature (t') is the boiling point of the solution containing w g. of solute in S c.c. of solution.

By replacing the cork and allowing more solvent to condense, further readings for temperature and volume of solution are obtained.

The molecular weight M is given by

$$t' - t = \frac{cw}{SM}.$$

where c is a special ebullioscopic constant in which allowance is made for the fact that S is expressed in c.c. and not in grams.

Solvent.	Ebullioscopic constant (Landsberger).
Ethyl alcohol	1,560
Acetone	2,220
Ether	3,030

16. Cryoscopic Methods of determining Molecular Weights.—The apparatus shown in Fig. 10 is usually employed. S g. of the solvent are weighed into the inner tube and in this are placed the Beckmann thermometer and stirrer. The tube is enclosed in an air jacket which is surrounded by a freezing mixture which should not be at a temperature lower than 2°—4° below the freezing point of the solvent. The solvent is steadily but gently stirred and the mercury thread is watched. This falls until a point a little below the true freezing point is reached. Freezing then begins and the mercury rises rapidly and finally remains steady at the true freezing point (t).

The inner tube is then removed and warmed with the hand until the solvent has melted. A weighed amount of solute (w g.) is added by the side tube and dissolved by stirring. The freezing point is then again determined as above (t'). The process may be repeated with fresh portions of solute.

The molecular weight M is again given by the formula

$$t - t' = \frac{cw}{SM}$$

where c is the cryoscopic constant.

Solvent.	Cryoscopic constant.
Water	1,850
Acetic acid	3,900
Benzene	5,000
Phenol	7,300

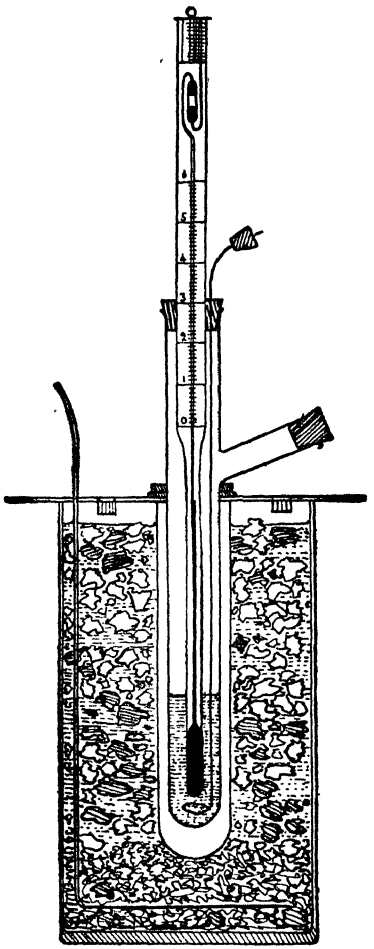


FIG. 10.—Cryoscopic Method for determining Molecular Weights.

Rast's Camphor Method.—Rast's camphor method, though not reliable with all organic substances, has come much into use owing to its simplicity. While the majority of solvents have their freezing point lowered by about 2—4° C., when 1 gm.-molecule of solute is dissolved in 1,000 g., camphor is exceptional in having a freezing point which is lowered by 40° C. for each gm.-molecule of solute per 1,000 g. camphor. Since the freezing point depression is so large the use of a Beckmann thermometer is unnecessary. As small a quantity of the substance as can be accurately weighed is weighed out into a very small test tube, previously cleaned with sulphuric acid and potassium dichromate, and well dried. Fifteen times its weight of camphor is weighed out into the same tube, which is then preferably sealed. The mixture is melted, best by heating the test tube in a small beaker of heated sulphuric acid, care being taken not to

volatilise the camphor. The mixture is allowed to solidify. The solid is crushed on a watch glass and some of the powder introduced into a thin-walled, somewhat conical capillary tube of 2—3 mm. bore, which is best made by drawing

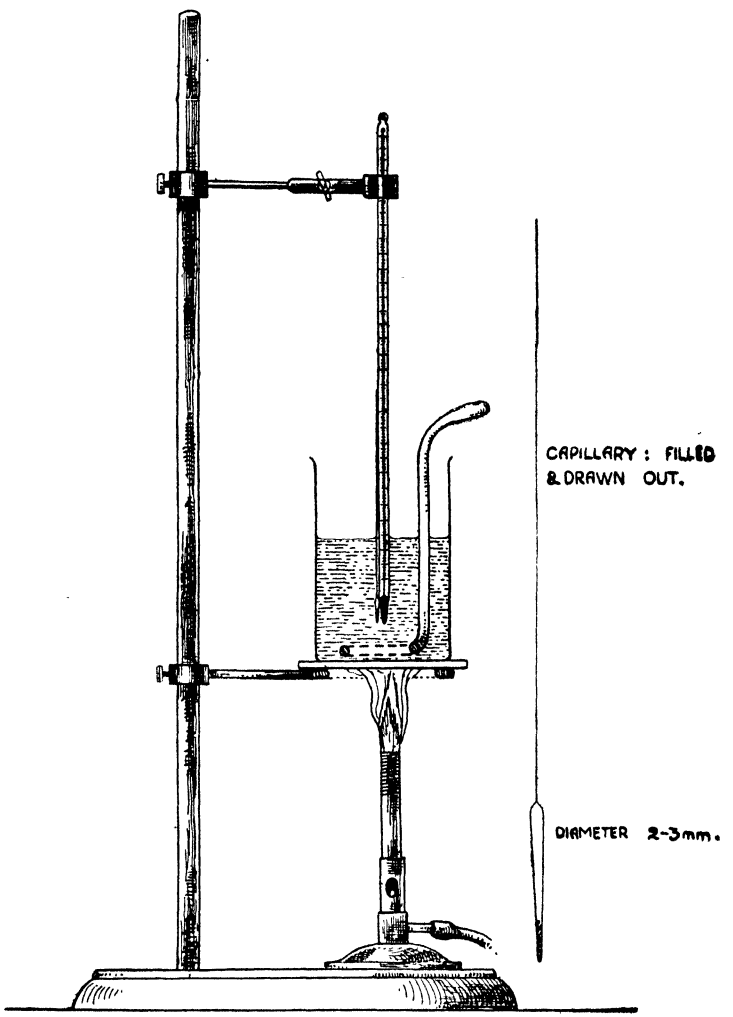


FIG. 11.—Rast's Cryoscopic Method of determining Molecular Weights.

out a test tube.[1] This is drawn off, leaving a long narrow capillary 15 cm. or more in length (Fig. 11). This is placed in contact with a thermometer previously moistened with concentrated sulphuric acid, to which it will adhere by

[1] If a micro-balance is available the camphor and the substance used may be weighed directly into the capillary.

capillary attraction. The thermometer and capillary are clamped in a beaker containing sulphuric acid and a glass stirrer. The acid is slowly heated and steadily stirred, and the capillary tube carefully observed. The solid melts at some temperature not far from 160° C. The acid is then allowed to cool until camphor crystals reappear in the capillary. It is then again heated, and the disappearance of the *last* crystal fragment indicates the correct melting point. The melting point of the unmixed camphor should also be determined by the above method. In this way the correction for emergent stem and other thermometric errors are avoided.

As an example of the calculation of results the following may be taken.

112 mg. of picric acid and 1·000 g. of camphor were weighed out and melted together. The melting point of the pure camphor was 174° C. and that of the mixture 154·5° C.

1000 g. camphor has its F.P. lowered by 40° C. by 1 gm.-mol. solute

$\therefore$ „ „ „ 19·5° C. by $\frac{19{\cdot}5}{40}$ gm.-mol. „

$\therefore$ 1 gm. „ „ „ „ $\frac{19{\cdot}5}{40000}$ gm.-mol. „

$\therefore$ 0·112 g. picric acid is $\frac{19{\cdot}5}{40000}$ gm.-mols.

$\therefore$ 1 gm.-mol. picric acid is $\frac{40000 \times 0{\cdot}112}{19{\cdot}5} = 230$

The correct result is 229.

The accuracy of the method is less than that of the Beckmann or other cryoscopic methods, but its simplicity and rapidity make it very suitable for rough determinations.

17. Molecular Weights of Acids and Bases.—The molecular weight of an acid or base *of which the basicity or acidity is known* can be determined by the analysis of a metallic compound.

Molecular Weight of an Acid.—If an acid HX is monobasic its silver salt is AgX. On ignition of this salt metallic silver will remain. If the molecular weight of the acid is M the molecular weight of the acid radical X is $M - 1$, and the molecular weight of the silver salt is $108 + M - 1$. It follows, then, that the ratio of the weight of the silver salt to the weight of the silver left on igniting it is $\frac{107 + M}{108}$.

Accordingly, the silver salt of an organic acid may be prepared, weighed out into a crucible and heated, at first gently and then strongly. The residue of silver is weighed. If the weight of the silver salt is w and that of the residue of silver is w', then

$$\frac{107 + M}{108} = \frac{w}{w'}$$

and

$$M = \frac{108w - 107w'}{w'}$$

The silver salts of some organic acids are explosive and should not be used (*e.g.*, silver oxalate). As a laboratory exercise, silver acetate may be prepared by dissolving 2 g. of silver nitrate in 5 c.c. water and adding a solution of 2 g. of sodium acetate in 5 c.c. of dilute acetic acid. The precipitate is filtered and well washed, first with water, then with alcohol and ether. It is dried in the water-oven. About 1 gm. may be weighed into a porcelain crucible with lid, and heated, at first gently, then strongly. The residual silver is weighed and the calculation performed as above.

Molecular Weight of a Base.—The platinichloride (also known as chloroplatinate) of a base is readily prepared by treating it with hexachloroplatinic acid ("platinum tetrachloride"). The former when ignited leaves a residue of platinum. If the base is monoacidic and has the formula X, the platinichloride will be $X_2.H_2PtCl_6$. If the molecular weight of X is M, then $2M + (2 + 195{\cdot}2 + 6 \times 35{\cdot}5)$g. of the salt will yield 195·2 g. of platinum as residue. The procedure and calculation are as for the silver salts of acids.

18. Calculation of True Formula.—If the percentage composition of a compound is known, the simplest formula is readily calculated as in § 10. The true formula must either be this or an integral multiple of it. The molecular weight indicates the total atomic weights of all the atoms in the formula, and thus gives the multiple of the empirical formula required. Thus the percentage composition of benzene is C, 92·31 per cent., H, 7·69 per cent., which indicates a simplest formula CH. The molecular weight of benzene is readily found from its vapour density (§ 13) to be 78. The formula CH indicates a value of 13, exactly one-sixth of this. Accordingly the true formula is $(CH)_6$ or C_6H_6.

EXAMPLES OF CALCULATION OF FORMULÆ

(1) *A liquid yielded the following results on analysis:*

(i) *Elements present: carbon, nitrogen, hydrogen, sulphur.*

(ii) *On combustion analysis* 0·201 *g. yielded* 0·3049 *g. carbon dioxide and* 0·1040 *g. water.*

(iii) *On conversion of the nitrogen into ammonia by the Kjeldahl process, the ammonia obtained from* 1·01 *g. of the substance was neutralised by* 11·6 *c.c. of normal HCl.*

(iv) *When the sulphur was oxidised to sulphuric acid by the Carius process the use of* 0·2066 *g. of the substance resulted in the precipitation of* 0·5544 *g.* $BaSO_4$.

(v) *The vapour density was determined by the Victor Meyer method, and* 0·1015 *gm. of the liquid, when vaporised, displaced* 27·96 *c.c. of air measured at* 15° *C. and* 750 *mm. Find the true formula of the substance.*

0·2010 g. yielded 0·3049 g. carbon dioxide and 0·1040 g. water.

$$\therefore \text{ per cent. carbon } = \frac{0{\cdot}3049 \times 12 \times 100}{44 \times 0{\cdot}2010} = 41{\cdot}37 \text{ per cent.}$$

$$\text{and per cent. hydrogen } = \frac{0{\cdot}1040 \times 2 \times 100}{18 \times 0{\cdot}2010} = 5{\cdot}75 \text{ per cent.}$$

11·6 c.c. of N-HC neutralise $\frac{11{\cdot}6 \times 17}{1000}$ g. NH_3 which contain $\frac{11{\cdot}6 \times 14}{1000}$ g. nitrogen. This is derived from 1·01 g. of the substance, which therefore contain

$$\frac{11{\cdot}6 \times 14 \times 100}{1000 \times 1{\cdot}01} \text{ per cent. N}$$

$$\text{per cent. nitrogen} = 16{\cdot}08 \text{ per cent.}$$

0·2066 g. of the substance produce 0·5544 g. $BaSO_4$ which contains

$$\frac{0{\cdot}5544 \times 32}{233{\cdot}4} \text{ g. S;}$$

$$\text{per cent. of sulphur} = \frac{0{\cdot}5544 \times 32 \times 100}{233{\cdot}4 \times 0{\cdot}2066} = 36{\cdot}79.$$

Percentage composition of the substance.		Relative number of atoms.
Carbon	41·37 per cent.	$\frac{41{\cdot}37}{12} = 3{\cdot}45$
Hydrogen	5·75 „	$\frac{5{\cdot}75}{1} = 5{\cdot}75$
Nitrogen	16·08 „	$\frac{16{\cdot}08}{14} = 1{\cdot}15$
Sulphur	$\frac{36{\cdot}79}{99{\cdot}99}$ „	$\frac{36{\cdot}79}{32} = 1{\cdot}15$

(It follows that no oxygen is present.)

Simplest formula is $C_{3{\cdot}45}H_{5{\cdot}75}N_{1{\cdot}15}S_{1{\cdot}15} = C_3H_5NS$.

The molecular weight is the weight of 22·4 l. of the vapour at N.T.P.

$27{\cdot}96 \times \frac{750}{760} \times \frac{273}{288}$ c.c. vapour at N.T.P. weight 0·1015 g.

$\therefore$ 22·4 l. vapour weigh $\frac{0{\cdot}1015 \times 22400 \times 760 \times 288}{27{\cdot}96 \times 750 \times 273}$ g.

Molecular weight = 86·9.

Molecular weight calculated from formula C_3H_5NS = 87.

∴ true formula is C_3H_5NS.

(2) *A certain organic substance was shown to contain carbon, hydrogen, nitrogen and chlorine. No test for oxygen was attempted. In a combustion analysis* 0·2021 *g. gave* 0·2506 *g. carbon dioxide and* 0·0854 *g. water. In a determination by Dumas' method* 0·2005 *g. gave* 22·34 *c.c. nitrogen measured at* 778 *mm. pressure and* 20° *C. over caustic potash solution of v.p.* 8 *mm. In a Carius determination* 0·3412 *g. of silver chloride was obtained from* 0·2531 *g. of the substance.* 0·707 *g. of the substance lowered the freezing point of* 20 *c.c. of water by* 0·308° *C. (cryoscopic constant of water* = 1850). 0·2021 *g.* of the substance gives 0·2506 g. CO_2, which contains $\frac{0{\cdot}2506 \times 12}{44}$ g. carbon.

$$\text{Carbon} = \frac{0{\cdot}2506 \times 12 \times 100}{44 \times 0{\cdot}2021} = 33{\cdot}82 \text{ per cent.}$$

0·2021 g. of the substance gives 0·0854 g. water, which contains $\frac{0{\cdot}0854}{9}$ g. hydrogen.

$$\text{Hydrogen} = \frac{0{\cdot}0854 \times 100}{9 \times 0{\cdot}2021} = 4{\cdot}69 \text{ per cent.}$$

0·2005 g. of the substance yields 22·34 c.c. moist N_2 at 778 mm. and 20° C, *i.e.*, 22·34 c.c. dry N_2 at 778 — 8 mm. and 20° C.,

$$= 22{\cdot}34 \times \frac{770}{760} \times \frac{273}{293} \text{ c.c. at N.T.P.}$$

$$= \frac{22{\cdot}34 \times 770 \times 273 \times 28}{760 \times 293 \times 22400} \text{ g.}$$

$$\text{Nitrogen} = \frac{22{\cdot}34 \times 770 \times 273 \times 28 \times 100}{760 \times 293 \times 22400 \times 0{\cdot}2005} = 13{\cdot}15 \text{ per cent.}$$

0·2531 g. of the substance yields 0·3412 g. AgCl containing $\frac{0{\cdot}3412 \times 35{\cdot}45}{143{\cdot}33}$ g. chlorine.

$$\text{Chlorine} = \frac{0{\cdot}3412 \times 35{\cdot}45 \times 100}{143{\cdot}33 \times 0{\cdot}2531} = 33{\cdot}35 \text{ per cent.}$$

	Percentage composition.	Relative number of atoms.
Carbon . . .	33·82	$\frac{33{\cdot}82}{12} = 2{\cdot}82$
Hydrogen . . .	4·69	$\frac{4{\cdot}69}{1} = 4{\cdot}69$
Nitrogen . .	13·15	$\frac{13{\cdot}15}{14} = 0{\cdot}94$
Chlorine . . .	33·35	$\frac{33{\cdot}35}{35{\cdot}45} = 0{\cdot}94$
	85·01	
Oxygen (by difference) .	14·99	$\frac{14{\cdot}99}{16} = 0{\cdot}94$
	100·00	

Simplest formula = C_3H_5ONCl.[1]

Molecular wt. corresponding to this formula

$$= 3 \times 12 + 5 + 16 + 14 + 35{\cdot}5 = 106{\cdot}5.$$

Molecular weight is given by the relation

$$t - t' = \frac{cw}{SM}$$

$$0{\cdot}308 = \frac{1850 \times 0{\cdot}707}{20M}$$

$$M = \frac{1850 \times 0{\cdot}707}{20 \times 0{\cdot}308}$$

$$= 212{\cdot}3.$$

This is approximately twice the molecular weight corresponding to the simplest formula. The true formula is therefore $C_6H_{10}O_2N_2Cl_2$.

QUESTIONS

(1) Explain the method and principles involved in the detection of (*a*) sulphur; (*b*) the halogens; (*c*) nitrogen in an organic compound.

(2) Describe the method employed to determine the proportion of carbon and hydrogen in a compound. 0·356 g. of a solid hydrocarbon gave on combustion 1·222 g. of carbon dioxide and 0·200 g. of water. Its vapour density (hydrogen = 1) was 64. What was its formula?

(3) How may the proportion of nitrogen in a compound be determined? 0·200 g. of a compound on combustion yielded 74·6 c.c. of nitrogen gas at N.T.P. In a second experiment 0·200 g. yielded 0·147 g. of carbon dioxide and 0·12 g. of water. The compound contains only carbon, hydrogen, nitrogen and possibly oxygen. Find its simplest formula.

[1] It may be noted, as a useful check, that the sum of atoms of odd valency, *e.g.*, H, N, Cl, etc., must be an *even* number. Thus in this case, the total being 5 + 1 + 1 = 7, it is clear that this formula cannot represent any *stable* compound, and the indication is either that the formula must be doubled (or quadrupled, etc.) throughout, or that a mistake has been made in analyses or calculations.

(4) How is the proportion of sulphur and of the halogens in an organic compound determined?

In a Carius determination 0·302 g. of a substance produced 0·406 g. of silver chloride. In a combustion analysis 0·205 g. yielded 0·423 g. of carbon dioxide and 0·1906 g. of water. The vapour density is 53·25 (hydrogen = 1). Find the simplest formula.

(5) 0·1513 g. of a substance vaporised in a Victor Meyer apparatus caused 23·1 c.c. of air measured at 12° C. and 750 mm. pressure to be expelled. Calculate the vapour density and molecular weight of the substance and describe the practical procedure required to obtain the above results.

(6) A specimen of pure benzene froze at 5·402° C. After dissolving 0·2 g. of a certain solid in 20 g. of this benzene it froze at 5·148° C. If the simplest formula of the compound is C_5H_3Cl, what is its true formula?

APPENDIX (*see page* 4)

MIDDLETON'S METHOD FOR DETECTING NITROGEN, HALOGENS AND SULPHUR IN ORGANIC COMPOUNDS

Grind together in a dry mortar 25 g. of the purest anhydrous sodium carbonate and 50 g. of the purest zinc dust, and keep the reagent in a stoppered bottle. The ordinary commercial quality is not satisfactory and it is advisable to try a blank test to make sure that halogen and sulphur are absent. The treatment of an organic compound with this reagent converts halogen and nitrogen into sodium halides and cyanide, and sulphur into zinc sulphide.

If the substance to be tested is solid, place *c.* 0·2 g. of it in a small dry hard glass test-tube and add 1 cm. depth of the reagent. Shake well, add a further 2–3 cm. of reagent on top of the mixture. If the substance is a liquid, add 2–3 drops of it to 1 cm. of reagent; cover with 3 cm. more of the reagent. Then, in either case, take the test-tube in a holder and heat the mixture at the *open* end, first gently then strongly, till this part is red-hot. Slowly extend the heating until the whole of the mixture is red-hot. Finally heat the tube vertically for a short time. While it is still red-hot plunge it into 20 c.c. of cold distilled water in an evaporating basin. Boil gently, allow to cool slightly and decant through a filter.

Divide the filtrate into two parts, and test these for cyanides and halides as in Lassaigne's test (p. 4).

The test for sulphur is carried out by placing a drop of lead acetate on a filter-paper. Add 10 c.c. of dilute hydrochloric acid to the residue in the basin and at once cover with the filter. If sulphur was present, a *dark* brown colour will appear on the lead acetate and the smell of hydrogen sulphide may be noticed.

CHAPTER II

THE PARAFFIN HYDROCARBONS

A HYDROCARBON is a compound containing hydrogen and carbon only. An enormous number of these hydrocarbons exist and the relationships between them can only be understood by the aid of structural formulæ, representing the manner in which the atoms of carbon and hydrogen are arranged in the molecule.

Once the principle on which these formulæ are built up is understood, it is possible immediately to write the formulæ of all the simpler hydrocarbons and their simple derivatives.

19. Valency Linkages.—The atoms in a chemical compound can be linked in three ways.

(1) *Polar Linkages.*—The acid and basic radicals of acids, alkalis and salts are held together by electrostatic attraction. The acid radical has more electrons than the uncombined atoms which compose it, and is therefore negatively charged: the basic radical has fewer electrons and is therefore positively charged. The electrostatic attraction between these oppositely charged atoms or groups holds them together.

Thus a chlorine atom has seven electrons in its outer ring and a sodium atom has one electron in its outer ring. When sodium and chlorine combine, the sodium atom loses its single outer electron and becomes positively charged, while the chlorine atom gains this electron and becomes negatively charged. The structures so formed have both *complete* outer electronic rings and are therefore stable arrangements of electrons. They are oppositely charged and so are held together by electrostatic attraction.

Compounds linked in this way are dissociated into ions in solution.

When we wish to distinguish a polar linkage from the other types we separate the formulæ of the component atoms or groups by square brackets.

$$Cl_2 + 2Na = 2Na^+[Cl]^-.$$

The carbon atom cannot be linked by polar linkages, but, of course, the formulæ of such of its compounds as are acids, bases, or salts, involve linkages of this type. Weak acids probably exist both in the polar and in the covalent (see below) form.

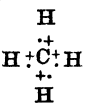
$$CH_3 \cdot \underset{\underset{O}{\|}}{C} \cdot OH \rightleftharpoons \left[CH_3 \cdot \underset{\underset{O}{\|}}{C} \cdot O\right]^- H^+$$

Acetic acid covalent form. Acetic acid ionisable form.

(2) *Covalent Linkages.*—The vast majority of linkages connecting the atoms of organic compounds are covalent.

A covalent linkage is brought about by the sharing of two electrons, one of which is contributed by each of the two atoms to be linked. By this means the number of electrons associated with each atom is increased till a condition of peculiar stability is reached. This is usually when the electrons in the outer ring reach the number of eight (in the case of hydrogen, two).

The structure of methane CH_4 may be taken to illustrate covalent linkages (Fig. 12). It may be more simply symbolised as



where · represents the electrons contributed by carbon, and + the electrons contributed by hydrogen. A covalent linkage is represented in the written formula by a line —. It should be remembered that this line represents *two* electronic orbits linking the atoms.

Covalent linkages do not ionise and are not broken up by electrolysis. With very few exceptions they are the means of linking the atoms of organic compounds.

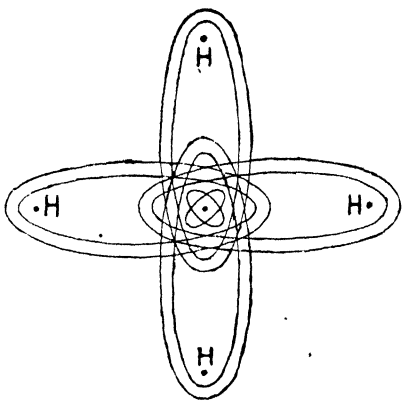


FIG. 12.—Diagram illustrating structure of Methane Molecule.

(3) *Co-ordinate Linkages.*—A special case of covalency arises when one atom contributes both the electrons necessary to form a valency linkage. The case is uncommon in organic chemistry, but probably occurs in carbon monoxide, the *iso*-cyanides and the nitro-compounds. The linkage is symbolised by an arrow → or ⇀ pointing from the *donor* atom which contributes the two electrons to the *acceptor* atom which receives them. Carbon monoxide is considered to have the formula $C \rightleftharpoons O$. Such linkages are also known as *semipolar bonds*.

In this formula it is intended to convey by *each* of the single linkages that the carbon atom shares an electron, originally belonging to it, with the oxygen atom, and that the oxygen atom shares an electron, originally belonging to it with the carbon atom. The arrow signifies that the oxygen atom shares *two* of the electrons originally belonging to it with the carbon atom.

Remembering that the carbon atom has four valency electrons and the oxygen atom has six, we see that in CO the carbon atom has:—

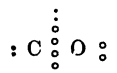
Electrons originally belonging to it, and unshared	2
Electrons originally belonging to it, and now shared with the oxygen atom:	
Two single linkages . . .	2
Electrons belonging originally to the oxygen atom and now shared:	
Two single linkages . . .	2
One co-ordinate linkage . . .	2
Total number of electrons rotating round the carbon atom . . .	8

The oxygen atom has:—

Electrons originally belonging to it and unshared	2
Electrons originally belonging to it and shared with C atom:	
Two single linkages . . .	2
One co-ordinate linkage . . .	2
Electrons contributed by C atom. Two single linkages . . .	2
Total number of electrons rotating round C atom	8

Both atoms now have the number of electrons (8) appropriate to the maximum stability.

The state of affairs may be symbolised as:—



where the electrons from the carbon are written as . and those from the oxygen as ₀.

20. Structural Formulæ.—Carbon is quadrivalent and we have

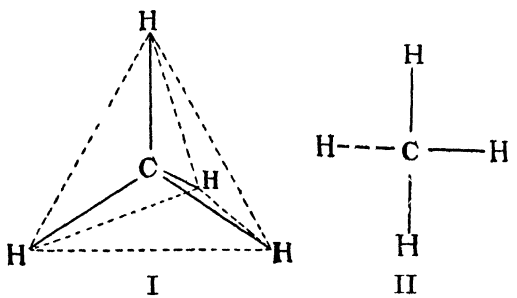


FIG. 13.—Representation of the Formula of Methane.

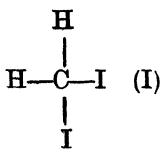
reason to regard all four of its valency linkages as being equal in strength and alike in every respect.

It is possible by the process described in the Appendix (p. 567) to make such a compound as nitromethane, CH_3NO_2, in four different ways so that the nitro-group must in each case be attached to a *different* valency bond, and the substances so obtained are identical in every respect.

The evidence detailed in Chapter XVII indicates that these valencies are distributed in space so that the four atoms or groups attached to the carbon atom are at a maximum distance from each other; the valencies being directed towards the corners of an imaginary tetrahedron of which the carbon atom is the centre. Thus the actual arrangement of the atoms of such a compound as methane, CH_4, is as shown in Fig. 13, I, the valency bonds being shown by the continuous lines and the imaginery tetrahedron by dotted lines. Since this arrangement is difficult to represent without careful drawing, the formulæ are ordinarily drawn with the valency bonds symmetrically distributed in a plane (Fig. 13, II). This representation is found satisfactory as long as its limitations are

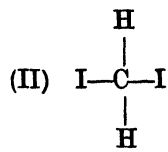
remembered. These limitations are most apparent in the asymmetric compounds discussed in Chapters XVII and XIX, but a simpler illustration may be of interest here.

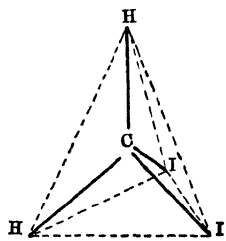
The plane formula (Fig. 13, III) would indicate two compounds, CH_2I_2 (methylene iodide) of the formulæ (I) and (II), which could not be converted one into the other without breaking one of the valency bonds, whereas in fact only one methylene iodide exists.



(I)

(II)





(III)

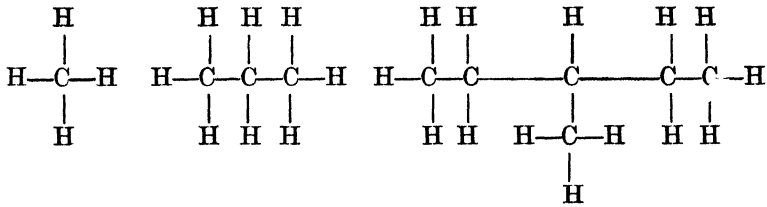
The three-dimensional formula (III) remains identical in everything save position when the iodine atoms are placed on any two of the valency bonds and thus correctly indicates the existence of only one methylene iodide.

In writing structural formulæ we draw the bonds of any length we may fancy and incline them at any angle; but the atoms in the molecule are arranged in a fixed pattern and at fixed distances. Thus Fig. 43 shows the arrangement of the atoms in glucose, while on pp. 269, 271 there are two quite correct but quite different ways of writing the structural formula.

If, however, it is not forgotten that plane structural formulæ are a distorted representation of three-dimensional formulæ, we may use them to represent the structure of organic compounds with remarkably accurate results.

21. Classification of Hydrocarbons.—Hydrocarbons are of three main types as indicated below:—

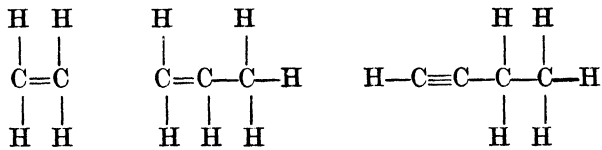
(1) *The Paraffin Hydrocarbons.*—These have the formula C_nH_{2n+2}, where n is a whole number. The carbon atoms in them are joined by single linkages only, and are not linked into rings.



Methane. Propane. 3-Methylpentane.

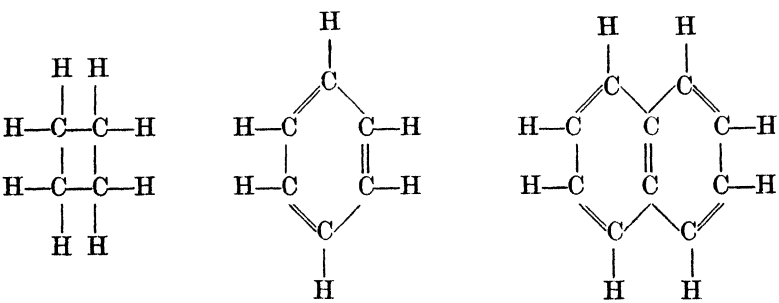
Only this type of hydrocarbon is dealt with in the succeeding chapter.

(2) *Unsaturated Hydrocarbons.*—Unsaturated hydrocarbons contain two or more carbon atoms linked by a double or triple valency-bond (*v.* Chap. XIII). Examples are:—



Ethylene. Propylene. Ethylacetylene (1-Butine).

(3) *Cyclic Hydrocarbons.*—These contain one or more *ring* structures composed of closed chains of carbon atoms joined by either saturated or unsaturated linkages.



*cyclo*Butane. Benzene. Naphthalene.

PARAFFIN HYDROCARBONS

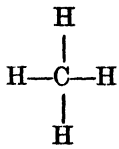
22. The Paraffin Series.—Remembering

(1) that the valency of carbon is four,

(2) that all linkages in the paraffin hydrocarbons are single,

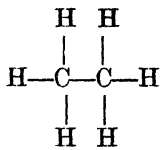
it is interesting to predict what hydrocarbons of this type are possible.

Hydrocarbon with One Carbon Atom.—Clearly only one hydrocarbon is possible—



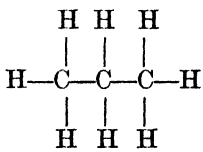
which is known as *methane.*

Hydrocarbon with Two Carbon Atoms.—Again only one hydrocarbon is possible if we consider all the linkages on a carbon atom to be identical.



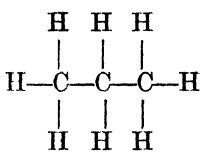
C_2H_6, ethane.

Hydrocarbon with Three Carbon Atoms.—Here again only one can exist.

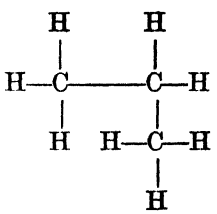


C_3H_8, propane.

It should be noted that the formulæ (I) and (II) are identical,



(I)



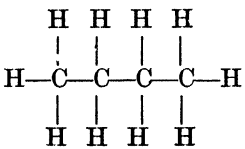
(II)

the second being only the first bent at right angles. A single bond is considered to allow the carbon atoms attached to it to move or rotate in any way as long as the bond is not broken.

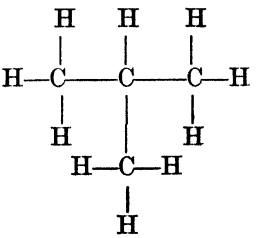
Formula (II) can readily be turned into (I) by bending it straight and rotating a hydrogen atom to the other side of the carbon atom. No bonds would have to be *broken* in order to do this. If the formula is written three-dimensionally (as in Fig. 13) it will be seen at once that only one such arrangement is possible.

Hydrocarbons with Four Carbon Atoms.—Here we have two

possible structural formulæ, both of which can represent the formula C_4H_{10},



and

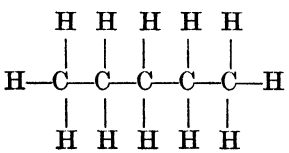


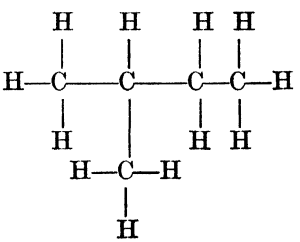
(I) Normal Butane. (II) *iso*Butane.

and formula (II) cannot be converted into formula (I) without breaking a bond and moving a hydrogen atom.

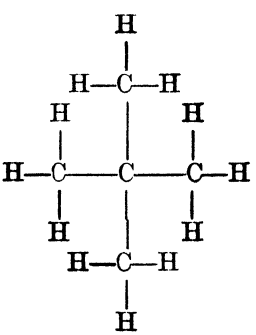
Two compounds of the above formula do in fact exist, very similar, though not identical, in chemical properties, and having different physical properties, *e.g.*, boiling points and densities in the liquid state. They are called normal butane or *n*-butane (I) and *iso*butane (or trimethylmethane) (II).

Hydrocarbons with Five Carbon Atoms.—Here three compounds, all of the formula C_5H_{12}, are possible.



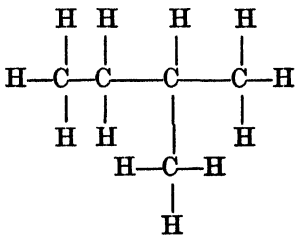


(I) Normal Pentane. (II) *iso*Pentane (or dimethylethylmethane).



(III) neo-Pentane (or tetramethylmethane).

Note that the formula



is identical with (II) and is obtained from it by lifting the formula off the paper and laying it on its reverse side.

Hydrocarbons with more than Five Carbon Atoms.—As the number of carbon atoms in a hydrocarbon increases, so the number of *isomerides*, or compounds with the same formula but different properties and structure, increases rapidly. There are 802 possible compounds of the formula $C_{13}H_{28}$ and, though all these could doubtless be prepared, in fact only one tridecane, the normal hydrocarbon, is known.

All the forty possible paraffins with eight carbon atoms or less have been prepared but of the higher hydrocarbons as a rule only one isomeride out of the many thousands possible is known.

General Formula of the Paraffin Series.—The formula of any member of the series must be C_nH_{2n+2}. By examining any of the formulæ on pp. 38, 39, it will be seen that the *end* of a chain of carbon atoms must be the group $-CH_3$. Suppose a hydrocarbon has n carbon atoms arranged in a chain without branches, there will be two $-CH_3$ groups and $(n-2)$ $-CH_2-$ groups. The formula will then be $C_{2+n-2}H_{6+2(n-2)}$ or C_nH_{2n+2}.

Suppose, however, that the chain is branched. The carbon atom at the junction from which one new chain of atoms arises will have only one hydrogen atom attached to it. The new chain will, however have at its end a $-CH_3$ group, so that the total number of hydrogen atoms is the same in a branched or unbranched chain. If two new chains of atoms start from the same carbon atom this latter has no hydrogen atom attached to it but *two* more $-CH_3$ groups will be present. Thus all paraffin hydrocarbons have the general formula C_nH_{2n+2}.

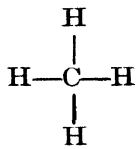
23. Homologous Series.—A group of chemically similar compounds in which each member differs from the next by the presence of an additional $-CH_2$ group is called a *homologous series* and the members are called *homologues* of each other.

The physical properties of the members show a steady gradation. Thus, each addition of a $-CH_2-$ group increases the boiling point

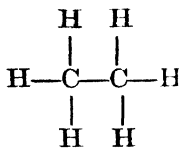
Isomerism of the Paraffins

General Formula C_nH_{2n+2}.

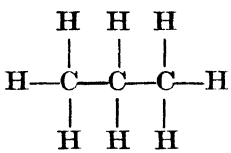
One Methane, CH_4.



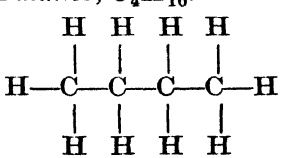
One Ethane, C_2H_6.

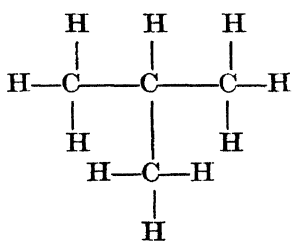


One Propane, C_3H_8.

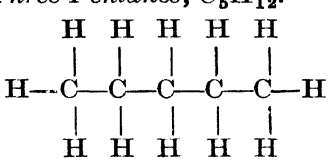


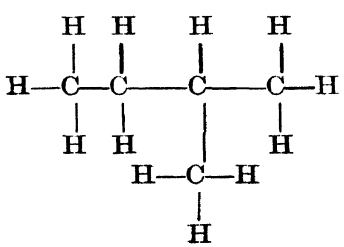
Two Butanes, C_4H_{10}.

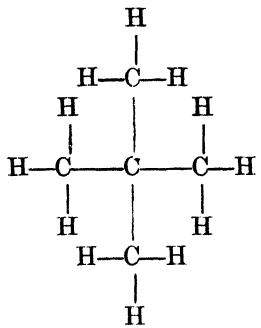




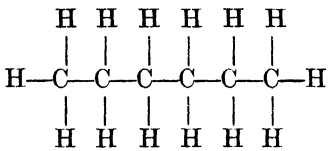
Three Pentanes, C_5H_{12}.

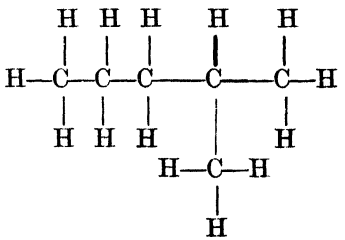


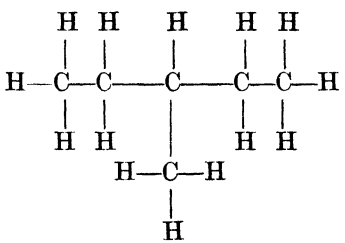


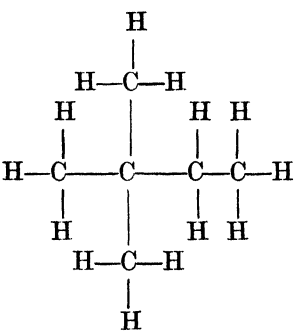


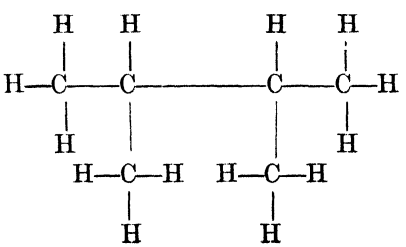
Five Hexanes, C_6H_{14}.











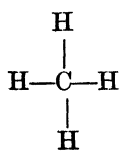
and density by a regularly decreasing amount. The regularities are most obvious when the straight-chain hydrocarbons are compared.

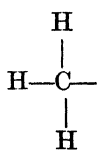
Number of carbon atoms	Name	Formula C_nH_{2n+2}	Density	State at 10° C.	M.p. °C.	B.p.°C.
1	Methane	CH_4	0·415/−160° C.	Gas	−186	−160
2	Ethane	C_2H_6	0·446/0° C.	Gas	−172	−93
3	Propane	C_3H_8	0·536/0° C.	Gas		−45
4	*n*-Butane	C_4H_{10}	0·600/0° C.	Gas		+1
5	*n*-Pentane	C_5H_{12}	0·627/14° C.	Liquid		36·3
6	*n*-Hexane	C_6H_{14}	0·658/20° C.	Liquid		69
7	*n*-Heptane	C_7H_{16}	0·683/20° C.	Liquid		98
16	*n*-Hexadecane	$C_{16}H_{34}$	0·775/18° C.	Solid	18	287
60	*n*-Hexacontane	$C_{60}H_{122}$		Solid	101	Decomposes

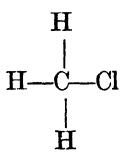
The chemical properties of the members of a series vary in a somewhat similar way; the paraffin hydrocarbons are, however, so stable and unreactive that it is difficult to point out such a variation.

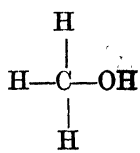
23a. Alkyl Compounds.—A very great number of compounds are derived from these hydrocarbons by a process of *substitution*, that is to say, the removal of hydrogen atoms and the insertion of other groups in their place. Thus from methane we can prepare directly, or more commonly indirectly, chlorine compounds, a hydroxyl compound, cyanogen compounds, etc.

The substitution of a single univalent group for a hydrogen atom gives what are known as *methyl* compounds, the name methyl being given to the univalent group $-CH_3$.

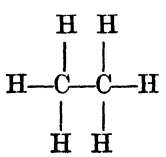

Methane.

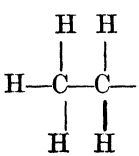

Methyl radical.

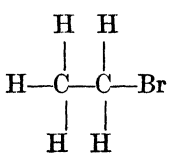

Methyl chloride.

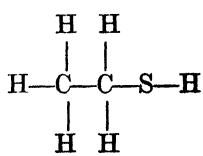

Methyl hydroxide (methyl alcohol).

In the same way, substitution of a univalent group for one hydrogen atom of ethane gives an *ethyl* compound:—


Ethane.


Ethyl radical.


Ethyl bromide.


Ethyl hydrogen sulphide (mercaptan)

In general, the substitution of a single univalent group for a single hydrogen atom of a paraffin hydrocarbon is said to give an *alkyl* compound:—

C_nH_{2n+2}	C_nH_{2n+1}	$C_nH_{2n+1}R'$
Paraffin.	Alkyl radical.	Alkyl compound.

The substitution of other groups for two or more hydrogen atoms also occurs, as further explained in §§ 24, 54. The nomenclature of such compounds will be discussed as and when they are encountered

INDIVIDUAL HYDROCARBONS

24. Methane. CH_4.—*Occurrence.*—Methane occurs naturally—

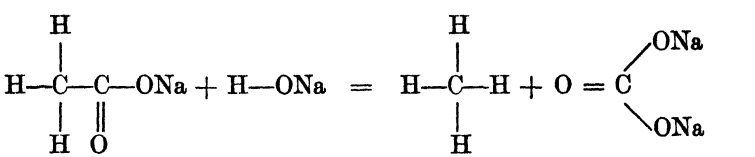
(1) in 'natural gas' evolved from oil-wells (§ 26),
(2) in the gases evolved from coal when it is mined ('fire-damp'),
(3) in the gas evolved from swamps, pond mud, etc., in which vegetable matter is undergoing bacterial decomposition in absence of air.

In all the above cases methane is the final product of the decomposition of organic matter, for there is little doubt that petroleum and the gases associated with it are derived from the decay of minute forms of marine life (see, however, § 26).

Methane is evolved from coal and wood when they are destructively distilled and therefore occurs in coal gas to the extent of about 35–45 per cent. by volume.

Laboratory Preparation.—Methane can be prepared:—

(1) By the action of alkalis on an acetate. Sodium hydroxide, in the form of soda-lime, and anhydrous sodium acetate are commonly employed.



Other paraffin hydrocarbons may be prepared by using the salts of homologues of acetic acid. Thus, a mixture of sodium butyrate, $CH_3—CH_2—CH_2—CO_2Na$ and soda-lime yields propane

$$CH_3—CH_2—CH_3.$$

The gas so obtained is not very pure, and contains hydrogen:

ethylene, and traces of complex compounds which give it an *empyreumatic* odour, as of burnt wood.

Expt. 1. *To prepare Methane.*—Some sodium acetate is melted on an iron tray and heated until its water of crystallisation is driven off, when it solidifies. By further heating the resulting solid is melted, and then allowed to cool. It is powdered and 10 g. of it are well mixed with 10 g. of soda-lime and loosely charged into a hard-glass test-tube. The mixture is heated and the methane is collected over water. An iron tube or

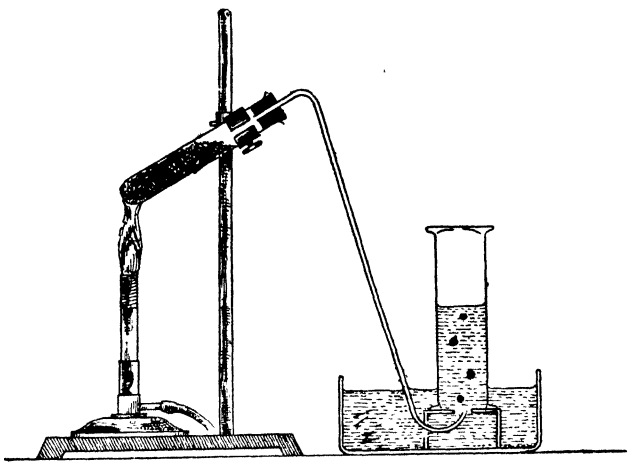


FIG. 14.—Preparation of Methane from Sodium Acetate.

copper flask may with advantage replace the hard-glass test-tube.

(2) The action of aluminium carbide on water yields methane:

$$Al_4C_3 + 12H_2O = 4Al(OH)_3 + 3CH_4.$$

The aluminium carbide with a little water may be placed in a flask furnished with thistle funnel and delivery tube and gently warmed. The addition of a little dilute hydrochloric acid accelerates the reaction. The methane is collected over water.

(3) Pure methane is best prepared by the action of the zinc-copper or aluminium-mercury couple on methyl iodide mixed with alcohol.

$$Zn + 2H_2O = Zn(OH)_2 + 2H,$$
$$CH_3I + 2H = CH_4 + HI.$$

Expt. 2. *Preparation of Methane from Methyl Iodide.*—Set up the apparatus shown in Fig. 15. In the conical flask place

about 25 sq. cm. of aluminium foil cut into small pieces. Have ready a mixture of 10 c.c. of methyl iodide and 2·5 c.c. of methyl alcohol. Remove the flask and pour on to the aluminium a solution of mercuric chloride. Within about a minute the aluminium becomes coated with mercury. Pour off the liquid and *at once* wash the metal twice with methyl alcohol. Pour over the aluminium about 10 c.c. of pure methyl iodide, replace the flask and allow the mixture of methyl iodide and alcohol to run in from the tap-funnel. A rapid reaction takes place and methane is evolved. The gas contains methyl iodide vapour, which is best removed by passing it through an empty U-tube cooled by a freezing mixture.

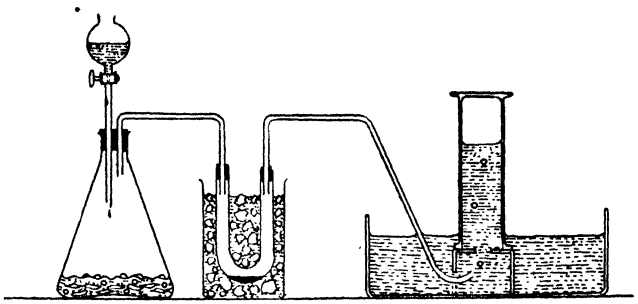


FIG. 15.—Preparation of Methane from Methyl Iodide.

(4) The action of water on dimethylzinc or methylmagnesium iodide (§§ 161, 163) gives pure methane:

$$Zn(CH_3)_2 + 2H_2O = Zn(OH)_2 + 2CH_4,$$
$$CH_3MgI + H_2O = CH_4 + MgI(OH).$$

(5) Methane is produced in sewage works where the sludge is acted on by anærobic bacteria in closed tanks. The quantity of gas produced may be enough to provide all the power required by the plant.

Physical Properties of Methane.—Methane is a colourless, odourless and non-poisonous gas which is much lighter than air, its density being 8 (hydrogen = 1). It is liquefied only with difficulty (b.p. −160° C.). It is very slightly soluble in water, of which 100 volumes dissolve about 3 volumes of the gas at 15° C.

Chemical Properties of Methane.—Methane is extremely stable, being unaffected by any of the usual reagents with the exception of chlorine.

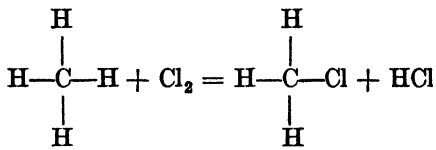
Methane burns in oxygen to carbon dioxide and water, burning in air with a blue or faintly luminous flame. Mixed with air it forms an explosive mixture when as little as 5 per cent. is present.

Methane can be directly oxidised to methyl alcohol and formaldehyde in presence of suitable catalysts, but the process is not available on the laboratory scale.

The action of chlorine on methane is typical of its action on many other organic compounds.

If a mixture of chlorine and methane is sparked or exposed to bright sunlight an explosion takes place and carbon and hydrogen chloride are the products: $CH_4 + 2Cl_2 = C + 4HCl$.

In diffused daylight *substitution of chlorine for hydrogen* takes place and methyl chloride, methylene chloride, chloroform and carbon tetrachloride are produced, together with hydrogen chloride.



$$CH_3Cl + Cl_2 = CH_2Cl_2 + HCl$$
$$CH_2Cl_2 + Cl_2 = CHCl_3 + HCl$$
$$CHCl_3 + Cl_2 = CCl_4 + HCl.$$

The products are sometimes known as monochloromethane, dichloromethane, trichloromethane and tetrachloromethane respectively.

The reaction does not constitute a practicable laboratory method owing to the difficulty of separating any one of the four chloromethanes in a pure condition.

Methane is practically unaffected by all other reagents at temperatures below a red heat. This remarkable stability is shown by all the paraffin hydrocarbons in greater or less degree, and the name 'paraffin' is derived from the Latin *parum affinis*, 'of little affinity.'

(25) **Ethane,** C_2H_6.—Ethane occurs in natural gas and to a small extent in coal gas. Many of the methods used to prepare methane are also available for the preparation of ethane. Thus the gas may be prepared:—

(1) By the action of alkalis on a propionate (see Expt. 1):

$$CH_3{\cdot}CH_2{\cdot}CO{\cdot}ONa + HONa = CH_3{\cdot}CH_3 + Na_2CO_3.$$

(2) By the action of the aluminium-mercury or zinc-copper couple on ethyl iodide in ethyl alcohol (see Expt. 2):

$$C_2H_5I + 2H = C_2H_6 + HI.$$

(3) By the action of diethylzinc or ethylmagnesium bromide on water.

In addition to the above, ethane and the higher paraffins can be made by the methods given below, viz., the action of sodium on a halogen derivative of a paraffin, and the electrolysis of salts of a suitable fatty acid.

(4) Methyl iodide, dissolved in ether, may be treated with clean sodium:

$$\begin{matrix} CH_3I \\ + \\ CH_3I \end{matrix} + 2Na = \begin{matrix} CH_3 \\ | \\ CH_3 \end{matrix} + 2NaI.$$

This method, known as *Wurtz's reaction*, enables us to make any paraffin from the halide of a paraffin having half its number of carbon atoms.

(5) If a solution of an acetate is electrolysed, ethane is formed at the anode. The salt ionises into metallic ions and acetate ions $CH_3{\cdot}CO{\cdot}O^-$. These are discharged at the anode and form ethane and carbon dioxide.

$$2CH_3{\cdot}CO{\cdot}O^- - 2\ominus = C_2H_6 + 2CO_2.$$

The gas is passed through concentrated caustic potash to remove the carbon dioxide.

This method enables us to make a paraffin containing n carbon atoms from a fatty acid of $\frac{n}{2} + 1$ carbon atoms.

(6) A mixture of ethylene, C_2H_4 (§ 168), and hydrogen is reduced to ethane when passed over heated nickel:

$$C_2H_4 + H_2 = C_2H_6.$$

Properties.—Ethane resembles methane closely. It differs in its vapour density (15, hydrogen = 1) and in its higher boiling point (−93° C.) and melting point (−172° C.).

In its chemical properties it resembles methane strongly. Ethane burns with a bright flame.

The action of chlorine produces six different substitution products of formulæ:

$$C_2H_5Cl,\ C_2H_4Cl_2,\ C_2H_3Cl_3,\ C_2H_2Cl_4,\ C_2HCl_5,\ C_2Cl_6.$$

In other respects it is, like methane, highly inert. *Propane*, C_3H_8, and *butane*, C_4H_{10}, much resemble ethane.

THE HIGHER PARAFFINS

The higher paraffins are chiefly of interest as constituting the greater part of the petroleum from which most of our oil-fuels and lubricants are derived.

26. Petroleum.—Petroleum is found in many parts of the world, the greatest oil-field being in the southern part of North America. Occasionally the oil oozes from the ground but in the great majority of districts it is reached by sinking bore-holes. The oil is usually found in porous strata capped by impervious rock and is associated

with 'natural gas,' the pressure of which often drives the oil to the surface with great velocity.

The origin of the oil is almost certainly the decomposition of the remains of living creatures, probably the minute life with which the sea abounds. In favour of this belief is the fact that petroleum is commonly found in company with salt and brine, that organic remains are associated with it, and that a liquid closely resembling petroleum has been obtained from the ooze of the sea bottom by subjecting it to heat and pressure.

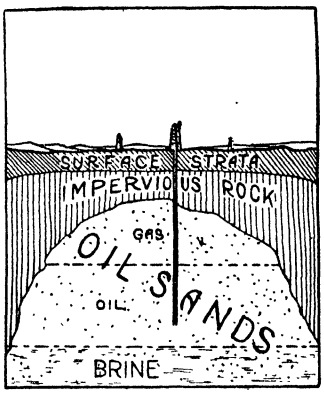


FIG. 16.—Occurrence of Petroleum.

The crude oil and gas formed in this way are thought to have been forced by the pressure of overlying strata to the top of geological 'folds' and to remain pent up there till released by boring.

Another theory of the origin of petroleum is that it arises from the action of water on metallic carbides in the depths of the earth. Though a petroleum-like liquid can be made in this way, we know of no widespread deposits of carbides which could produce the vast oil fields of the world. The theory, moreover, fails to account for its association with salt.

27. Utilisation of Petroleum.—About 275,000,000 tons of petroleum are obtained yearly. This vast quantity of material is separated by fractional distillation into four main products.

Fraction.	Boiling point.	Proportion of petroleum.
(1) Petrol (gasoline) . . .	*c.* 30—200° C.	35%
(2) Paraffin oil (kerosene) . .	*c.* 200—260° C.	12%
(3) Gas oil	*c.* 260—300° C.	15%
(4) Crude oil (left as residue) .	300° upwards	36%

The crude oil is often further separated into lubricating oils and paraffin wax.

Petrol and paraffin oil are freed from unpleasantly odorous unsaturated compounds and sulphur derivatives in various ways, notably treatment with sulphuric acid followed by agitation with

sodium plumbite—a solution of lead oxide in caustic soda. A solution of sodium hypochlorite is also largely employed.

Petrol.—Petrol consists mainly of the paraffin hydrocarbons, hexane, heptane and octane, together with a variable proportion of hydrocarbons of other series (hexamethylene, benzene, etc.). Its volatility makes it a suitable fuel for internal combustion engines, but also renders it dangerously easy to ignite and therefore unsuitable for use as a domestic fuel.

Paraffin oil or kerosene consists mainly of the paraffin hydrocarbons between nonane and tridecane, together with polymethylenes, etc. In this country paraffin oil must be of flash-point 73·0° F. or more, which means that a small flame applied to the surface of the oil at a temperature of less than 73·0° F. will not ignite the vapour. This comparatively non-volatile oil burns excellently when volatilised in a wick or the heated tube of a Primus stove, and is not so liable as petrol to accidental ignition.

Gas oil.—Gas oil, as its name implies, is used in the manufacture of illuminating gas. Water-gas, which is made by passing steam over white-hot coke and consists of carbon monoxide and hydrogen, has good heating power but does not give a luminous flame. Water-gas is often led through a heated brick chamber into which gas oil is sprayed. The mixture of carbon monoxide, hydrogen and hydrocarbon vapour is then passed through a highly heated brick chamber. At this temperature the hydrocarbons break up, giving gases of the paraffin and olefine series, which have good illuminating power. The product is known as 'carburetted water-gas.'

Crude oil.—Crude oil is much used for burning under steam boilers or in Diesel engines. A great part of it is used, however, for making lubricating oils and paraffin wax.

The crude oil is distilled, often under reduced pressure. The product contains paraffin wax which is removed by freezing the mixture and pressing the oil from the separated wax. The wax is further pressed to remove oil and finally forms *paraffin wax.* The oil thus separated is redistilled under reduced pressure and gives *lubricating oils.*

Crude oil is often *cracked* by distilling it at high pressures (*c.* 750 lbs. per sq. in.) and high temperatures, 750—1200° C. This treatment decomposes some of the higher hydrocarbons and produces more of the volatile hydrocarbons—olefines and paraffins—suitable for use as petrol. The demand for petrol is considerably greater than the demand for crude oil, so that the cracking process is a profitable one.

27a. Synthetic Petroleum.—Mixtures of hydrocarbons which closely resemble petroleum can be made:—

(1) by treating coal with hydrogen under great pressure and in presence of a catalyst (Bergius process).

(2) by passing a mixture of carbon monoxide with twice its volume of hydrogen over a nickel catalyst (Fischer-Tropsch process).

The petroleum thus produced is, at present, several times as expensive as the natural product.

28. Synthetic Preparation of the Higher Hydrocarbons of the Paraffin Series.—Many of the hydrocarbons can be separated from petroleum or paraffin oil by careful fractional distillation, but the number of hydrocarbons is so great and their boiling points are so near together that tedious and repeated fractionations are required.

If a pure hydrocarbon is required, the synthetic methods enumerated below are ordinarily used.

(1) Action of the zinc-copper or aluminium-mercury couple on a paraffin halide, which may be made from the corresponding alcohol, etc., if available (§ 24):

$$R{\cdot}I + 2H = R{\cdot}H + HI.$$

(2) The action of sodium on a paraffin halide (§ 25):

$$2R{\cdot}Cl + 2Na = R{\cdot}R + 2NaCl.$$

(3) The reduction of an unsaturated hydrocarbon (§ 25):

$$R-CH=CH-R' + H_2 \quad = \quad R-CH_2-CH_2-R'.$$

(4) The action of sodium hydroxide on the sodium salt of a fatty acid (§ 24):

$$R{\cdot}CO_2Na + NaOH = R{\cdot}H + Na_2CO_3.$$

(5) Electrolysis of a salt of a fatty acid (§ 25):

$$R{\cdot}CO_2Na \rightleftharpoons R{\cdot}CO_2^- + Na^+,$$

$$2R{\cdot}CO_2 \quad = R{\cdot}R + 2CO_2.$$

Other methods are mentioned in Chapter XII (§§ 161, 163).

29. General Properties of the Higher Paraffin Hydrocarbons.—The physical properties vary as described in § 23, the melting points, boiling points and densities of the hydrocarbons becoming higher as the number of carbon atoms is increased.

The chemical properties of all the members are very similar. They readily burn, the flame of the highest members being brightest and most smoky. Chlorine and bromine form various substitution derivatives.

$$C_nH_{2n+2} + xCl_2 = C_nH_{2n+2-x}Cl_x + xHCl,$$

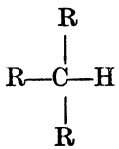
but iodine does not as a rule react.

Fuming sulphuric acid does not attack the lower members but forms sulphonic acids (§ 154) with the higher ones:

$$C_nH_{2n+2} + H_2SO_4 = C_nH_{2n+1}{\cdot}SO_2{\cdot}OH + H_2O.$$

Nitric acid does not attack them readily. It either forms nitro-

derivatives (§ 132) or oxidises them to fatty acids. The tertiary hydrocarbons of the type



are particularly vigorously attacked.

Other reagents have no effect on these hydrocarbons.

QUESTIONS.

(1) Explain exactly what is meant by the 'paraffin series of hydrocarbons'? Could hydrocarbons of the formulæ (*a*) C_3H_6, (*b*) C_7H_{12}, (*c*) C_5H_{12}, (*d*) C_7H_9 belong to this series?

(2) How many paraffin hydrocarbons of the formula C_4H_{10} can exist? Suggest three methods for making one of these hydrocarbons.

(3) Explain the meaning of the term 'isomerism,' giving examples taken from the paraffin series of hydrocarbons.

(4) Write the formulæ of *n*-pentane, tetramethylmethane, *iso*butane, and give the names of the hydrocarbons of formula

$$CH_3{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3;\ (CH_3)_2CH{\cdot}CH_2{\cdot}CH_3;\ (CH_3)_3C{\cdot}C_2H_5.$$

(5) What is meant by an homologous series? How do the physical properties of the paraffin hydrocarbons vary with their position in the series?

(6) State briefly the methods available for the preparation of methane. How could the gas be distinguished, (*a*) from hydrogen, (*b*) from *n*-butane?

(7) What is meant by *substitution*? What products are obtained by substitution of chlorine in methane?

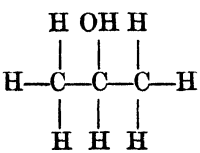
(8) How could you make (*a*) methane, (*b*) ethane, from acetic acid and inorganic reagents only?

CHAPTER III

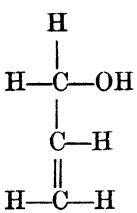
THE ALCOHOLS

30. Meaning of the term Alcohol.—The term *alcohol* is applied to organic compounds which contain one or more hydroxyl groups (–OH) linked to a grouping of carbon and hydrogen atoms only.

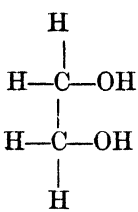
Thus the following are alcohols:—



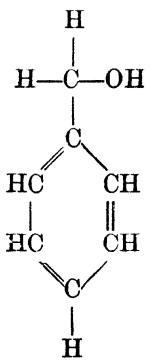
*iso*Propyl alcohol.



Allyl alcohol.

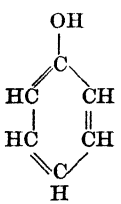


Glycol.



Benzyl alcohol.

The phenols, however, are not classed with the alcohols. These are organic hydroxides of the aromatic series, with their hydroxyl groups directly attached to the benzene ring (see § 353), *e.g.*,



Common phenol or carbolic acid.

Although they fall under the above definition, they are excluded because they are definitely acidic, the hydrogen of their hydroxyl groups ionising in aqueous solution. The alcohols do not ionise appreciably.

When the hydroxyl group is attached to a carbon atom carrying an atom other than hydrogen or to an atom of an element other than carbon, the compound is definitely not an alcohol.

The preparation of tertiary butyl alcohol is described in § 163, Expt. 46

Tertiary amyl alcohol $C_2H_5—\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}—OH$ has been used in medicine as a hypnotic, but is not much employed to-day. It is sometimes called amylene hydrate. It is prepared by converting *iso*amyl alcohol into amylene by treatment with a dehydrating agent, *e.g.*, zinc chloride. The amylene is converted into amyl hydrogen sulphate by the action of sulphuric acid, and this, when treated with alkali, gives tertiary amyl alcohol.

$$(CH_3)_2CH\cdot CH_2\cdot CH_2\cdot OH \xrightarrow{-H_2O} (CH_3)_2CH\cdot CH = CH_2$$

$$(CH_3)_2CH\cdot CH = CH_2 \xrightarrow[\text{at } 530^\circ \text{ C.}]{Al_2O_3 \text{ (catalyst)}} (CH_3)_2C = CH\cdot CH_3$$

$$(CH_3)_2C(HSO_4)\cdot CH_2\cdot CH_3 \xrightarrow{H_2SO_4} (CH_3)_2C = CH\cdot CH_3$$

$$(CH_3)_2C(HSO_4)\cdot CH_2\cdot CH_3 \xrightarrow{KOH} (CH_3)_2C(OH)\cdot C_2H_5$$

53a. Halogen-substituted Alcohols.—By indirect methods various alcohols may be prepared in which some of the hydrogen atoms attached to the carbon atoms are replaced by halogen atoms. Some of these are useful as hypnotics or anæsthetics. Tribromethyl alcohol $CBr_3\cdot CH_2OH$ is known as *Avertin*, and is used as an anæsthetic, especially in obstetric work. Trichloromethyl-dimethylcarbinol $CCl_3—\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}—OH$ is known as *Chloretone*. It is made by the action of chloroform on acetone and is a useful gastric sedative of especial use for relieving nausea *e.g.* sea-sickness.

QUESTIONS

(1) What evidence is there that ethyl alcohol contains a hydroxyl group? Compare its properties with those of (*a*) sodium hydroxide, (*b*) water.

(2) Describe the preparation of pure ethyl alcohol from glucose.

(3) How would you attempt to detect the presence of alcohol in a specimen of ginger-beer?

(4) How does alcohol react with acids in general? In what respect does its reaction with (*a*) sulphuric acid, (*b*) nitric acid, depart from the general rule?

(5) Describe the effect of oxidising agents on ethyl alcohol. How can an oxidising agent be used to detect the presence of methyl alcohol in ethyl alcohol?

(6) Give equations for the reactions of ethyl alcohol with (1) phosphorus pentachloride, (2) sulphuric acid, (3) chromic acid, (4) bleaching powder, (5) iodine in presence of alkali, (6) atmospheric oxygen.

(7) How is methyl alcohol prepared? In what respects does it differ from ethyl alcohol?

(8) What are *primary*, *secondary* and *tertiary* alcohols? Write the formula of one member of each class and explain the effect of oxidising agents upon it.

(9) Write the formulæ for *sec.*-butyl alcohol, *tert.*-amyl alcohol, *iso*-propyl alcohol, methyldiethylcarbinol, and name the alcohols of the formulæ:—

$CH_3\cdot CH(OH)\cdot CH_2\cdot CH_3$; $(CH_3)_2CH\cdot CH_2OH$
$(CH_3)_3C\cdot OH$; $CH_3\cdot CH_2\cdot CH_2OH$.

CHAPTER IV

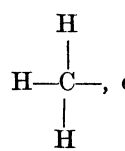
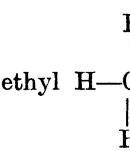
HALOGEN DERIVATIVES OF THE PARAFFIN HYDROCARBONS

54. Number and Nomenclature of Halogen Derivatives.—It has already been seen (§ 24) that the hydrogen in a hydrocarbon can be replaced step by step by halogen atoms. Thus ethane yields nine chloro-compounds:—

One monochloroethane . .	C_2H_5Cl.
Two dichloroethanes . . .	$CH_3{\cdot}CHCl_2$ and $CH_2Cl{\cdot}CH_2Cl$.
Two trichloroethanes . . .	$CH_2Cl{\cdot}CHCl_2$ and $CH_3{\cdot}CCl_3$.
Two tetrachloroethanes . .	$CH_2Cl{\cdot}CCl_3$ and $CHCl_2{\cdot}CHCl_2$.
One pentachloroethane . .	$CCl_3{\cdot}CHCl_2$.
One hexachloroethane . . .	$CCl_3{\cdot}CCl_3$.

Fortunately for the student of organic chemistry, very few of these are of importance.

The monohalogen derivatives of the hydrocarbons are by far the most important. These exist in considerable number, and the table which follows gives a list of these derivatives of the first five hydrocarbons of the series.

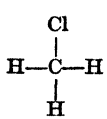
The monohalogen derivatives of the paraffins are regarded as halides of the radicals, methyl  , ethyl  , etc.

Thus the compound C_2H_5I can be called ethyl iodide or mono-iodo-ethane.

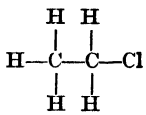
The univalent radicals such as the above, of formula C_nH_{2n+1} are called *alkyl* radicals (§ 23a).

Isomerism of the Monochloroparaffins

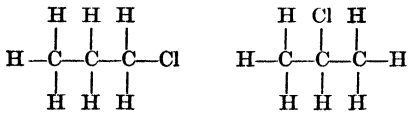
One Monochloromethane.



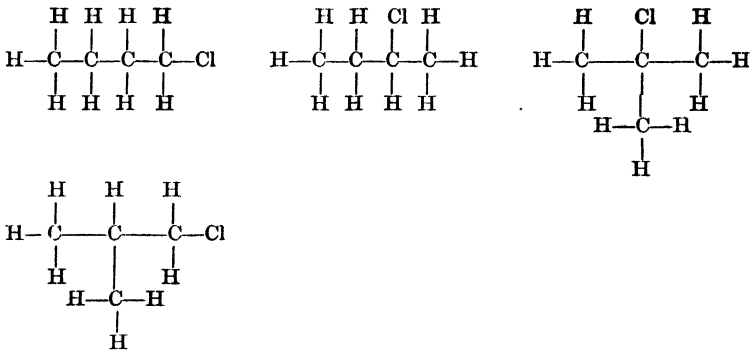
One Monochloroethane.



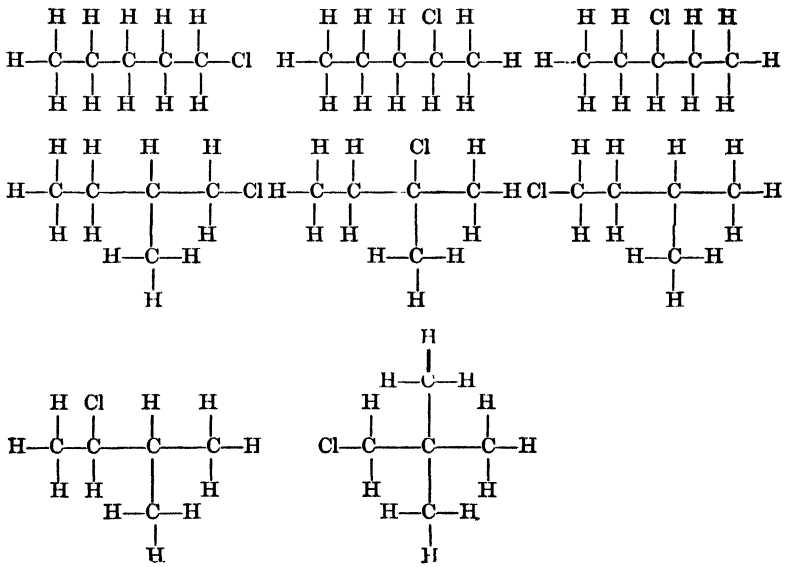
Two Monochloropropanes.



Four Monochlorobutanes.



Eight Monochloropentanes.



surrounded by a water-bath containing cold water. The bromine is added a few drops at a time at such a rate that no liquid distils over. A good deal of heat is evolved. When all the bromine has been added the flask is left to stand for a few

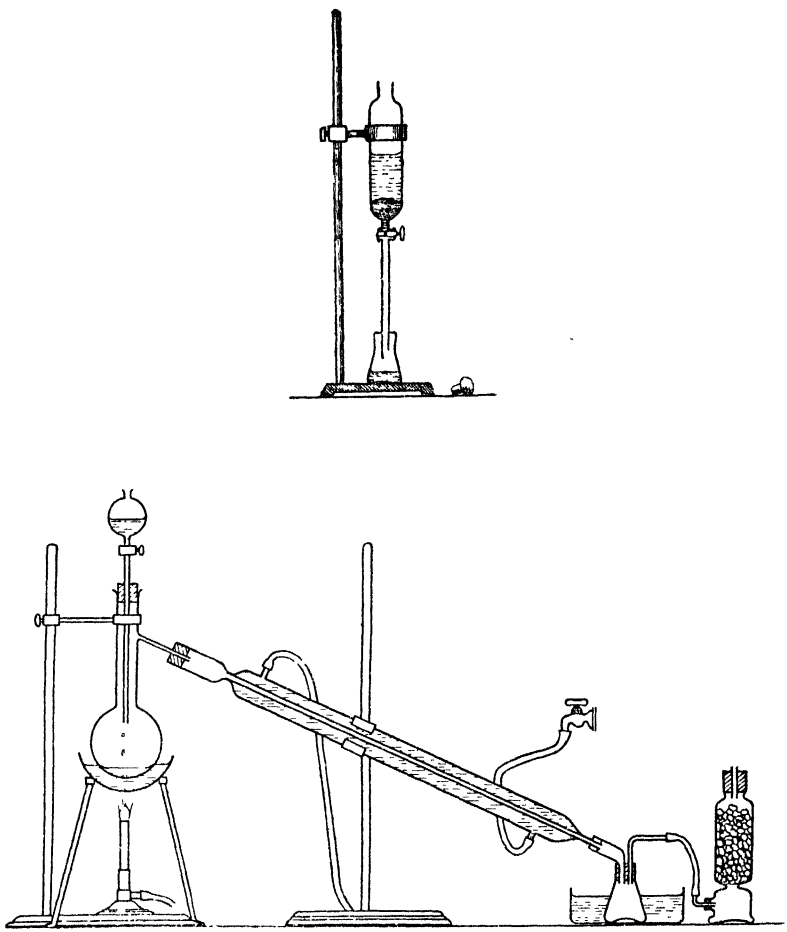


FIG. 20.—Preparation of Ethyl Bromide, using Phosphorus and Bromine.

hours, preferably over-night. The tap-funnel is then replaced by a thermometer and the water-bath is heated. The liquid distilling up to 60° C. is collected. This consists of ethyl bromide (b.p. 38·4° C.) with some alcohol, water, hydrogen bromide, etc. It is poured into a separating funnel and dilute

sodium hydroxide is added (Fig. 20). The funnel is stoppered and the liquids are violently shaken together, the pressure being relieved from time to time by loosening the stopper. The ethyl bromide is now left to settle to the bottom and is run off into a flask, in which are placed a few large pieces of fused calcium chloride. The flask is firmly corked and left for some hours. The ethyl bromide is then poured off and redistilled, the liquid boiling between 37° C. and 40° C., being collected separately and stored in a well-stoppered bottle.

Expt. 8. *Preparation of Methyl Iodide.*—The method and apparatus is in principle the same as that described for ethyl bromide (Expt. 7). The tap-funnel is not used, however, and a thermometer takes its place. 5 G. of red phosphorus and 18 g. of dry methyl alcohol are placed in the flask. 50 G. of dry powdered iodine are weighed out and added, a little at a time, to the contents of the flask, which is gently shaken after each addition. After standing for some hours, the methyl iodide is distilled over and purified in the same way as ethyl bromide (b.p. of methyl iodide 42·3° C.). It should be stored in the dark, as light liberates iodine from it.

Ethyl bromide can readily be prepared from ethyl alcohol by the action of hydrogen bromide. As the action of acids on alcohols (§§ 42, 90) takes place most readily in presence of strong acids and in absence of water, the use of aqueous hydrogen bromide is not advisable. The best method is to allow sulphuric acid to act on a mixture of potassium bromide and the alcohol. The hydrogen bromide liberated reacts with the alcohol and forms ethyl bromide:

$$KBr + H_2SO_4 = KHSO_4 + HBr$$

$$C_2H_5OH + HBr = C_2H_5Br + H_2O$$

which is distilled over, and purified as in Expt. 7.

Expt. 9. *Preparation of Ethyl Bromide.*—100 G. of concentrated sulphuric acid are poured slowly with steady stirring into 50 g. of alcohol (methylated spirit may be used). 40 G. of potassium bromide are placed in a 500-c.c. distilling flask connected to a condenser with an adapter just dipping under water. The mixture of acid and alcohol is added from a tap-funnel, the contents of the flask being well shaken from time to time, and the liquid is then distilled by gentle heating (Fig. 21). Ethyl bromide passes over and sinks to the bottom of the beaker. When no more droplets of ethyl bromide pass over, the heating is stopped and the ethyl bromide is separated

by means of a separating funnel, shaken with dilute alkali and dried and redistilled as in Expt. 7.

57. Properties of the Alkyl Monohalides.—The monohalides of ethane and methane are gases or colourless liquids with a peculiar chloroform-like odour. They are nearly insoluble in water. Their boiling points and densities are given in the table below:—

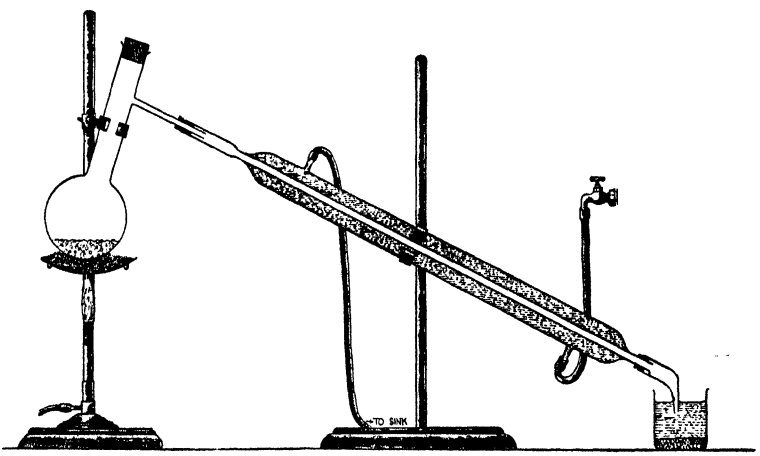


FIG. 21.—Preparation of Ethyl Bromide, using Potassium Bromide.

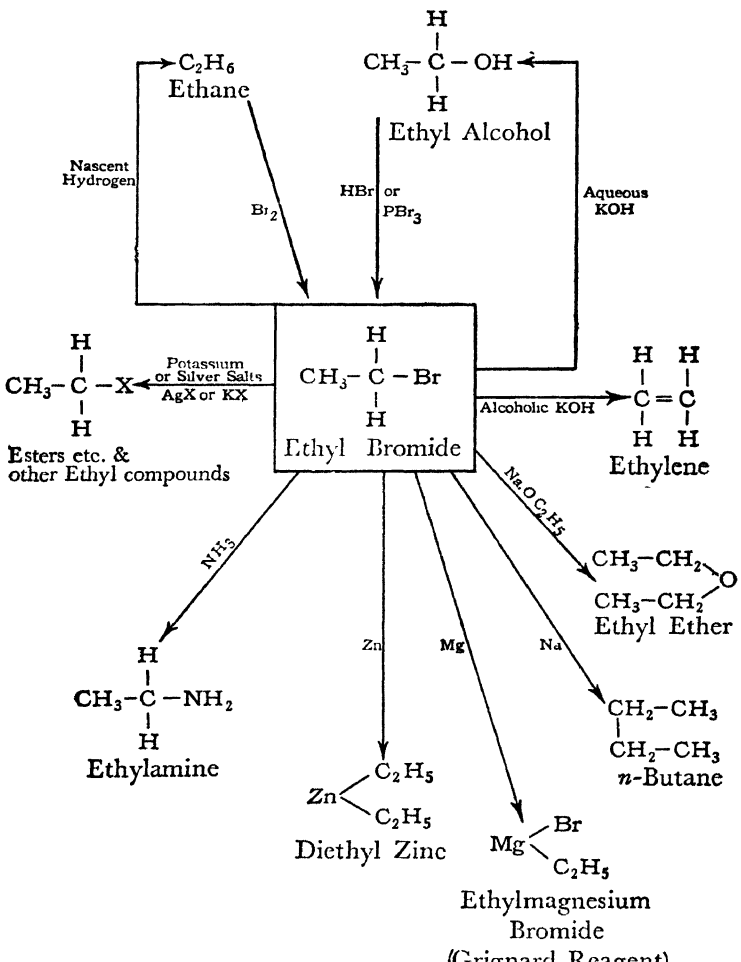
Halide.	Formula.	B.P.	Density of Liquid.
Methyl chloride . .	CH_3Cl	−23°	0·95 /0° C.
Methyl bromide . .	CH_3Br	4·5°	1·73 /0° C.
Methyl iodide . .	CH_3I	42·3°	2·28 /15° C.
Ethyl chloride . .	C_2H_5Cl	12·5°	0·92 /0° C.
Ethyl bromide . .	C_2H_5Br	38·37°	1·47 /15° C.
Ethyl iodide . . .	C_2H_5I	71·5°	1·94 /15° C.

The liquids are excellent solvents for organic substances, though rarely employed for this purpose.

58. Chemical Reactions of the Alkyl Monohalides.—The reactions of a typical alkyl halide—ethyl bromide—are shown on p. 78. It will be seen that a remarkable range of compounds may be made from the alkyl halides, and they are in fact one of the most useful means of synthesising new substances.

The alkyl halides burn with a green-edged flame, but are not readily oxidised by ordinary oxidising agents.

REACTIONS OF ETHYL BROMIDE.



They may be reduced by nascent hydrogen, *e.g.*, zinc and hydrochloric acid, to the hydrocarbons:—

$$CH_3I + 2H = CH_4 + HI.$$

Their most important reaction is that by which they react with the salts of metals, preferably those of potassium or silver, forming compounds of the alkyl group and the acid radical of the salt.

Thus we may make ethyl cyanide by the action of potassium cyanide on ethyl bromide (cf. § 144):—

$$KCN + C_2H_5Br = KBr + C_2H_5CN.$$

Ethyl nitrate may be made by the action of cold ethyl iodide on powdered silver nitrate:—

$$C_2H_5I + AgNO_3 = C_2H_5NO_3 + AgI.$$

These reactions superficially resemble those of the halide of a metal. Thus with sodium iodide and silver nitrate we have the reaction

$$NaI + AgNO_3 = NaNO_3 + AgI.$$

The great difference between the reaction of, say, a sodium compound and an ethyl compound is that the former is a *polar* or *ionised* compound. Polar compounds undergo double decompositions such as the above almost instantaneously and with all classes of salts. Non-polar halides, such as the alkyl compounds, react comparatively slowly and in many cases give a very poor yield of the product.

Somewhat analogous to these reactions is the synthesis of ethyl ether from an ethyl halide and sodium ethoxide. These react giving ethyl ether and a sodium halide (see § 102):

$$C_2H_5O\,Na + Br\cdot C_2H_5 = C_2H_5—O—C_2H_5 + NaBr.$$

When an ethyl halide is treated with ammonia under pressure ethylamine (§ 124) is formed, together with secondary and tertiary amines (§§ 126–8).

$$C_2H_5Cl + NH_3 = C_2H_5NH_2 + HCl.$$

The action of aqueous alkalis on the alkyl halides gives the alcohols, the reaction in some cases being slow and requiring long boiling:

$$C_2H_5I + KOH = C_2H_5OH + KI.$$

Potassium hydroxide dissolved in alcohol, however, converts ethyl halides into ethylene,

$$\begin{matrix} CH_2I \\ | \\ CH_3 \end{matrix} + KOH = KI + H_2O + \begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix}$$

The action of metals on the alkyl halides differs according to the metal employed. The action of sodium yields a hydrocarbon. Thus, ethyl bromide and sodium yield butane:

$$\begin{matrix} C_2H_5Br \\ \\ C_2H_5Br \end{matrix} + 2Na = \begin{matrix} C_2H_5 \\ | \\ C_2H_5 \end{matrix} + 2NaBr.$$

Certain other metals form alkyl compounds of the type $M(C_2N_5)_n$. The formation of alkyl zincs and alkyl magnesium halides is discussed in Chapter XII.

Expt. 10.—*Ethyl Bromide: Reactions.*—(1) Warm ½ c.c. ethyl bromide with a small piece of sodium. Note slow evolution of butane.

(2) Heat and shake with NaOH solution. Alcohol is not easily demonstrated, but aqueous layer may be acidified and tested with $AgNO_3$ for NaBr.

(3) Warm and shake with aqueous silver nitrate. Ppt. of AgBr very slowly formed.

(4) Warm with a solution of Na_2S in alcohol: powerful odour of diethyl sulphide $(C_2H_5)_2S$.

(5) Show that liquid does not burn, though vapour will burn if maintained in contact with a flame.

DIHALIDES OF METHANE AND ETHANE

59. Methylene Halides, CH_2Ha_2.—Dichloromethane, dibromomethane, and di-iodomethane are all known and are also called methylene chloride, bromide and iodide. The radical $=CH_2$ is known as methylene. The chlorine and bromine derivatives may be made by the action of the halogen on methyl chloride and bromide:

$$CH_3Br + Br_2 = CH_2Br_2 + HBr.$$

They are liquids of high density.

The reason why only one methylene chloride, bromide and iodide exists is discussed on p. 33.

60. Ethylene and Ethylidene Compounds.—It is readily seen that two isomeric dichloroethanes can exist, *i.e.*, $CH_2Cl - CH_2Cl$ and $CHCl_2 - CH_3$. The first is made by the action of chlorine on ethylene and is called ethylene chloride; the second, made by the action of phosphorus pentachloride on acetaldehyde (§ 70) is called ethylidene chloride. Similar bromine and iodine compounds exist.

Ethylene Chloride.—The reactions of ethylene chloride are on the whole similar to those of the monohalides (§ 58). Thus the halogen atom may be replaced by other groups through the action of metallic

salts, and boiling alkalis slowly convert it into an alcohol with two hydroxyl groups, known as glycol (§ 188):

$$\begin{matrix}CH_2Cl\\|\\CH_2Cl\end{matrix} + 2KOH = \begin{matrix}CH_2OH\\|\\CH_2OH\end{matrix} + 2KCl.$$

Ethylene dibromide is very similar (*v.* § 169).

Ethylidene chloride, $CH_3{\cdot}CHCl_2$, is made by treating acetaldehyde with phosphorus pentachloride (§ 70):

$$\begin{matrix}CH_3\\|\\CHO\end{matrix} + PCl_5 = \begin{matrix}CH_3\\|\\CHCl_2\end{matrix} + POCl_3$$

It is a colourless liquid boiling at 60° C. The action of alkalis upon it does not result in the formation of an alcohol, $CH_3{\cdot}CH(OH)_2$. It is very rare for two hydroxyl groups to remain attached to the same carbon atom and accordingly acetaldehyde is produced:

$$\begin{matrix}CH_3\\|\\CHCl_2\end{matrix} + 2H_2O = 2HCl + \begin{matrix}CH_3\\|\\CH\langle^{OH}_{OH}\end{matrix}$$

$$\begin{matrix}CH_3\\|\\CH\langle^{OH}_{OH}\end{matrix} = \begin{matrix}CH_3\\|\\H{-}C{=}O\end{matrix} + H_2O$$

TRIHALIDES OF METHANE AND ETHANE

The compounds chloroform, $CHCl_3$, and iodoform CHI_3, are of practical value in medicine. Bromoform has not yet found practical uses.

61. Chloroform, Trichloromethane, $CHCl_3$.—Chloroform is formed when chlorine acts on methane (§ 24), but the method is not of practical value.

It is ordinarily made by the action of bleaching powder on ethyl alcohol or acetone. The action is rather complex. Probably the alcohol is first oxidised to acetaldehyde, $CH_3{\cdot}CHO$, then chlorinated to chloral, trichloroaldehyde, $CCl_3{\cdot}CHO$, which is then hydrolysed to chloroform and a formate:

(1) $CH_3{\cdot}CH_2OH + CaOCl_2 = CH_3{\cdot}CHO + H_2O + CaCl_2$,

(2) $2CH_3{\cdot}CHO + 6CaOCl_2 = 2CCl_3{\cdot}CHO + 3CaCl_2 + 3Ca(OH)_2$

(3) $2CCl_3{\cdot}CHO + Ca(OH)_2 = (H{\cdot}CO{\cdot}O)_2Ca + 2CHCl_3$,

or $2C_2H_6O + 8CaOCl_2 = 2CHCl_3 + (H{\cdot}CO{\cdot}O)_2Ca + 5CaCl_2 + 2Ca(OH)_2 + 2H_2O$.

The reaction with acetone is similar, the stages being

(1) acetone, $CH_3—CO—CH_3$.
(2) trichloroacetone, $CCl_3—CO—CH_3$.
(3) chloroform, $CHCl_3$, and calcium acetate, $Ca(CH_3 \cdot COO)_2$.

Expt. 11.—*Preparation of Chloroform.*—Arrange a 1,500 c.c. flask connected by a cork and wide bent tube to a condenser and receiver as in Fig. 22.

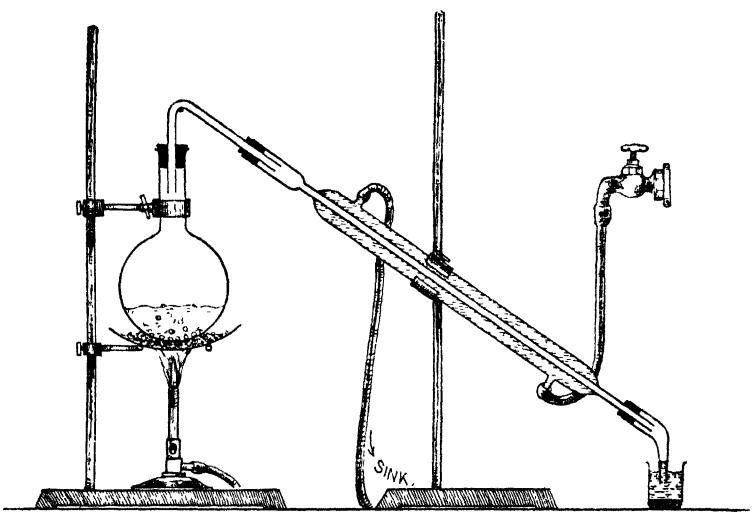


FIG. 22.—Preparation of Chloroform.

150 G. of bleaching powder are placed in a large basin or mortar and 600 c.c. of water are added a little at a time, with stirring and rubbing so as to break up all lumps. The suspension is poured into the flask and 35 c.c. of ethyl alcohol are added and well mixed. The flask is then heated on the sand bath till the reaction starts. The flame is now withdrawn until the reaction has moderated. The contents of the flask are then gently heated and distillation is continued until no more heavy drops of chloroform come over. The chloroform is separated and purified in the same way as ethyl bromide (Expt. 7).

Chloroform which is to be used as an anæsthetic must be free from any injurious impurities. Chloroform decomposes slowly in presence of air and light, forming hydrochloric acid and the poisonous and irritating carbonyl chloride or phosgene. This decomposition is much retarded by the addition of about 1 per cent of ethyl alcohol, and chloroform sold for anæsthetic purposes is always treated in this

way. The presence of carbonyl chloride and hydrogen chloride in chloroform is detected by shaking it with silver nitrate solution. This does not react with chloroform, but gives a white precipitate of silver chloride with the above impurities.

Physical Properties.—Chloroform is a colourless liquid with a sweetish taste and an ethereal odour. It is a valuable anæsthetic, being employed either pure or in conjunction with alcohol and ether.

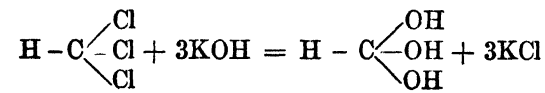
Chloroform boils at 61·2° C. It is heavier than water ($d = 1{\cdot}53$). It is very slightly soluble in water (1 : 200), and is a useful solvent for many substances, *e.g.*, fats, india-rubber, alkaloids, etc.

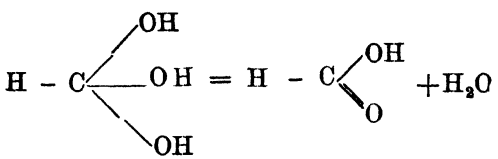
Chemical Properties.—Chloroform is not inflammable. It is not a very reactive substance.

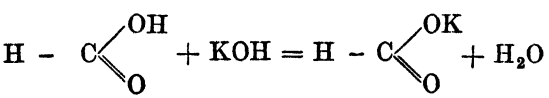
Powerful reducing agents, *e.g.*, zinc dust and water, will reduce it to lower chlorides and finally to methane:

$$CHCl_3 + 6H = CH_4 + 3HCl.$$

A solution of potassium hydroxide in water does not attack it, but a solution in alcohol, 'alcoholic potash,' produces potassium formate and chloride. The reactions may be represented as the formation of a hypothetical trihydroxymethane which breaks up to formic acid and water:







or $$CHCl_3 + 4KOH = H{\cdot}CO{\cdot}OK + 3KCl + 2H_2O.$$

A characteristic reaction of chloroform, known as the carbylamine test, is the formation of a strong-smelling *iso*cyanide with alcoholic potash and an amine (§ 146). Thus, on warming chloroform with alcoholic potash and aniline, the powerful and disgusting smell of phenyl *iso*cyanide is perceived:

$$C_6H_5NH_2 + CHCl_3 + 3KOH = C_6H_5{\cdot}NC + 3KCl + 3H_2O.$$

Expt. 12.—*Reactions of Chloroform.*—(1) Show that silver nitrate and potassium permanganate do not react with chloroform.

(2) Heat with alcoholic potash. Potassium chloride and formate produced.

(3) Heat 1 drop chloroform with 3 c.c. Fehling's solution. Note this is reduced. (The chloroform gives potassium carbonate and chloride.)

(4) To 1 c.c. alcoholic potash add 1 drop aniline and 1 drop chloroform. Warm. Strong odour of phenyl *iso*cyanide. The smell can be removed by addition of conc. hydrochloric acid, which hydrolyses the *iso*cyanide.

(5) Show that chloroform does not burn.

62. Bromoform, $CHBr_3$, much resembles chloroform and is made in a similar manner by the action of a hypobromite on acetone. It is a liquid of very high specific gravity (2·9).

63. Iodoform, CHI_3.—Iodoform is of some medical importance. It is made by the action of iodine and an alkali (which form a hypoiodite) upon ethyl alcohol or acetone. The reactions are similar to those described under the heading chloroform, and probably follow a similar course.

If ethyl alcohol, iodine and caustic potash are employed the equation is:

$$4I_2 + 6KOH + C_2H_5OH = CHI_3 + H{\cdot}CO{\cdot}OK + 5KI + 5H_2O.$$

The practical method is different from that employed to prepare chloroform, owing to the fact that iodoform is a solid.

Expt. 13.—*Preparation of Iodoform.*—Dissolve 2 parts of crystallised sodium carbonate in 10 parts of water and add 1 part of ethyl alcohol. Warm to *ca.* 70° C. and slowly add 1 part of iodine, stirring till the liquid becomes colourless. Allow to cool; filter off the iodoform, wash it and dry it.

The formation of iodoform in the above manner is used as a test for alcohol (*Expt.* 4).

Properties of Iodoform.—Iodoform crystallises in lemon-yellow rosettes consisting of hexagonal plates. It has a disagreeable and characteristic smell reminiscent of the hospital. It melts at 119° C. and decomposes below its boiling point. Iodoform is almost insoluble in water but easily soluble in alcohol.

It finds a use as an antiseptic in surgery, exerting a mild action without the irritating effect of iodine and many other antiseptics.

Iodoform is less stable than chloroform. In solution it is rapidly oxidised in presence of oxygen and light, liberating iodine.

It reacts with silver nitrate, precipitating silver iodide.

COMPOUNDS OF CARBON AND HALOGENS ONLY

Carbon tetrachloride, tetrabromide and tetraiodide are all known, as also are carbon hexachloride, C_2Cl_6, and one or two other com-

pounds of carbon and halogens only. Carbon tetrachloride is the most important of these.

64. Carbon Tetrachloride, CCl_4.—Carbon tetrachloride can be made by the action of chlorine upon methane (§ 24), but is commonly made by the action of chlorine upon carbon disulphide in presence of aluminium chloride, which acts as a catalyst,

$$CS_2 + 3Cl_2 = CCl_4 + S_2Cl_2.$$

It is a heavy colourless liquid with a chloroform-like odour. It boils at 77° C. It is used as a solvent and also as a fire extinguisher (Pyrene). Its heavy non-inflammable vapour excludes the air from the burning object and so extinguishes it.

It is a very stable substance, and is attacked by none of the commoner reagents. Sulphur trioxide or fuming sulphuric acid converts it into carbonyl chloride (§ 305).

Carbon hexachloride, C_2Cl_6, or hexachloroethane, is a white volatile crystalline solid with a camphor-like odour.

QUESTIONS

(1) How would you prepare a specimen of ethyl bromide from ethyl alcohol and reconvert your product into the latter substance?

(2) In what respects does ethyl bromide resemble and differ from the bromide of a metal?

(3) 1 050 G. of an alkyl halide were heated with nitric acid and silver nitrate according to the Carius method. 1 604 G. silver bromide were precipitated. The substance contained 29 3 per cent. carbon and 5·7 per cent. hydrogen, and its vapour density was 61 5. What was its formula? Could more than one substance have this formula?

(4) 0 25 G. of an alkyl iodide was vaporised in a Victor Meyer apparatus and displaced 38 1 c.c. of air, measured over water at 13° C. and 761 mm. pressure (V.P. of water at 13° C. = 11 mm.). What is its molecular weight and formula?

(5) Describe the effect of sodium, sodium hydroxide, sodium cyanide and sodium ethoxide on ethyl bromide.

(6) What substances are obtained when (*a*) ethyl iodide, (*b*) ethylidene chloride, (*c*) chloroform are heated with caustic potash solution?

(7) Describe the preparation of a specimen of chloroform. What impurities are commonly found in chloroform, and how may they be detected and removed?

(8) Write formulæ for: methylene iodide, $\beta\beta$-dichloropropane, ethylene chloride, ethylidene chloride, bromoform, and give names to the compounds of formulæ $CH_3{\cdot}CHCl{\cdot}CH_3$, $CH_3{\cdot}CH_2Br$, $CH_3{\cdot}CH_2{\cdot}CHBr_2$, CHI_3, C_2Cl_6.

CHAPTER V

THE ALDEHYDES

65. The Aldehydic Group.—When a primary alcohol is oxidised, the first product is an aldehyde. The aldehydes are characterised by the group —C(=O)—H usually written —CHO.

The evidence for the structure of this group is given under acetaldehyde (§ 69). The aldehydes share many of their properties with the ketones (Chap. IX), which also contain the —C(=O)— group.

66. Nomenclature.—The aldehydes are ordinarily named from the acid which is formed when they are oxidised. Thus formaldehyde H—C(=O)—H is so named because it is oxidised to formic acid, H·CO·OH, butyraldehyde $CH_3 \cdot CH_2 \cdot CH_2 \cdot CHO$ because it is oxidised to butyric acid.

Alternatively, the termination -al replaces the final -e in the name of the hydrocarbon with the same number of carbon atoms as the aldehyde. Thus acetaldehyde $CH_3 \cdot CHO$ may be called ethanal.

The simplest aldehyde is formaldehyde H—C(=O)—H; a list of the lower aldehydes derived from the paraffin series of hydrocarbons is given below.

Aldehyde.	Formula.	B.P.	Density.	Solubility in water.
Formaldehyde .	H·CHO	−21°	0·815 /−20° C.	Miscible
Acetaldehyde .	$CH_3 \cdot CHO$	20·8°	0·79 /16° C.	Miscible
Propionaldehyde	$C_2H_5 \cdot CHO$	49·5°	0·807 /20° C.	1 : 5 /20° C.
n-Butyraldehyde .	$C_3H_7 \cdot CHO$	73°	0·817 /20° C.	1 : 27
n-Valeraldehyde .	$C_4H_9 \cdot CHO$	102°	0·819 /11·2° C.	—

Other compounds containing the aldehyde grouping include the unsaturated aldehydes (§ 177), aromatic aldehydes (§ 450), etc. Some

of the sugars, though not actually aldehydes, react in a very similar manner (§§ 265, 272).

67. Acetaldehyde, Ethanal, C_2H_4O.—Formaldehyde, the first member of the series, differs in some important respects from the others: it is convenient therefore to consider acetaldehyde first, as being a typical member of the series of aldehydes.

Preparation of Acetaldehyde.—The most important method of preparing aldehydes is by the oxidation of alcohols.

(1) Numerous methods of oxidation may be used, but the usual method employed is the oxidation of ethyl alcohol by a solution of potassium dichromate and sulphuric acid (see Expt. 14):

$$K_2Cr_2O_7 + 5H_2SO_4 + 3C_2H_6O = 3C_2H_4O + 7H_2O + 2KHSO_4 + Cr_2(SO_4)_3.$$

(2) Oxidation by atmospheric air, using metallic platinum or copper as a catalyst, can be employed (method as under Formaldehyde: Expt. 20):—

$$2CH_3{\cdot}CH_2{\cdot}OH + O_2 = 2CH_3{\cdot}CHO + 2H_2O.$$

(3) Acetaldehyde is prepared on the commercial scale by the direct combination of acetylene and water at 50°—60° C. in presence of mercuric sulphate as a catalyst (Expt. 16):—

$$C_2H_2 + H_2O = C_2H_4O.$$

(4) The action of superheated water on ethylidene chloride (§ 60) yields aldehyde:

$$CH_3{\cdot}CHCl_2 + H_2O = CH_3{\cdot}CHO + 2HCl.$$

(5) When calcium formate is heated with calcium acetate, acetaldehyde is formed:—

$$Ca\begin{<}O{\cdot}\ OCH\\ O{\cdot}OC\ \ H\end{>} + \begin{<}CH_3\ COO\\ CH_3{\cdot}CO\ \ O\end{>}Ca = 2CaCO_3 + 2C_2H_4O$$

Methods (1), (4) and (5) are general methods by which the higher aldehydes may be prepared from the appropriate compounds.

Expt. 14.—*Preparation of Acetaldehyde from Ethyl Alcohol.*—A distilling flask (500 c.c.) is fitted with a tap-funnel and supported on a sand-bath. It is connected to a condenser, which is connected by an adapter to a flask surrounded by ice. All corks must be well fitting, as aldehyde is very volatile. In the distilling flask are placed 50 g. of sodium dichromate and 150 c.c. of water. 70 c.c. of alcohol are placed in a beaker and 40 c.c. of concentrated sulphuric acid gradually stirred in. This mixture is then placed in the tap-funnel. The flask is gently heated and, when the liquid is warm, the flame is withdrawn

and the alcohol mixture is added a little at a time. The flask is occasionally shaken and the alcohol is added at such a rate that the mixture boils gently. When all has been added the flask is heated until 75 c.c. of distillate have passed over. The distilling flask is then removed. 75 G. of anhydrous calcium chloride are then placed in a 250 c.c. distilling flask. This is placed on a water-bath and connected to the same condenser and receiver, and the distillate (which contains water, alcohol and aldehyde) is then poured upon the calcium chloride. The calcium chloride combines with both water and alcohol and the

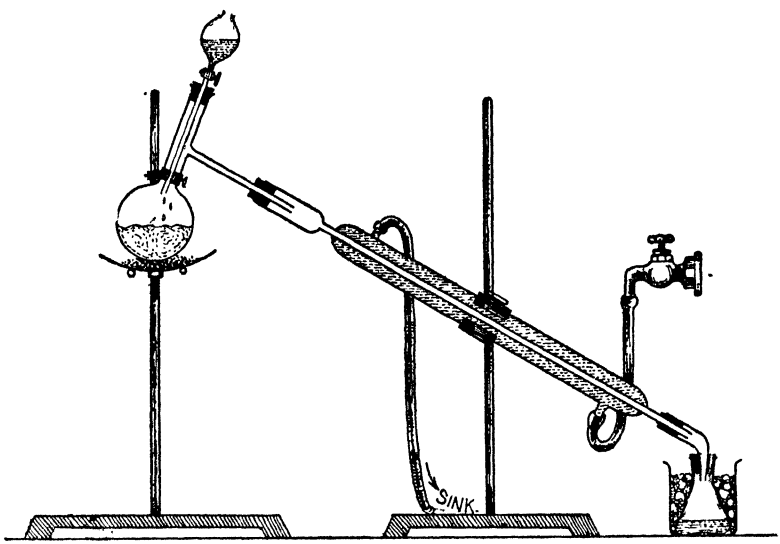


FIG. 23.—Preparation of Acetaldehyde from Ethyl Alcohol.

aldehyde floats on the concentrated solution formed. The flask is gently shaken and the contents are distilled into the ice-cold receiver until all the aldehyde has come off. The distillate now contains a large proportion of aldehyde.

The distilling flask is cleaned out and dried and 40 g. of fresh calcium chloride are placed in it. The distillate is poured in and once more distilled into an ice-cooled receiver. It is now nearly pure aldehyde. (Yield about 10 g.).

Expt. 15.—*Preparation of Aldehyde-ammonia.*—The final product from Expt. 14 is dissolved in twice its volume of ether and placed in a large test-tube fitted to an inverted 50-c.c. pipette, as shown (Fig. 24). The test-tube is cooled, best by ice, and ammonia gas, produced by heating 0·880 ammonia and

dried by a lime-tower, is passed in. After a short time white crystals of *aldehyde-ammonia* separate in quantity. These may be dried by pressing with filter papers and stored in a well-stoppered bottle.

Very pure aldehyde is best obtained by distilling these with dilute sulphuric acid into an ice-cooled receiver and dehydrating the product with calcium chloride as in Expt. 14.

Expt. 16.—*Formation of Acetaldehyde from Acetylene.*—Dissolve 1½ g. of mercuric oxide in 30 c.c. of dilute sulphuric acid. The resulting solution is placed in a wash-bottle immersed in a water-bath heated to 60° C. Acetylene is slowly passed through this solution for half an hour. The solution of

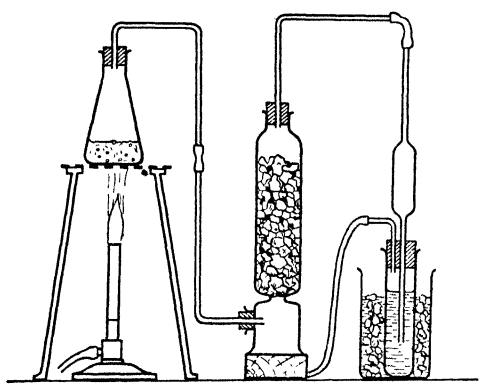


FIG. 24.—Preparation of Aldehyde-ammonia.

mercuric sulphate when removed will smell of acetaldehyde. If it is distilled and the first 5 c.c. are collected, the weak solution of acetaldehyde so obtained will reduce Fehling's solution.

68. Physical Properties of Acetaldehyde.—Acetaldehyde is a colourless liquid with a strong suffocating smell, which has been compared to that of ivy-leaves. When much diluted it has a fruity odour—not unlike that of apples. It boils at 20·8° C., and has a density of 0·79. It is miscible with water in all proportions, but may be 'salted out' by the addition of much calcium chloride.

69. Structure of Acetaldehyde.—The formula of acetaldehyde is C_2H_4O. It is reduced by sodium amalgam and water to ethyl alcohol:

$$C_2H_4O + 2H = CH_3{\cdot}CH_2OH,$$

and it may therefore be supposed to contain a methyl group and so to be $CH_3{\cdot}CHO$. The $-CHO$ group does not contain a hydroxyl group, as is shown by the action of phosphorus pentachloride, which

reacts with hydroxyl groups forming a chloride and hydrogen chloride:

$$X{\cdot}OH + PCl_5 = XCl + HCl + POCl_3.$$

Phosphorus pentachloride and aldehyde, on the other hand, give ethylidene chloride, $C_2H_4Cl_2$, and no hydrogen chloride:

$$CH_3{\cdot}CHO + PCl_5 = CH_3{\cdot}CHCl_2 + POCl_3.$$

We therefore write the formula of acetaldehyde as $CH_3—\overset{\overset{O}{\|}}{C}—H$.

70. Chemical Properties of Acetaldehyde.—

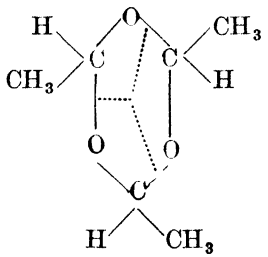
Polymerisation.—Like many reactive substances, acetaldehyde tends to combine with itself and form *polymerides*, *i.e.*, compounds formed by the combination of two or more identical molecules.

When acetaldehyde is treated with a small quantity of sulphuric acid[1] at the ordinary temperature, *paraldehyde* $(C_2H_4O)_3$ is produced. Paraldehyde is a colourless liquid boiling at 124° C. It is used in medicine as a hypnotic.

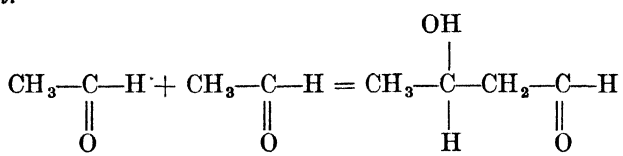
If the above preparation is performed at 0° C. or below *metaldehyde*, $(C_2H_4O)_4$, is produced. It is a crystalline solid, which when heated once more produces acetaldehyde.

When aldehyde is heated with an alkali a brown 'aldehyde resin' of unknown structure is produced.

Paraldehyde has the structural formula given below, the dotted lines indicating the three acetaldehyde molecules.



When acetaldehyde is left in contact with dilute alkali two molecules can also combine in a somewhat firmer fashion to form *aldol*.

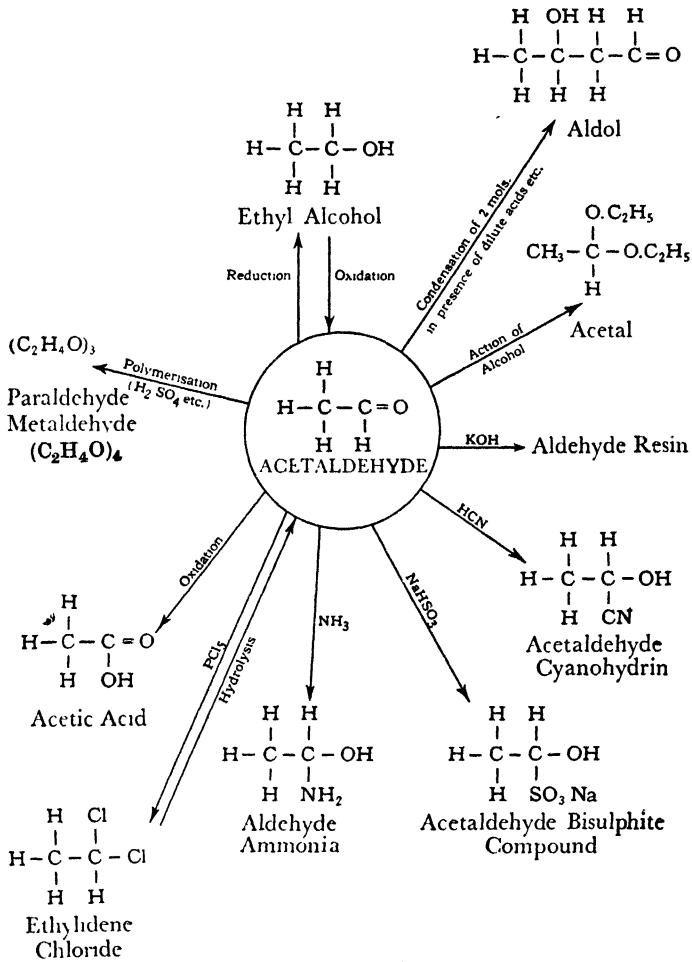


Aldol
(β-hydroxybutyraldehyde).

This reaction should be compared with those on pp. 92, 93.

[1] Many other substances may be used in place of sulphuric acid.

REACTIONS OF ACETALDEHYDE.



Action of Oxidising Agents.—

Acetaldehyde is very readily oxidised to acetic acid:

$$CH_3—\underset{\underset{O}{\|}}{C}—H + O = CH_3—\underset{\underset{O}{\|}}{C}—OH.$$

The oxygen of the air will slowly oxidise it, finely divided manganese dioxide acting as a catalyst; other oxidising agents *e.g.*, acid potassium dichromate solution, do so rapidly.

Being so readily oxidised, it acts as a strong reducing agent and readily reduces alkaline solutions of silver salts to metallic silver.

Expt. 17.—*Reducing Action of Acetaldehyde.*—A solution of silver nitrate is treated with ammonia until any precipitate just redissolves. A little aldehyde is then added. The mixture is placed in a very clean test-tube and warmed by immersion in a beaker of warm water. A mirror of metallic silver is formed on the glass.

Cupric salts in presence of alkalis are reduced to cuprous oxide.

Fehling's solution, used as a test for aldehydes, consists of an alkaline solution of potassium cupritartrate. On warming it with an aldehyde a yellowish-red precipitate of cuprous oxide is obtained.

Expt. 18.—*To make Fehling's Solution.*—Dissolve 3·5 g. of crystallised copper sulphate in 50 c.c. of distilled water. In another 40 c.c. of distilled water dissolve 7 g. of sodium hydroxide and 18 g. of potassium sodium tartrate (Rochelle salt). This solution is diluted to 50 c.c. To test for an aldehyde equal volumes of the two solutions are mixed,[1] and heated. The suspected substance is then added and the whole heated again. A yellow precipitate of hydrated cuprous oxide becoming orange-red on further heating shows the presence of an aldehyde. A few substances which do not contain the aldehyde group reduce Fehling's solution.

The halogens do not oxidise aldehyde. Chlorine gives trichloro-aldehyde, known as chloral (§ 72):

$$CH_3{\cdot}CHO + 3Cl_2 = CCl_3{\cdot}CHO + 3HCl.$$

Phosphorus pentachloride converts acetaldehyde into ethylidene chloride (§ 60):

$$CH_3{\cdot}CHO + PCl_5 = CH_3{\cdot}CHCl_2 + POCl_3.$$

Acetaldehyde when reduced with nascent hydrogen (sodium amalgam and water), gives ethyl alcohol:

$$CH_3{\cdot}CHO + 2H = CH_3{\cdot}CH_2{\cdot}OH.$$

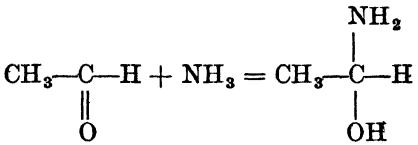
Addition Products.—Acetaldehyde reacts with many hydrogen compounds forming addition products. The reaction is of the type

$$CH_3{-}\underset{\underset{O}{\|}}{C}{-}H + HX = CH_3{-}\underset{\underset{OH}{|}}{\overset{\overset{X}{|}}{C}}{-}H.$$

Among the hydrogen compounds with which it reacts in this way are ammonia, hydrogen cyanide and bisulphites.

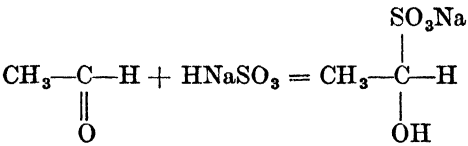
[1] The copper in Fehling's solution is present in the acid radical in the salt sodium potassium cupritartrate. For this reason the sodium hydroxide added does not precipitate cupric hydroxide, $Cu(OH)_2$, as it would if, say, copper sulphate were used.

Thus on passing ammonia gas into acetaldehyde, as described in Expt. 15, white crystals of acetaldehyde-ammonia separate:



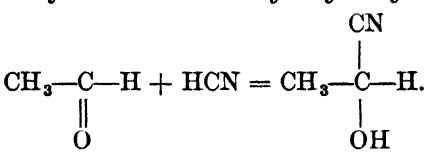
The compound is readily decomposed by acids yielding acetaldehyde once more.

Sodium bisulphite when shaken with an aldehyde forms a crystalline compound:



These compounds are also readily decomposed by the action of acids or of alkalis such as sodium carbonate.

With hydrocyanic acid *acetaldehyde cyanohydrin* is formed:



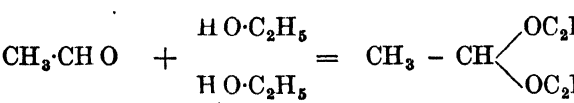
In addition to the above reactions which are *additive*, aldehyde reacts with several substances containing hydrogen, with elimination of water. Thus aldehydes react with hydroxylamine forming *aldoximes* and eliminating water.

$$CH_3{\cdot}CHO + H_2N{\cdot}OH = CH_3{\cdot}CH{:}N{\cdot}OH + H_2O.$$

With phenylhydrazine compounds called phenylhydrazones are formed. These are readily crystallised and have definite melting points, and so are useful for identifying aldehydes and such sugars (§ 272) as contain a potential aldehyde grouping:

$$CH_3 - CHO + H_2N{\cdot}NH{\cdot}C_6H_5 = CH_3{\cdot}CH{:}N{\cdot}NH{\cdot}C_6H_5 + H_2O.$$

Aldehyde reacts with alcohol in presence of a little hydrogen chloride and forms *acetal*, a liquid boiling at 103° C. and sparingly soluble in water:



Test for Aldehydes.—Schiff's test for aldehydes consists of adding

water into sugars, etc., by green plants, the mixture of green and yellow pigments known as chlorophyll acting as a catalyst (*v.* § 300).

Physical Properties.—Formaldehyde is a colourless gas of intensely irritating odour; it may be condensed to a liquid boiling at – 21° C. It is readily soluble in water and the formaldehyde or 'formalin' commonly sold is an aqueous solution containing 40 per cent. of the gas. Formaldehyde is poisonous. It coagulates proteins and, probably for this reason, is a most effective destroyer of bacteria and other low forms of life. Formaldehyde is much used in biological work for preserving tissues of various kinds. It at once hardens these and preserves them from putrefaction.

Chemical Properties of Formaldehyde.—When the solution of formaldehyde is concentrated by evaporation it yields a white

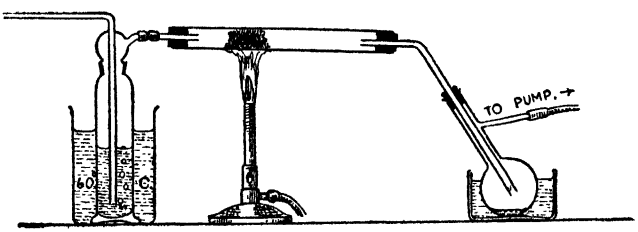


FIG. 25.—Preparation of Formaldehyde.

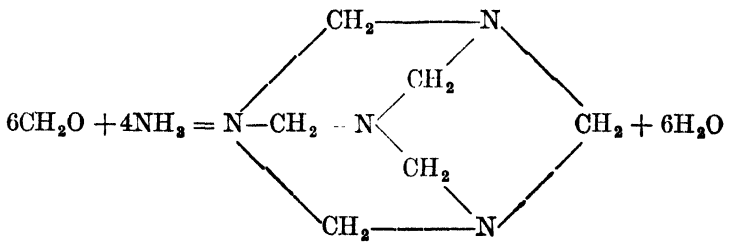
solid polymeride called 'paraformaldehyde,' or polyoxymethylene, $(CH_2O)x$ where $x = 30 - 40$. This is an article of commerce and is used for fumigation. The solid paraformaldehyde is heated over a small lamp and evolves gaseous formaldehyde which acts as an efficient disinfectant.

When the gas is liquefied by cooling, the liquid rapidly changes to another polymeride, probably of formula $(CH_2O)_3$, and known as metaformaldehyde or trioxymethylene.

Formaldehyde polymerises in weakly alkaline aqueous solution to a sugary substance containing chiefly *dl*-acrose (§ 272), a fact which may be of importance in showing a way in which plants might build up sugars, etc., from carbon dioxide and water. The subject is further discussed in § 300.

In most other respects the reactions of formaldehyde resemble those of acetaldehyde. It is oxidised to formic acid H·CO·OH. It produces numerous addition products, *e.g.*, with hydrocyanic acid and with bisulphites (§ 70). Formaldehyde-ammonia is not, however,

produced, but instead the compound hexamethylene-tetramine is formed:



This substance is used in medicine as a urinary antiseptic under the name of *hexamine* or *urotropine*.

Formaldehyde condenses with phenols (§ 354) to form the valuable synthetic resins, which are much used for electrical insulation, ornamental horn-like and amber-like materials, etc. It also condenses with urea and gives valuable plastic materials (§ 312).

Higher Aldehydes.—Most of these are unimportant. In general they resemble acetaldehyde in their chemical properties. Undecylaldehyde $C_{11}H_{22}O$ and some of the other higher aldehydes are used in perfumery.

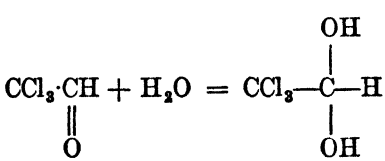
72. Chloral, Trichloroaldehyde, $CCl_3 . CHO$, is a substance of some importance in medicine, and is used in the manufacture of the insecticide D.D.T. (dichlordiphenyltrichlorethane).

It is prepared on the large scale by the action of chlorine on alcohol. The reaction is

$$CH_3{\cdot}CH_2OH + 4Cl_2 = CCl_3{\cdot}CHO + 5HCl.$$

The chlorine at once *oxidises* the primary alcohol group $—CH_2OH$ to the aldehyde group —CHO and *substitutes* itself for hydrogen in the methyl group.

The product of the reaction is mixed with a small quantity of water, whereupon 'chloral hydrate' crystallises out:



This compound is one of the very few in which two hydroxyl groups are attached to a single carbon atom.

Chloral can also be made by the action of chlorine on acetaldehyde.

Properties of Chloral.—Chloral is a colourless liquid with a pungent odour. It boils at 97·7° C.

It combines with water to form chloral hydrate (*q.v.*). In most respects it behaves like acetaldehyde. Thus it is oxidised to trichloroacetic acid, $CCl_3 \cdot CO \cdot OH$. It reduces silver salts to metals and forms addition compounds with ammonia, hydrogen cyanide and sodium bisulphite.

When heated with solutions of alkalis it forms *chloroform* and a formate:

$$CCl_3 \cdot CHO + KOH = CHCl_3 + H \cdot CO \cdot OK.$$

This reaction takes place during the preparation of chloroform (§ 61).

73. Chloral Hydrate, $CCl_3—CH(OH)_2$.—Chloral hydrate is made by the action of water on chloral (*v. supra*).

It forms monoclinic crystals with a peculiar odour and a sharp taste, readily soluble in water (1 : 4·7 at 17·5° C.).

It is a valuable hypnotic. A dose of about 5 grains induces a natural and refreshing sleep; its great danger is the ease with which a chloral-habit is established.

74. Butylchloral Hydrate, $CH_3 \cdot CHCl \cdot CCl_2 \cdot CH(OH)_2$, is used in medicine as a means of relieving severe pain. It is obtained by the action of chlorine on paraldehyde.

QUESTIONS

(1) What is the structural formula of acetaldehyde? Explain the evidence which leads to it.

(2) What is a polymeride? Illustrate your answer by reference to the various polymerides formed by (*a*) formaldehyde, (*b*) acetaldehyde.

(3) How would you try to find out whether a mixture of ethyl alcohol and air, when passed through an empty glass tube at a temperature just insufficient to ignite it, formed any acetaldehyde?

(4) Describe the preparation of acetaldehyde from ethyl alcohol. Why is the yield always a good deal less than the equation indicates?

(5) What is an addition compound? What addition products are formed by acetaldehyde, and of what practical value are they?

(6) Describe the preparation of a solution of formaldehyde. How would you try to detect the presence of methyl alcohol in the product?

(7) Oil of bitter almonds, a liquid boiling at 180° C., and insoluble in water, is said to be an aldehyde. How would you try to test the truth of this statement by an experimental study of its chemical properties?

CHAPTER VI

THE FATTY ACIDS

75. Structure of Fatty Acids.—When an aldehyde is oxidised, a compound with one additional oxygen atom is formed. This compound is an acid. In the case of acetaldehyde the compound formed is acetic acid, $C_2H_4O_2$:

$$CH_3—\underset{\underset{O}{\|}}{C}—H + O = C_2H_4O_2.$$

The structure of this compound is cleared up by its reaction with phosphorus pentachloride. One molecule of the acid yields one molecule of HCl, thus,

$$C_2H_4O_2 + PCl_5 = C_2H_3OCl + POCl_3 + HCl.$$

The analogy to the reaction of alcohol (§ 42) makes it clear that acetic acid contains one hydroxyl group and is $C_2H_3O{\cdot}OH$. Since only one hydroxyl group is present, the other oxygen must be otherwise combined and in view of its formation from aldehyde we may write the formula:

$$\begin{array}{l} \quad\quad H \\ \quad\quad | \\ H—C—C—OH \\ \quad\quad | \;\; \| \\ \quad\quad H \;\; O \end{array}$$

The great majority of organic acids[1] contain this *carboxyl* group $\underset{\underset{O}{\|}}{C}—OH$, and the series of acids which consist of an alkyl group (§ 54) and one carboxyl group are called the fatty acids. This name was given them because the acids contained in many fats (§ 192) belong to this series. Their general formula is $C_nH_{2n+1}CO{\cdot}OH$ or $C_nH_{2n}O_2$.

The most important fatty acids are given in the following table.

[1] But see uric acid (§ 320), phenols (§ 354), sulphonic acids (§ 351).

No. of C Atoms.	Name.	Formula.	M.P.	B.P.	Solubility.	Density.
1.	Formic acid .	$H CO_2H$.	8·5°	100 6°	Miscible	1·226/15° C.
2.	Acetic acid .	$CH_3 \cdot CO_2H$	16·7°	117·9°	Miscible	1 055/15° C.
3.	Propionic acid.	$CH_3 CH_2 \cdot CO_2H$	−19·3°	140 5°	Miscible	0 987/20° C.
4.	*n*-Butyric acid.	$CH_3 \cdot CH_2 \cdot CH_2 CO_2H$	− 8°	162·3°	Miscible	0·975/0° C.
4.	*iso*Butyric acid	$(CH_3)_2CH CO_2H$	−79°	155 5°	1 : 5	0 949/20° C.
5.	*n*-Valeric acid .	$CH_3 \cdot (CH_2)_3 CO_2H$	−19°	185°	1 : 27 (16° C.)	0·942/20° C.
5.	*iso*Valeric acid	$(CH_3)_2CH CH_2 \cdot CO_2H$	−51°	173·7°	1 : 24 (20° C.)	0 930/20° C.
5.	Active valeric acid.[1]	$CH_3 \cdot CH_2 \cdot CH(CH_3) \cdot CO_2H$	25°	175°	—	0 938
5.	Trimethylacetic acid . .	$(CH_3)_3 \cdot C \cdot CO_2H$	38°	163°	1 : 45 (20° C.)	0 905/50° C.
16.	Palmitic acid .	$C_{15}H_{31} \cdot CO_2H$	62 6°	278/100 mm.	Insoluble	0 8527/64° C.
18.	Stearic acid .	$C_{17}H_{34} CO_2H$	69·3°	291/100 mm.	Insoluble.	0 8521/69 5

Formic acid is in some respects not a typical fatty acid and, accordingly, acetic acid may be first considered, as being at once the most important fatty acid and at the same time typical of the group.

76. Acetic Acid, $CH_3 \cdot CO \cdot OH$.—*Manufacture.*—Acetic acid is made:

(1) By the oxidation of alcohol:

$$CH_3 \cdot CH_2OH + 2O = CH_3 \cdot CO \cdot OH + H_2O.$$

This oxidation may be performed by atmospheric oxygen in presence of a suitable catalyst.

Platinum-black or bone-black can be used as catalyst, but the most efficient method of oxidising alcohol is by using a living fungus, the *Mycoderma aceti*, which flourishes in dilute alcoholic solutions and produces an *enzyme* or complex organic catalyst which brings about the reaction of alcohol and oxygen.

Vinegar is a dilute solution of acetic acid and is obtained by fermenting wine or 'wash' (a malt infusion which has already undergone alcoholic fermentation), in such a way as to convert the alcohol into acetic acid.

Vinegar is often made by leaving the wine or 'wash' in casks with open bung-holes for some months. The manufacture is, however, greatly shortened by the use of the 'quick vinegar process,' in which the surface of the alcoholic liquid exposed to the air is greatly increased. A wide and tall cylindrical vat is packed with beechwood shavings or lumps of charcoal. Vents are arranged so as to provide a free circulation of the air which is required for the oxidation. The

[1] Three stereoisomeric forms of this acid exist, *d*-valeric acid, *l*-valeric acid, and inactive or *dl*-valeric acid. See Chapter XVII, where stereoisomerism is discussed.

shavings or charcoal are soaked in vinegar and in use soon develop a coating of the fungus, *Mycoderma aceti* (mother of vinegar). The dilute alcoholic solution is allowed to flow over the shavings, and when it reaches the bottom of the vat the alcohol originally present has been transformed into acetic acid.

(2) A great part of the world's acetic acid is made by the destructive distillation of wood.

Wood is a mixture of complex compounds, chiefly carbohydrates. When it is heated it breaks up into numerous simpler compounds, the chief products being:

(i) A gas, chiefly methane, carbon monoxide and carbon dioxide.
(ii) A brown watery liquid known as *pyroligneous acid* which is a solution of acetic acid containing some 6—10 per cent. of the acid and a small proportion of methyl alcohol and acetone.
(iii) An oily liquid insoluble in water, known as wood-tar, containing numerous compounds resembling the cresols (§ 430).
(iv) A solid residue of charcoal.

The wood is usually packed into iron retorts and heated to redness. The 'pyroligneous acid' so obtained is distilled to remove and recover methyl alcohol and acetone, and is then neutralised with lime, impure calcium acetate being obtained. This product is mixed with calcium chloride, when calcium aceto-chloride $Ca(C_2H_3O_2)Cl{\cdot}5H_2O$ crystallises out in comparatively pure condition. These crystals are recrystallised and distilled with 33 per cent. sulphuric acid. The acetic acid so produced is concentrated by distillation.

(3) Acetic acid is now made by preparing acetaldehyde synthetically and oxidising it (§ 67, 70).

Calcium carbide is made by heating coke and lime in the electric furnace and this, when treated with water, yields acetylene. The acetylene is passed into a solution of mercuric sulphate in hot dilute sulphuric acid and combines with water forming acetaldehyde.

This is oxidised by atmospheric air to acetic acid, metallic salts (*e.g.*, manganous acetate, iron or uranium salts) being used as a catalyst:

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2,$$
$$C_2H_2 + H_2O = CH_3{\cdot}CHO$$
$$2CH_3{\cdot}CHO + O_2 = 2CH_3{\cdot}CO{\cdot}OH$$

Purification of Acetic Acid.—Acetic acid readily absorbs moisture from the air. To purify acetic acid from water it may be cooled till about three-quarters have solidified and the remaining quarter, containing most of the water, may be poured off. The final traces of water may be removed by determining the proportion of water

present by titration or otherwise, and then adding the theoretical amount of acetic anhydride (§ 86) necessary to convert this water into acetic acid. Acetic acid which is pure enough to solidify in cold weather is known as *glacial* acetic acid.

77. Physical Properties of Acetic Acid.—Acetic acid forms colourless ice-like crystals, melting at 17° C. to a colourless liquid, with a sharp vinegar-like smell. It is therefore liquid in summer and solid in winter in temperate climates. Acetic acid boils at 118° C.

It is slightly heavier than water and has a density of 1·055 at 15° C. It is miscible with water in all proportions, and absorbs moisture from the air. Acetic acid is a useful solvent for organic substances which are to be oxidised, as it is itself peculiarly resistant to oxidation.

Liquid acetic acid may be shown, by vapour density and surface tension measurements, to be an associated liquid and to consist mainly of double molecules $(C_2H_4O_2)_2$.

Acetic acid burns and blisters the skin, and has been used for destroying warts, etc. In dilute solution it is not poisonous.

78. Chemical Properties.—Acetic acid is a typical weak acid, though stronger than many organic acids. It reacts with many metals, giving acetates and hydrogen, and also with metallic oxides, hydroxides and carbonates Zinc dust and acetic acid form a useful reducing agent for organic substances.

The vapour of acetic acid burns with a blue flame, but in the liquid state or in solution it is very resistant both to oxidation and reduction; even such an energetic oxidising agent as chromium trioxide does not affect it.

Chlorine and bromine produce substituted acetic acids. Thus when chlorine is passed into boiling acetic acid, mono-, di- and trichloroacetic acids are formed (§§ 219–222):

$$CH_3{\cdot}CO_2H + Cl_2 = CH_2Cl{\cdot}CO_2H + HCl,$$
$$CH_2Cl{\cdot}CO_2H + Cl_2 = CHCl_2{\cdot}CO_2H + HCl,$$
$$CHCl_2{\cdot}CO_2H + Cl_2 = CCl_3{\cdot}CO_2H + HCl.$$

The change is catalysed by the addition of a little sulphur, and proceeds most rapidly in sunlight.

Phosphorus trichloride and pentachloride convert acetic acid into acetyl chloride:

$$PCl_3 + 3CH_3{\cdot}CO{\cdot}OH = P(OH)_3 + 3CH_3{\cdot}COCl,$$
$$PCl_5 + CH_3{\cdot}CO{\cdot}OH = POCl_3 + CH_3{\cdot}COCl + HCl.$$

Thionyl chloride, $SOCl_2$, is now much used in place of the phosphorus compounds.

Expt. 21.—*Reactions of Acetic Acid.*—(1) Try its action as an acid on $CaCO_3$ and CuO: respective acetates formed.

(2) Mix 1 c.c. acetic acid with 1 c.c. amyl alcohol and ½ c.c. conc. H_2SO_4. Heat: cool, dilute. Strong smell of amyl acetate (pear drops) is noticeable.

(3) Heat a mixture of ½ c.c. conc. HNO_3 and ½ c.c. glacial acetic acid: no reaction.

(4) Add a piece of phosphorus pentachloride to 1 c.c. acetic acid: vigorous reaction with evolution of HCl.

79. Formic Acid, CH_2O_2.—Formic acid occurs in ants, the name being taken from the Latin *formica*, an ant. It also occurs in the stinging hairs of nettles.

Preparation of Formic Acid and Formates.—1. Sodium formate is made on the industrial scale by the action of carbon monoxide, under high pressure, on heated sodium hydroxide:

$$NaOH + CO = NaO{\cdot}OC{\cdot}H$$

Formic acid cannot be made from the sodium formate so produced by distilling it with sulphuric acid, as carbon monoxide and water are produced.

2 Formic acid is usually made on the laboratory scale by heating oxalic acid with glycerol to 100—110° C. and then adding more oxalic acid. The total result of the reaction is expressed by the equation:

$$HO{\cdot}OC{\cdot}CO{\cdot}OH = CO_2 + H{\cdot}CO{\cdot}OH$$

but actually the process involves:

(1) The production of glyceryl mono-oxalate,

$$C_3H_5(OH)_3 + H_2C_2O_4 = C_3H_5(OH)_2{\cdot}HC_2O_4 + H_2O.$$

(2) This decomposes forming glyceryl monoformate,

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}O{\cdot}CO{\cdot}CO{\cdot}OH \end{array} = \begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}O{\cdot}CO{\cdot}H \end{array} + CO_2.$$

(3) This is then decomposed by the addition of fresh oxalic acid producing formic acid and more glyceryl mono-oxalate:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}O{\cdot}CO{\cdot}H \end{array} + \begin{array}{l} CO{\cdot}OH \\ | \\ CO{\cdot}OH \end{array} = \begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}O{\cdot}CO{\cdot}COOH \end{array} + HO{\cdot}CO{\cdot}H.$$

The formic acid distils over and the glyceryl mono-oxalate again decomposes; and by addition of more oxalic acid it may be made to yield more formic acid according to reactions (2) and (3) above.

Thus a little glycerol will convert a large quantity of oxalic acid into formic acid.

The liquid distilling contains water. As the boiling points of formic acid and water are almost the same, distillation will not separate them. The liquid is best purified by boiling it with lead oxide, so producing lead formate. The solution so obtained is evaporated and lead formate crystallises. The well-dried crystals are packed into an upright Liebig condenser, being retained in position by cotton wool plugs. Steam is passed through the outer jacket and hydrogen sulphide is led downwards over the lead formate. Lead sulphide and formic acid are produced:

$$Pb(H{\cdot}CO{\cdot}O)_2 + H_2S = PbS + 2H{\cdot}CO{\cdot}OH,$$

and the latter drains into a receiver at the base of the condenser. It is freed from hydrogen sulphide by distillation with a little lead formate.

3. Formic acid can be obtained by careful oxidation of formaldehyde. Formates are also obtainable from hydrocyanic acid (§ 136) and chloroform (§ 61).

Physical Properties of Formic Acid.—Formic acid is a colourless liquid with a pungent odour, recalling that of red ants. It irritates and corrodes the skin. Formic acid melts at 9° C. and boils at 101° C. It is heavier than water (sp. gr. 1·22) and is miscible with it in all proportions.

Chemical Properties of Formic Acid.—Formic acid is considerably stronger than acetic acid. It resembles the latter acid except in two important particulars.

In the first place, formic acid is readily decomposed by concentrated sulphuric acid, forming carbon monoxide and water:

$$CH_2O_2 = CO + H_2O.$$

Secondly, the acid is readily oxidised to carbon dioxide and water, and is in fact a strong reducing agent. Silver salts are reduced by it or by formates to metallic silver; mercuric chloride is reduced to mercurous chloride and, if excess of formic acid is present, to mercury. Formic acid has this reducing power which the other fatty acids have not, because of the single hydrogen atom which gives it an aldehyde-like structure. Thus compare

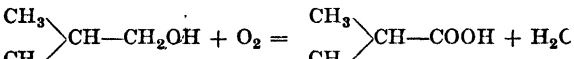
Formaldehyde	Formic acid	Acetic acid
$H—C—H$	$HO—C—H$	$HO—C—CH_3$
$\parallel$	$\parallel$	$\parallel$
O	O	O

80. Preparation of Higher Fatty Acids.—(1) These are often obtained from naturally occurring esters or glycerides (§§ 192 *seq.*), chiefly oils and fats. They can be obtained by heating these with caustic potash dissolved in

alcohol and decomposing the potassium salt so obtained with dilute hydrochloric acid. The acid, being comparatively insoluble, rises to the surface as an oil or as a solid, and can be separated, dried and distilled:

$$C_3H_5(O\,CO{\cdot}C_{17}H_{35})_3 + 3KOH = C_3H_5(OH)_3 + 3C_{17}H_{35}{\cdot}CO{\cdot}OK$$
Glyceryl stearate. Glycerol + potassium stearate.

(2) Oxidation of the appropriate alcohol or aldehyde yields the acid:



*iso*Butyl alcohol. *iso*Butyric acid.

(3) Hydrolysis of an alkyl cyanide (§ 144) yields the ammonium salt of a fatty acid:

$$(CH_3)_2 : CH{\cdot}CH_2CN + 2H_2O = (CH_3)_2 : CH{\cdot}CH_2{\cdot}CO{\cdot}ONH_4$$
*iso*Butyl cyanide. Ammonium valerate.

Other reactions giving the fatty acids are mentioned in Chapter XVIII. Acetoacetic ester, malonic ester and the Grignard reagent are particularly valuable reagents for the synthesis of fatty acids (§§ 258, 259).

Propionic acid, $C_2H_5CO{\cdot}OH$, is made by oxidation of *n*-propyl alcohol. It much resembles acetic acid.

n-Butyric acid is made by fermentation of sugars by the butyric ferment (*Bacillus butylicus*) Glucose may be fermented by the addition of decaying cheese, zinc carbonate or calcium carbonate being added to neutralise the acid as soon as it is formed.

It is a liquid of rancid odour.

Valeric and caproic (hexoic) acids are liquids of unpleasant odour obtainable from naturally occurring products or by the oxidation of the appropriate alcohol.

The salts of the fatty acids of high molecular weight are the *soaps* and their glyceryl esters are the *fats*. These are discussed in Chapter XIV under glycerol. The most important of these higher acids are palmitic acid, $C_{15}H_{31}{\cdot}CO{\cdot}OH$, and stearic acid, $C_{17}H_{35}{\cdot}CO{\cdot}OH$.

81. The Acetates.—Acetic acid forms stable salts with most metals. The acetates of the tervalent metals, ferric iron, aluminium, etc., are much hydrolysed and only exist in solution.

Normal acetates.	*Formula.*	*Appearance.*	*Solubility, g./100 g. water.*
Ammonium acetate	$NH_4C_2H_3O_2$	White crystals	89·9 /0° C.
Sodium acetate .	$NaC_2H_3O_2{\cdot}3H_2O$	White crystals	26 /6° C.
Potassium acetate	$KC_2H_3O_2$	White crystals	188 /5° C.
Calcium acetate .	$Ca(C_2H_3O_2)_2{\cdot}H_2O$	White crystals	43·6 /0° C.
Copper acetate .	$Cu(C_2H_3O_2)_2{\cdot}H_2O$	Blue crystals	7·2
Lead acetate .	$Pb(C_2H_3O_2)_2{\cdot}3H_2O$	White crystals	46 /15° C.
Basic acetates.			
Basic lead acetate .	$PbO{\cdot}Pb(C_2H_3O_2)_2{\cdot}2H_2O$	White crystals	v. soluble
Basic copper acetate	$CuO{\cdot}2Cu(C_2H_3O_2)_2$	Green powder	Insoluble

The acetates are all decomposed by concentrated sulphuric acid, giving acetic acid and a sulphate. They are recognised by heating with sulphuric acid and alcohol. Ethyl acetate (§ 98) is formed and is recognised by its fruity odour.

When heated they behave in varying manners. Ammonium acetate gives acetamide (§ 115).

$$CH_3{\cdot}CO{\cdot}O{\cdot}NH_4 = CH_3{\cdot}CO{\cdot}NH_2 + H_2O,$$

while calcium acetate and the acetates of the more electro-positive metals give acetone (§ 109):

$$Ca\begin{<}O{\cdot}CO{\cdot}CH_3\\O{\cdot}CO{\cdot}CH_3\end{} = CaCO_3 + CH_3{\cdot}CO{\cdot}CH_3.$$

The acetates of metals of which the oxides are easily reduced, *e.g.*, copper and lead, give a complex mixture of products, mainly the metal, acetic acid and carbon dioxide.

Some of the acetates are of other than scientific interest.

Calcium acetate is used in the manufacture of acetone (§ 109).

Basic copper acetate of the approximate formula, $CuO{\cdot}2Cu(C_2H_3O_2)_2$, is made by the action of air on copper plates kept in contact with cloths moistened with some form of dilute acetic acid. It is known as Verdigris and is a fine green pigment.

Lead acetate, $Pb(C_2H_3O_2)_2$, is made by the action of acetic acid on lead oxide. It is used in dyeing in the manufacture of other lead compounds and in medicine as an astringent lotion for the treatment of skin diseases, etc.

Basic lead acetates are obtained by boiling lead acetate with lead oxide and are employed as lotions in medicine.

82. The Formates.—The formates are in general well-crystallised salts, soluble in water. When heated, they give hydrogen and carbon monoxide:

$$Ca\begin{<}O{\cdot}CO{\cdot}H\\O{\cdot}CO{\cdot}H\end{} = CaCO_3 + CO + H_2.$$

When heated with acetates or the salts of higher fatty acids they yield aldehydes:

$$Ca\begin{<}O{\cdot}CO{\cdot}H\\O{\cdot}CO{\cdot}H\end{} + \begin{>}CH_3{\cdot}CO\cdot O\\CH_3{\cdot}CO{\cdot}O\end{}Ca = 2CH_3{\cdot}CHO + 2CaCO_3.$$

83. Substituted Acetic Acids.

Monochloroacetic acid . . .	$CH_2Cl{\cdot}CO{\cdot}OH$
Dichloroacetic acid . . .	$CHCl_2{\cdot}CO{\cdot}OH$
Trichloroacetic acid . . .	$CCl_3{\cdot}CO{\cdot}OH$

can be made by the action of chlorine on acetic acid. Corresponding bromoacetic acids can be made by the action of bromine on the acid. They are further discussed in Chapter XVI.

84. Acetyl Compounds.—Just as we regard ethyl alcohol C_2H_5OH, as the hydroxide of a hypothetical radical ethyl, C_2H_5-, so acetic acid may be regarded as the hydroxide of a hypothetical radical *acetyl*, $CH_3{\cdot}CO-$. This and similar radicals are known as *acyl* radicals. Thus we have $H{\cdot}CO-$, formyl, $CH_3{\cdot}CH_2{\cdot}CH_2{\cdot}CO-$, butyryl, etc.

Acetyl does not form the same variety of compounds as ethyl or methyl, but the chloride, oxide and amide are important. The formulæ of the chief acetyl compounds are:—

Acetyl hydroxide, Acetic acid . .	$CH_3{\cdot}CO{\cdot}OH$
Acetyl chloride	$CH_3{\cdot}CO{\cdot}Cl$
Acetyl oxide, Acetic anhydride .	$(CH_3{\cdot}CO)_2O$
Acetyl amide, Acetamide . .	$CH_3{\cdot}CO{\cdot}NH_2$

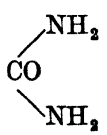
Acetyl cyanide and nitrate are known but acetyl compounds of most oxyacids, *e.g.*, acetyl sulphate or carbonate, are not formed.

Acetyl derivatives of many hydroxy-compounds are known, *e.g.*, acetylsalicylic acid, aspirin.

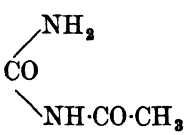
$HO{\cdot}C_6H_4{\cdot}CO{\cdot}OH$ — Salicylic acid.

$CH_3{\cdot}CO{\cdot}O{\cdot}C_6H_4{\cdot}CO{\cdot}OH$ — Acetylsalicylic acid.

Acetyl compounds of many amino-compounds are also known:



Urea.



Acetylurea.

ACYL HALIDES AND ANHYDRIDES

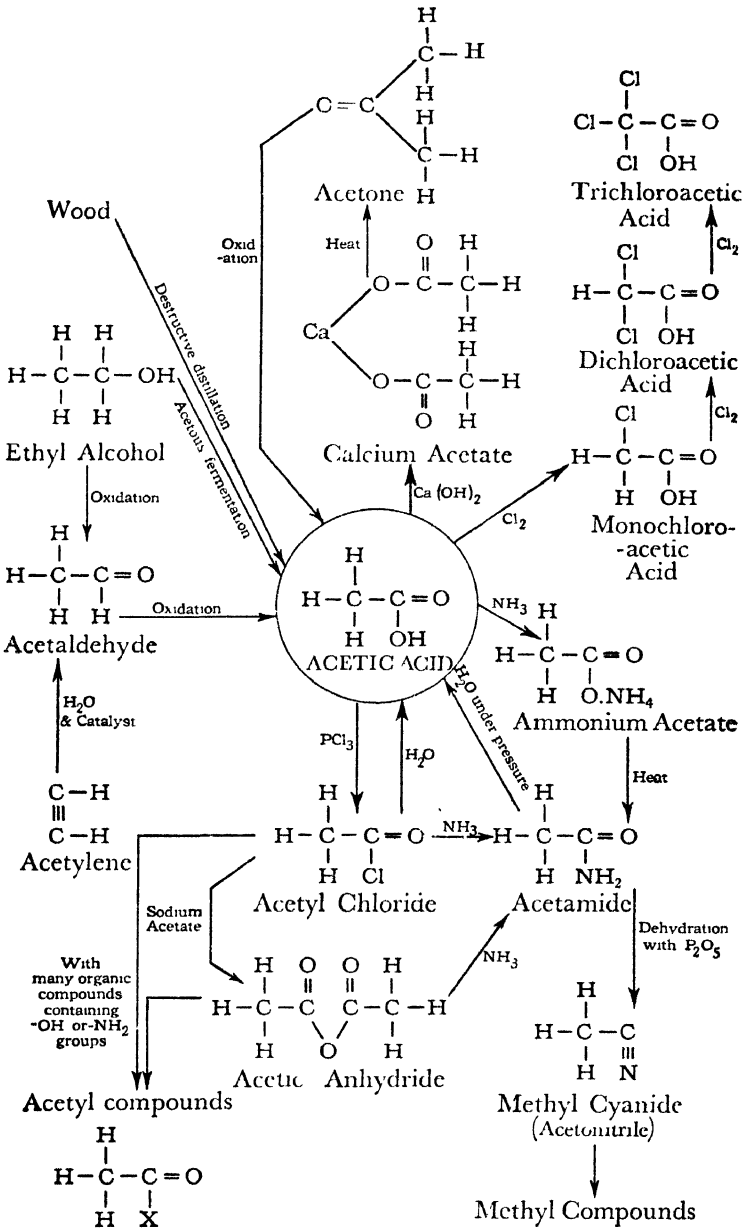
85. Acetyl Chloride, CH_3COCl, is made by the action of phosphorus trichloride or pentachloride on acetic acid, or by the action of phosphorus oxychloride on anhydrous sodium acetate. The former is ordinarily employed; the latter gives a purer product but a less good yield:

$$PCl_3 + 3CH_3{\cdot}CO{\cdot}OH = P(OH)_3 + 3CH_3{\cdot}CO{\cdot}Cl$$

$$PCl_5 + CH_3{\cdot}CO{\cdot}OH = POCl_3 + CH_3{\cdot}CO{\cdot}Cl + HCl.$$

Many acid chlorides are now prepared by the action of thionyl chloride, $SOCl_2$, on acids. The only products besides the acid chloride are readily volatile or gaseous, which is a considerable

DERIVATIVES OF ACETIC ACID



convenience in purifying the product. Moreover, thionyl chloride is a good deal cheaper than phosphorus trichloride.

$$R{\cdot}CO{\cdot}OH + SOCl_2 = R{\cdot}CO{\cdot}Cl + HCl + SO_2.$$

Expt. 22.—*Preparation of Acetyl Chloride.*—The apparatus shown in Fig. 20 is employed. In the flask (250 c.c.) are placed 30 g. of anhydrous acetic acid. The acetic acid should be from a newly opened bottle of the glacial acid, or should alternatively be purified by freezing.

In the tap-funnel are placed 24 g. of phosphorus trichloride. The latter is added cautiously and left to stand for a short time. The water-bath is heated gently and the acetyl chloride distilled over (b.p. 55° C.).

Physical Properties.—Acetyl chloride is a colourless volatile liquid which fumes copiously in moist air, giving off clouds of hydrochloric and acetic acids. It has a most irritating odour. Acetyl chloride boils at 55° C. It is heavier than water (sp. gr. 1·13), in which it rapidly dissolves with decomposition (see below).

Chemical Properties.—Acetyl chloride reacts with most hydroxyl compounds, forming an acetyl compound and hydrogen chloride.

Thus with water it forms acetic acid:

$$CH_3{\cdot}CO{\cdot}Cl + H{\cdot}OH = CH_3{\cdot}COOH + HCl.$$

With alcohols it forms an alkyl acetate (known as an ester, §§ 89, 90):

$$CH_3{\cdot}CO{\cdot}Cl + H{\cdot}OC_2H_5 = CH_3{\cdot}CO{\cdot}OC_2H_5 + HCl.$$

With ammonia it forms acetamide (§ 115):

$$CH_3{\cdot}CO{\cdot}Cl + NH_3 = CH_3{\cdot}CO{\cdot}NH_2 + HCl.$$

With amino-compounds it also reacts in much the same way. Thus with aniline (aminobenzene):

$$CH_3{\cdot}CO{\cdot}Cl + H_2NC_6H_5 = CH_3{\cdot}CO{\cdot}HN{\cdot}C_6H_5 + HCl.$$

Acetanilide (acetamidobenzene).

When acetyl chloride reacts with sodium acetate, acetic anhydride is formed:

$$CH_3{\cdot}CO{\cdot}\ Cl + Na\ O{\cdot}CO{\cdot}CH_3 = CH_3{\cdot}CO{\cdot}O{\cdot}CO{\cdot}CH_3 + NaCl.$$

Expt. 23.—*Reactions of Acetyl Chloride.*—(1) Mix ½ c.c. acetyl chloride with 1 c.c. water. HCl fumes evolved and acetic acid formed.

(2) Mix 1 c.c. acetyl chloride with 2 c.c. ethyl alcohol. Boil: dilute. Smell of ethyl acetate.

(3) To 1 drop aniline add 3 drops acetyl chloride. Heat, cool and boil with excess of water. Solid acetanilide separates on cooling.

86. Acetic anhydride, acetyl oxide, $(CH_3{\cdot}CO)_2O$, is prepared by

distilling acetyl chloride with anhydrous sodium acetate. The equation is given above.

A second method, often used, is the action of phosphorus oxychloride on an excess of sodium acetate. Acetyl chloride is first formed, which then reacts with more sodium acetate, forming acetic anhydride:

$$2CH_3{\cdot}CO{\cdot}ONa + POCl_3 = NaPO_3 + NaCl + 2CH_3{\cdot}COCl,$$
$$CH_3{\cdot}COCl + NaO{\cdot}CO{\cdot}CH_3 = CH_3{\cdot}CO{\cdot}O{\cdot}OC{\cdot}CH_3 + NaCl.$$

Expt. 24.—*Preparation of Acetic Anhydride.*—The apparatus used is that shown in Fig. 20, an oil-bath being substituted for the water-bath shown. The absorption tower may also be omitted. In the flask are placed 21 g. of powdered anhydrous sodium acetate (for preparation, see Expt. 1). 38 G. of phosphorus oxychloride are slowly added from the tap-funnel. The flask is now heated until the acetic anhydride (b.p. 137° C.) has distilled over.

Properties of Acetic Anhydride.—Acetic anhydride is a colourless liquid with a sharp penetrating smell. It boils at 137° C. and has a specific gravity of 1·073 at 20° C.

Its reactions are analogous to those of acetyl chloride. With water it forms acetic acid:

$$(CH_3{\cdot}CO)_2O + H_2O = 2CH_3{\cdot}CO{\cdot}OH,$$

and with alcohols, esters are produced:

$$\underset{\text{Acetic anhydride.}}{CH_3{\cdot}CO\diagdown\!\!\diagup O\diagup\!\!\diagdown CH_3{\cdot}CO} + \underset{\text{Alcohol.}}{HO{\cdot}C_2H_5} = \underset{\text{Ethyl acetate.}}{CH_3{\cdot}CO{\cdot}OH + CH_3{\cdot}CO{\cdot}OC_2H_5}.$$

With ammonia, acetamide is produced, together with ammonium acetate.

$$CH_3{\cdot}CO\diagdown\!\!\diagup O\diagup\!\!\diagdown CH_3{\cdot}CO + 2NH_3 = CH_3{\cdot}CO{\cdot}NH_2 + CH_3{\cdot}CO{\cdot}ONH_4.$$

Expt. 25.—*Reactions of Acetic Anhydride.*—Perform reactions (1), (2), (3) of Expt. 23 with acetic anhydride. Same products are formed without evolution of HCl: reactions a good deal slower.

87. Acetamide, $CH_3{\cdot}CO{\cdot}NH_2$, is made by the action of heat on ammonium acetate (§ 115), or of ammonia upon acetyl chloride (§ 85) or acetic anhydride (§ 86).

Its preparation and properties are discussed in Chapter X, which deals with the simpler nitrogen derivatives of the paraffins.

88. Formyl Compounds.—Formyl chloride and formic anhydride do not exist.

Formamide, $H{\cdot}CO{\cdot}NH_2$, is made by heating pure dry ammonium formate in an atmosphere of ammonia. The product is fractionated at reduced pressure.

It is an unstable liquid which boils with decomposition at about 200° C. In general, its chemical properties resemble those of acetamide (§ 115). It is remarkable as being one of the few substances which, like water, liquid ammonia, and hydrocyanic acid, are ionising solvents.

The halides and anhydrides of the higher fatty acids much resemble those of acetic acid, but are less reactive and of higher boiling point and melting point.

QUESTIONS

(1) What likenesses and differences are to be found in the reactions of the hydroxyl group in ethyl alcohol and in acetic acid?

(2) How is acetic acid prepared commercially, and how would you prepare a specimen of pure glacial acetic acid from vinegar?

(3) How would you prepare a crystalline specimen of calcium acetate? What organic compounds could be prepared from it?

(4) How is formic acid prepared on the laboratory scale? Describe its properties, pointing out the manner in which it differs from acetic acid.

(5) How could you prepare acetic acid from (*a*) ethyl alcohol, (*b*) methyl alcohol, (*c*) acetyl chloride?

(6) What is the acetyl group? How is acetyl chloride prepared, and how could it be converted into ethyl acetate, acetamide, acetic acid, and acetic anhydride respectively?

(7) How many fatty acids of the formula $C_4H_8O_2$ are known? Give their ormulæ and name them.

(8) A green pigment is to be examined in order to find out whether it is verdigris or some other green copper-containing pigment, *e.g.*, *verditer*, basic copper carbonate, etc. Describe how you would carry out the test.

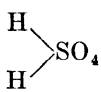
CHAPTER VII

THE ESTERS

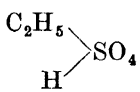
89. Esters.—Esters are formed when the replaceable hydrogen of an acid is replaced by an alkyl radical. They are therefore analogous to salts, though they differ from them in that they are not ionised (§ 58):

HNO_3	KNO_3	$C_2H_5{\cdot}NO_3$
Nitric acid.	Potassium nitrate.	Ethyl nitrate.
ACID.	SALT.	ESTER.

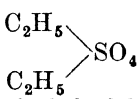
Just as a dibasic acid gives acid salts and neutral salts, so it also gives acid esters and neutral esters. Thus sulphuric acid gives two esters:



Sulphuric acid.



Acid ethyl sulphate *or* Ethyl hydrogen sulphate.



Normal ethyl sulphate *or* Diethyl sulphate.

90. Preparation of the Esters.—(1) Just as salts may be made by the action of an acid on a basic hydroxide, so the esters can be made by the action of acids upon alkyl hydroxides, *i.e.*, alcohols.

The action is always reversible and usually slow. We therefore (*a*) design our method to get the maximum amount of transformation; (*b*) use a catalyst to hasten the reaction.

Let us consider the case of ethyl acetate. The equation for its formation is:

$$C_2H_5{\cdot}OH + HO{\cdot}CO{\cdot}CH_3 \rightleftharpoons C_2H_5{\cdot}O{\cdot}CO{\cdot}CH_3 + H_2O.$$

This equation represents two simultaneous reactions:

(1) $C_2H_5OH + HO{\cdot}CO{\cdot}CH_3 \rightarrow C_2H_5{\cdot}O{\cdot}CO{\cdot}CH_3 + H_2O$,

(2) $H_2O + C_2H_5{\cdot}O{\cdot}CO{\cdot}CH_3 \rightarrow C_2H_5OH + HO{\cdot}CO{\cdot}CH_3$.

The first of these reactions is useful as producing the ester required, while the second is deleterious. If the water formed in the first reaction is removed this reaction will still proceed unhindered, while the second reaction will be totally prevented and complete transformation will be obtained. A dehydrating agent must therefore be employed to remove this water.

Moreover, both the reactions are catalysed by the presence of

strong acids and the reaction time may be shortened from months to hours by the addition of these.

The function of catalyst and dehydrating agent is combined in concentrated sulphuric acid or gaseous hydrogen chloride. The former is more convenient but is rather too reactive for use with some acids and alcohols.

The standard method for preparing an ester is, then, to mix the acid and alcohol and either add concentrated sulphuric acid or dissolve in it a small quantity of dry hydrogen chloride gas. The mixture is usually boiled for two or three hours and the ester is then separated by distillation or by pouring the liquid into excess of water in which most esters are insoluble.

Experiments which may serve as examples of the process are given under the headings of ethyl acetate, amyl acetate and amyl nitrite (*v.* Expts. 28, 29, 31).

(2) Esters are made by the action of the silver salt of the acid upon an alkyl iodide (§ 58). Thus methyl fluoride may be made by the reaction of methyl iodide and silver fluoride:

$$CH_3I + AgF = AgI + CH_3F.$$

The method is applicable to a number of esters of very weak or unstable acids.

(3) The action of an acid chloride on an alcohol yields the ester rapidly and easily.

$$C_2H_5{\cdot}OH + Cl{\cdot}CO{\cdot}CH_3 = C_2H_5{\cdot}O{\cdot}CO{\cdot}CH_3 + HCl.$$

Expt. 26.—*To make Amyl Benzoate*, $C_5H_{11}{\cdot}O{\cdot}CO{\cdot}C_6H_5$.—To 10 c.c. of amyl alcohol contained in a 250 c.c. flask are added 13 c.c. of benzoyl chloride. The mixture is heated on the water-bath for half an hour. The product is poured into a solution of sodium carbonate, transferred to a separating funnel and well shaken with successive quantities of sodium carbonate. The upper layer is then transferred to a small distilling flask, fitted with an air-condenser (Fig. 30) and thermometer reading up to 360° C., and distilled, using the naked flame. Amyl benzoate distils over at 260° C. as a pleasant smelling oil.

91. Physical Properties of the Esters.—The esters are liquids or solids which, as a rule, have strong pleasantly fragrant or fruity odours. The odorous principles of many plants are esters, and their manufacture is therefore of some consequence in perfumery and the preparation of flavouring essences.

The esters are for the most part lighter than water, and insoluble in it; though some of the esters of low molecular weight dissolve appreciably in, or are miscible with water.

They are good solvents, and amyl acetate in particular has been

found to be a valuable solvent for celluloid and various cellulose products, *e.g.*, collodion (§ 290), used in paints and lacquers.

92. Chemical Properties of the Esters.—The esters burn with a bright flame.

When heated with water at suitable temperatures in presence of a suitable catalyst they are hydrolysed, producing an acid and an

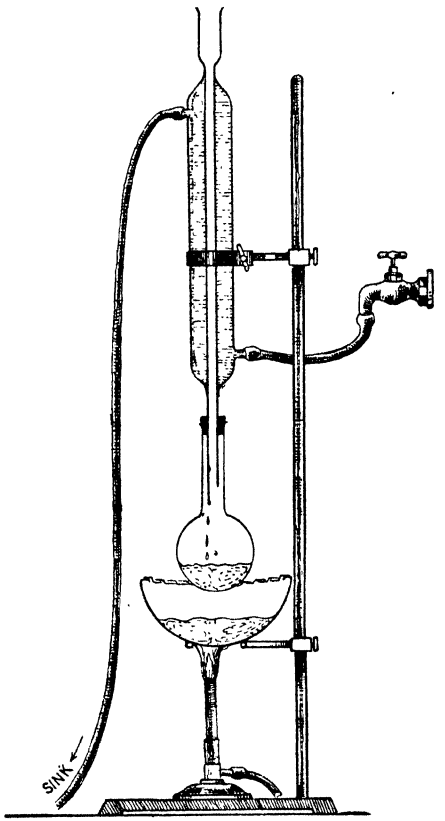


FIG. 26.—Hydrolysis of an Ester.

alcohol. Thus methyl acetate and water give methyl alcohol and acetic aid:

$$CH_3{\cdot}O{\cdot}CO{\cdot}CH_3 + H_2O \rightleftharpoons CH_3{\cdot}OH + CH_3{\cdot}CO{\cdot}OH.$$

The reaction between a pure ester and water is usually very slow. The addition of any acid catalyses the reaction in proportion to the concentration of hydrion present. At higher temperatures, too, the reaction is much more rapid, and esters are usually readily decomposed if heated to 150° C. with water under pressure.

Alkalis readily decompose esters, forming an alcohol and a salt of an acid:

$$KOH + C_2H_5{\cdot}NO_3 = C_2H_5OH + KNO_3.$$

If the ester is insoluble in water, alcoholic potash is more effective than an aqueous solution.

Expt. 27.—*To Isolate the Acid and Alcohol from Ethyl Acetate.*—Arrange a flask and reflux condenser as in Fig. 26. In the flask place 20 c.c. of ethyl acetate and add 25 g. of caustic potash previously dissolved in 40 c.c. of water. Heat on the water-bath until the upper layer of ethyl acetate has disappeared. Allow the liquid to cool somewhat, transfer to a distillation apparatus and distil off 20 c.c. of liquid.

The ethyl alcohol is contained in this and may be detected by the iodoform test (Expt. 4). Alternatively the alcohol may be separated by treatment with potassium carbonate as in Expt. 3.

The residue after distillation contains potassium acetate and free caustic potash. It is carefully neutralised with dilute sulphuric acid (1 : 2) and evaporated to dryness. The dry salt when distilled with concentrated sulphuric acid yields acetic acid.

When treated with ammonia, esters form amides:

$$CH_3{\cdot}CO{\cdot}O{\cdot}C_2H_5 + NH_3 = CH_3{\cdot}CO{\cdot}NH_2 + C_2H_5OH.$$

The method is of value for the preparation of oxamide (§ 210).

Phosphorus pentachloride decomposes the esters, forming an alkyl chloride and an acyl chloride:

$$\begin{matrix} CH_3{\cdot}CO \\ \qquad\quad\rangle O \\ C_2H_5 \end{matrix} + PCl_5 = \begin{matrix} CH_3COCl \\ + \\ C_2H_5Cl \end{matrix} + POCl_3.$$

The esters are otherwise fairly unreactive substances.

The action of sodium on ethyl acetate to form the sodium derivative of acetoacetic ester is of importance and is discussed in Chapter XVIII.

ESTERS OF INORGANIC ACIDS

93. The Alkyl Sulphates.—*Methyl hydrogen sulphate* is formed by the action of concentrated sulphuric acid on the alcohol. The product is treated with barium carbonate. The methyl hydrogen sulphate forms a soluble salt, barium methyl sulphate, while the excess of sulphuric acid is precipitated as insoluble barium sulphate.

The liquid is filtered and the solution of barium methyl sulphate is mixed with the correct quantity of sulphuric acid to precipitate the barium. The barium sulphate is filtered off and

$$CH_3{\cdot}OH + H_2SO_4 = CH_3{\cdot}HSO_4 + H_2O,$$
$$2CH_3{\cdot}HSO_4 + BaCO_3 = Ba(CH_3{\cdot}SO_4)_2 + H_2O + CO_2,$$
$$Ba(CH_3{\cdot}SO_4)_2 + H_2SO_4 = BaSO_4 + 2CH_3{\cdot}HSO_4.$$

the solution so obtained is evaporated in the cold and *in vacuo* over sulphuric acid, as the ester is hydrolysed by hot water. Ethyl hydrogen sulphate is made by a similar method.

Methyl and ethyl hydrogen sulphates are oily liquids soluble in water with decomposition.

When distilled, they decompose giving dimethyl or diethyl sulphate and sulphuric acid.

Water hydrolyses them to alcohol and sulphuric acid:

$$C_2H_5{\cdot}HSO_4 + H_2O = C_2H_5{\cdot}OH + H_2SO_4.$$

Since they contain a replaceable hydrogen atom they behave as acids and are sometimes known as methylsulphuric acid and ethylsulphuric acid respectively.

They form salts when treated with the carbonates of metals and these salts are stable and readily crystallised. An example of these is afforded by barium methyl sulphate, mentioned above.

Dimethyl sulphate $(CH_3)_2SO_4$, is of commercial importance as a methylating agent for amines and is also of great utility in the investigation of the sugars by "methylation" (§ 272).

It is usually made by the action of chlorosulphonic acid on methyl alcohol:

$$HClSO_3 + 2CH_3OH = (CH_3)_2SO_4 + H_2O + HCl.$$

It is a liquid with a vapour which is very poisonous on account of its liberation of sulphuric acid in the lungs.

94. Ethyl nitrate. $C_2H_5NO_3$, can be obtained by the action of nitric acid on alcohol, provided the absence of nitrous acid and lower oxides of nitrogen is assured. Ordinary concentrated nitric acid reacts with alcohol with explosive violence, but nitric acid which has been heated with a little urea and has been thereby freed from nitrous acid (§ 312) reacts quietly with a mixture of alcohol and urea nitrate. Ethyl nitrate may be distilled off.

Ethyl nitrate is a liquid with a pleasant odour and taste. It boils at 86° C.

95. Ethyl nitrite, $C_2H_5NO_2$, is prepared by the action of acids on a well-cooled mixture of potassium nitrite and alcohol.

The 'sweet spirits of nitre,' used in medicine as a stimulant and as a diuretic and diaphoretic, contains ethyl nitrite and alcohol and

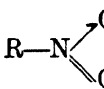
is made by the action of a mixture of sulphuric acid and nitric acid with an excess of alcohol on metallic copper. The liquid is then distilled and the distillate mixed with more alcohol.

96. Amyl Nitrite, $C_5H_{11} \cdot NO_2$, is a valuable vasodilator and is used in medicine for treatment of *angina pectoris*. It is prepared by methods similar to those employed for ethyl nitrite, and also by the action of a mixture of amyl alcohol and sulphuric acid upon a nitrite.

Expt. 28.—*Preparation of Amyl Nitrite.*—Dissolve 13 g. of potassium nitrite in 7·5 c.c. of water and in a separate vessel mix 15 g. (18 c.c.) of amyl alcohol with 30 g. of concentrated sulphuric acid. Cool the latter solution and add it *slowly* to the solution of the nitrite, stirring well. Perform this in a fume-cupboard or in a good draught. Transfer the liquid to a distilling flask and collect the liquid which comes over between 95° C. and 99° C.

$$C_5H_{11}\cdot OH + HNO_2 = C_5H_{11}\cdot NO_2 + H_2O.$$

The alkyl nitrites are isomeric with the nitro-compounds but differ entirely from them. The isomerism is further discussed in § 130. Briefly, there exist two compounds of the formula $R\cdot NO_2$ where R is an alkyl group The alkyl nitrite is generally supposed to have the formula R—O—N=O and the nitro-paraffin the formula



(§ 19).

The alkyl nitrites, besides their medicinal value, find a use in the preparation of diazo-compounds (Expt. 91).

97. Other Inorganic Esters.—The alkyl halides are, strictly speaking, esters, but are usually considered as a separate class and are treated in Chapter IV. The alkyl oxides are the ethers (Chapter VIII), the alkyl sulphides are known as the mercaptans and are considered in Chapter XII; the alkyl cyanides, thiocyanates, etc., are discussed in Chapter XI.

ESTERS OF ORGANIC ACIDS

These greatly outnumber the inorganic esters and only a few of the most important can be studied here.

98. Ethyl Acetate, $C_2H_5\cdot O\,CO\,CH_3$.—Ethyl acetate can be made by any of the methods described in § 90. It is most conveniently prepared by the action of sulphuric acid on a mixture of alcohol and acetic acid.

Expt. 29.—*Preparation of Ethyl Acetate.*—A 500 c.c. distilling flask is fitted with a tap-funnel and a thermometer dipping into

the liquid. It is connected to a condenser and receiver. In it is placed a mixture of 50 c.c. of alcohol and 50 c.c. of concentrated sulphuric acid. In the tap-funnel is placed a mixture of equal volumes of alcohol and acetic acid. The flask is heated on a sand-bath until the temperature of the liquid reaches 140° C. and the mixture is added from the tap-funnel at the same rate as the distillate comes over.

The product contains, besides ethyl acetate, some water, alcohol, sulphur dioxide, etc. It is placed in a separating funnel and shaken with strong sodium carbonate solution, care being taken to allow for the resulting effervescence. The lower layer is run off and the upper layer of ethyl acetate well shaken with a solution containing equal weights of calcium chloride and water. It is left to stand for a day over a few pieces of calcium chloride and then redistilled. The liquid boiling between 74° C. and 79° C. is collected.

Ethyl acetate is a colourless liquid with a pleasant fruity smell. It boils at 77·5° C. and has a specific gravity of 0·91. It is soluble in about eight times its volume of water, but is less soluble in solutions of salts.

Ethyl acetate has the usual reactions of esters (§ 92). Thus with water, acetic acid and alcohol are slowly formed.

With potassium hydroxide, potassium acetate and ethyl alcohol result.

Expt. 30.—*Reactions of Ethyl Acetate.*—(1) Dissolve ½ c.c. ethyl acetate in the minimum amount of water (about 5 c.c.). Saturate solution with salt. Ethyl acetate separates again as an upper layer.

(2) Warm ½ c.c. ethyl acetate with 2 c.c. alcoholic potash. Fruity odour soon disappears, owing to formation of potassium acetate and ethyl alcohol.

(3) Warm and shake ½ c.c. ethyl acetate with 5 c.c. dilute (5 per cent.) caustic soda solution. Upper layer slowly disappears and fruity odour vanishes, owing to hydrolysis of ester.

99. *iso*Amyl Acetate, $C_5H_{11}\cdot O\cdot CO\,CH_3$.—Among the more important esters may be mentioned amyl acetate, which is now of importance as a solvent.

It may be made by warming a mixture of amyl alcohol, acetic acid and sulphuric acid.

Expt. 31.—*Preparation of Amyl Acetate.*—In a flask place 25 c.c. of amyl alcohol, 25 c.c. of glacial acetic acid and 6 c.c. of concentrated sulphuric acid. Heat on a water-bath for an hour and pour into 250 c.c. of cold water. Separate the upper layer of amyl acetate and purify it as for ethyl acetate (Expt. 29), the shaking with calcium chloride solution being omitted.

*iso*Amyl acetate is a colourless liquid with a powerful odour of pears. It boils at 139° C. It is insoluble in water.

It is an excellent solvent for many organic substances and is largely used as a solvent for celluloid and nitrocellulose.

Its chemical properties are those typical of an ester.

100. Other Esters.—Numerous esters are employed as solvents, flavours or perfumes. The table given below indicates the nature and use of some of these.

Ester.	Uses.
Methyl salicylate (§ 460)	Medical
Ethyl formate	Flavouring rum.
Ethyl acetate	Medical.
Ethyl butyrate	Pineapple flavour.
Amyl salicylate	Artificial orange-blossom scent.
*iso*Amyl acetate	Solvent; pear flavour.
*iso*Amyl *iso*valerate	Apple flavour.
Geranyl acetate (§ 510)	Rose scent.
Benzyl acetate (§ 446)	Jasmin scent.

Some of the higher esters, *e.g.*, ceryl cerotate, $C_{25}H_{51}\cdot CO\ O\cdot C_{26}H_{53}$, are contained in waxes.

QUESTIONS

(1) What is meant by an ester? Write the formulæ of ethyl formate, methyl acetate, ethyl hydrogen sulphate, amyl nitrite.

(2) In what respect do esters resemble and differ from salts?

(3) How would you try to prepare ethyl valerate? Valeric acid has the formula $CH_3\cdot(CH_2)_3\cdot CO\cdot OH$, and is a liquid which boils at 185° C., and is sparingly soluble in water.

(4) How would you recognise a given liquid as being an ester, and how would you attempt to prepare an alcohol and an acid from it?

(5) How is amyl nitrite made? What is its chief use?

(6) How is ethyl hydrogen sulphate made? What is produced when it is (*a*) heated with water, (*b*) heated with ethyl alcohol, (*c*) heated with caustic potash?

(7) Describe the preparation of ethyl acetate? What steps would you take to obtain the maximum yield of ethyl acetate from a limited quantity of ethyl alcohol?

CHAPTER VIII

THE ETHERS

101. Structure of Ethers.—The structure of the ethers is clearly demonstrated by their formation from sodium alkoxides and alkyl iodides, and by the reactions further discussed in § 102.

When sodium ethoxide, C_2H_5ONa, is heated with ethyl iodide, C_2H_5I, sodium iodide separates and diethyl ether is formed. The reaction is clearly

$$\begin{matrix} C_2H_5ONa \\ + \\ C_2H_5I \end{matrix} = \begin{matrix} C_2H_5 \\ \diagdown \\ \quad O \\ \diagup \\ C_2H_5 \end{matrix} + NaI.$$

This is confirmed by the fact that the ethers do not give hydrogen chloride when treated with phosphorus pentachloride and therefore do not contain a hydroxyl group.

Ethers are accordingly regarded as the oxides of the alkyl radicals. They differ in nearly all respects, however, from inorganic oxides.

If, in the above reaction, materials containing different alkyl groups are employed mixed ethers are obtained. Thus, sodium ethoxide and butyl iodide give ethyl butyl ether, $C_2H_5—O—C_4H_9$.

The ethers are named from the alkyl groups contained in them. Thus we have

$\begin{matrix} CH_3 \\ \diagdown \\ \quad O \\ \diagup \\ CH_3 \end{matrix}$ Dimethyl ether, methyl ether.

$\begin{matrix} C_2H_5 \\ \diagdown \\ \quad O \\ \diagup \\ C_2H_5 \end{matrix}$ Diethyl ether, ethyl ether.

$\begin{matrix} CH_3 \\ \diagdown \\ \quad O \\ \diagup \\ C_2H_5 \end{matrix}$ Methyl ethyl ether.

Isomerism and Metamerism.—The ethers afford an opportunity of illustrating the distinction sometimes made between isomeric and metameric compounds. All compounds having the same molecular formula, but a different structural formula, are said to be *isomeric;* compounds which are isomeric, but which differ only in their alkyl

groups, are said to be *metameric*. Thus methyl propyl ether $\begin{matrix}CH_3\\C_3H_7\end{matrix}\!\!>\!O$ and diethyl ether $\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\!\!>\!O$ are said to be metameric, while these and *n*-butyl alcohol $CH_3{\cdot}CH_2{\cdot}CH_2{\cdot}CH_2OH$ are isomeric.

102. Preparation of the Ethers.—(1) Ethers may be synthesised by Williamson's reaction, described in § 101 above. The sodium alkoxide is formed by dissolving sodium in an excess of the alcohol. The alkyl halide is added, and the mixture heated under a reflux condenser. The practical details are given in Expt 34.

(2) Ethers are ordinarily made by the continuous etherification process. The alcohol is mixed with sulphuric acid and heated, an alkyl hydrogen sulphate being formed:

$$R{\cdot}OH + H_2SO_4 = R{\cdot}HSO_4 + H_2O.$$

On addition of more alcohol, the latter is decomposed, forming the ether and regenerating sulphuric acid:

$$\begin{matrix}R{\cdot}HSO_4\\+\\R{\cdot}OH\end{matrix} = \begin{matrix}R\\\\R\end{matrix}\!\!>\!O + H_2SO_4.$$

The sulphuric acid then forms more of the alkyl hydrogen sulphate, which with more alcohol again forms ether, and were it not for the destruction and dilution of the acid[1] by the products of side reactions, a given quantity of sulphuric acid could transform an unlimited quantity of alcohol into ether. Practical details of the method are given in Expt. 32.

103. Physical Properties of the Ethers.—The ethers are gases or liquids, much more volatile than the corresponding alcohols. They are nearly insoluble in water. They are excellent solvents for most organic substances, and their unreactive character makes them very suitable for dissolving substances which are to be treated with powerful reagents such as sodium.

104. Chemical Properties of the Ethers.—The ethers are remarkably unreactive. They burn readily to carbon dioxide and water but are unaffected by most reagents. Acids and alkalis have no effect upon them, nor does sodium or phosphorus pentachloride (in the cold) affect them.

They are decomposed by concentrated sulphuric acid, giving alkyl

[1] Benzenesulphonic acid ($C_6H_5{\cdot}SO_3H$, § 351) may be used instead of sulphuric acid; no formation of by-products then occurs and the process is really continuous, apart from the effect of dilution.

hydrogen sulphates. When saturated with gaseous hydrogen iodide at 0° C., they give alkyl iodides:

$$(C_2H_5)_2O + 2HI = 2C_2H_5I + H_2O.$$

Heated phosphorus pentachloride replaces their oxygen atom by chlorine:

$$(C_2H_5)_2O + PCl_5 = 2C_2H_5Cl + POCl_3.$$

The less powerful oxidising agents do not affect them but concentrated nitric and chromic acids oxidise them to fatty acids, etc.

INDIVIDUAL ETHERS

Dimethyl ether and methyl ethyl ether are gases at the ordinary temperatures and are not of practical importance. Diethyl ether is by far the most important member of the class.

105. Ethyl Ether, Diethyl Ether, Ethyl Oxide, $(C_2H_5)_2O$.—Ethyl ether can be synthesised from ethyl iodide and sodium ethoxide by Williamson's method, but in practice it is always made by the continuous etherification process, the principle of which is described by § 102.

Expt. 32.—*Preparation of Ethyl Ether.*—Set up the apparatus shown in Fig. 27, using a 500 c.c. distilling flask and a thermometer reading to 200° C. The receiver is closed by a cotton-wool plug.

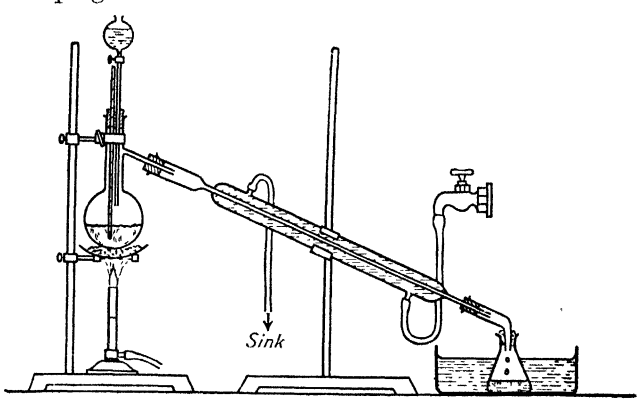


FIG. 27.—Preparation of Ether by the Continuous Process.

In the flask place 100 c.c. of alcohol and add 70 c.c. of concentrated sulphuric acid a little at a time, shaking well. Fill the tap-funnel with alcohol. Heat till the thermometer (the bulb of which dips in the liquid) indicates 140°—145° C. Allow alcohol to drop in slowly at such a rate that the temperature remains at 140°—145° C. Ether, with some water and

sulphurous acid, collects in the receiver, which is cooled throughout the experiment with water or ice. The distillate is transferred to a separating funnel and shaken, first with dilute sodium hydroxide solution to remove sulphur dioxide, and then with strong brine to dissolve out any alcohol. The ether is then left to stand over solid calcium chloride. It may finally be completely dehydrated by leaving it in contact with metallic sodium.

Physical Properties of Ether.—Ethyl ether is a colourless mobile liquid with a characteristic 'ethereal' odour and taste. When its vapour is inhaled it produces unconsciousness and it is therefore much used as an anæsthetic. It has the advantage over chloroform of having comparatively little effect on the heart, but is disadvantageous in that it induces anæsthesia rather slowly and is somewhat irritating to the lungs. The anæsthetic most commonly used is a mixture of alcohol, chloroform and ether.

Ether is lighter than water (sp. gr. = 0·72). It is very volatile, its boiling point being 34·9° C. It therefore evaporates very readily and its evaporation is often used to induce cold. If a rapid current of air is blown or drawn through ether contained in a test-tube it soon becomes coated with frost. Since the vapour is very inflammable, much care must be taken not to handle it near a flame. When ether is being distilled it is best to extinguish all burners and to use a bath of water previously heated to 50°—60° C. as the source of heat, so that any of the heavy vapour which escapes condensation shall have no chance of being ignited by a flame or by hot metal.

Ether is an excellent solvent and is much used in organic chemistry owing to its inertness and the ease with which it can be separated from the dissolved substance by evaporation or distillation. Ether is slightly soluble in water (1 : 10) and it also dissolves a small proportion of water. It is therefore very necessary to dry it when it is to be used in work where water is deleterious (*e.g.*, Expt. 45).

Ether is very inert chemically. It burns with a bright flame. None of the ordinary chemical reagents attacks it, except chlorine, which forms various substitution compounds of the type $C_4H_{10-n}Cl_nO$. When saturated with gaseous hydrogen iodide at 0° C. ethyl iodide is slowly formed. When heated with phosphorus pentachloride it gives ethyl chloride.

Expt. 33.—*Reactions of Ethyl Ether.*—(1) Show that anhydrous ether does not react with Na or cold PCl_5.

(2) Warm a little ether with CrO_3: ether slowly oxidised.

106. Higher Ethers.—These are of little importance. They resemble ethyl ether in their chemical inertness.

They are most readily made by Williamson's synthesis.

Expt. 34.—*To Prepare Methyl* iso*Amyl Ether.*—In a flask fitted with reflux condenser and heated on the water-bath place 20 c.c. of amyl alcohol,[1] previously dried by standing over quick-lime and redistillation, the portion boiling between 135° and 140° being collected. Heat to 100° C. and add, through the condenser, 3 g. of clean sodium cut into small pieces. Continue the heating till no sodium remains. Allow the water-bath to cool somewhat and add the theoretical quantity of methyl iodide (18 g.) and heat for about an hour. Distil the liquid. Any unchanged methyl iodide distils at 40° to 50° C. Methyl *iso*amyl ether distils at 91° C., while the residue is amyl alcohol. The methyl amyl ether may be purified by heating it with sodium and redistilling it.

The properties of the higher ethers much resemble those of ethyl ether. They are, of course, less volatile and less readily inflammable.

QUESTIONS

(1) What is an ether? Write as many structural formulæ as possible for the compound $C_4H_{10}O$. (At least six may be written.) Which of these is the formula for ether? On what evidence do you base your conclusions?

(2) How is ethyl ether made by the continuous process? What impurities might ether so prepared contain, and how could they be removed?

(3) Why is ethyl ether a particularly useful solvent for organic substances?

(4) What substances react with ethyl ether and how do their reactions throw light on its structure?

(5) How would you prepare ethyl propyl ether? If presented to you as an unknown substance, how would you try to identify it?

(6) On shaking an aqueous solution of a certain substance with ether, till equilibrium was obtained, it was found that it distributed itself between the ether and the water so that the concentrations of the aqueous and ethereal solutions were as 1 : 3. What weight of the solute could be extracted from 100 c.c. of aqueous solution (100 g. solute per litre) by shaking with 150 c.c. of ether (*a*) in one portion, (*b*) in five successive portions of 30 c.c. each?

[1] Commercial amyl alcohol contains several isomerides and accordingly a mixture of two or more ethers will be obtained; the main product will be methyl *iso*amyl ether. Pure *n*-amyl or *iso*amyl alcohol is more satisfactory if available.

CHAPTER IX

THE KETONES

107. Ketones.—The *ketones* are compounds containing a carbonyl group =CO linked to two carbon atoms. The simplest ketone is, therefore, the compound

$$\begin{array}{l} CH_3 \\ | \\ C{=}O \\ | \\ CH_3 \end{array}$$

which is known as acetone.

108. Evidence for the Structure of the Ketones.—The simplest ketone, acetone, has the formula C_3H_6O. The oxygen is not present as hydroxyl, for acetone does not give hydrogen chloride with phosphorus pentachloride. When reduced it gives a secondary alcohol, *iso*propyl alcohol, $CH_3{\cdot}CH(OH){\cdot}CH_3$, and the oxygen atom is therefore attached to the middle carbon atom of a chain of three. Bearing in mind that the oxygen is not present as hydroxyl, the structure must clearly be

$$\begin{array}{l} CH_3 \\ | \\ C{=}O \\ | \\ CH_3. \end{array}$$

The close resemblance of the ketones to the aldehydes, which also contain a =CO group, confirms this view.

Ketones thus consist of two alkyl radicals linked by a carbonyl group. Where these radicals are the same the ketone is said to be *simple*, when they are different it is said to be *mixed*. Thus acetone, $CH_3-CO-CH_3$, is a *simple* ketone, while methyl ethyl ketone, $CH_3-CO-C_2H_5$, is a *mixed* ketone.

The properties of the ketones in general are best illustrated by a study of the simplest and most important ketone—acetone.

109. Acetone, $CH_3—CO—CH_3$.—*Occurrence.*—Acetone is normally present in traces in the fluids of the body, probably as a product of the oxidation of fats. In some pathological conditions considerable quantities are found in the urine. It is contained in small quantity in the products of the distillation of wood (§§ 48, 76).

Preparation and Manufacture.—(1) Acetone is made, both on the

commercial scale and in the laboratory, by the action of heat on anhydrous calcium acetate.

$$Ca\begin{matrix}O\cdot CO\cdot CH_3\\ O\cdot CO\cdot CH_3\end{matrix} = CaCO_3 + \begin{matrix}CH_3\\ |\\ CO—CH_3.\end{matrix}$$

Expt. 35.—*Preparation of Acetone.*—Calcium (or better, barium) acetate is heated on an iron tray to drive off all water of crystallisation. The hydrated salt melts, boils vigorously and solidifies to a mass of the anhydrous salt, which finally melts once more. The salt is allowed to cool and is powdered. It is then placed in a retort (Fig. 28) which is connected to a

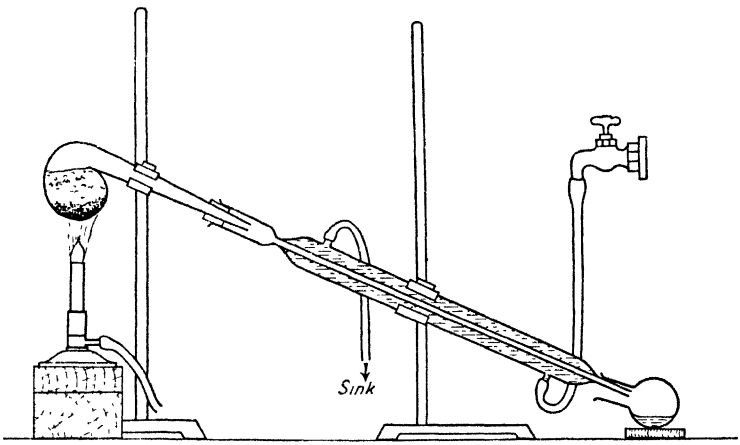


FIG. 28.—Preparation of Acetone.

Liebig condenser and receiver. The retort is heated with a luminous Bunsen flame and acetone slowly distils over.

The acetone may be purified by shaking it with a cold *concentrated* solution of sodium bisulphite,[1] when crystals of the acetone sodium bisulphite compound separate. These are dried on blotting paper and distilled with sodium carbonate solution (§ 112). The distillate containing acetone and water is treated with concentrated calcium chloride solution. The acetone separates as an upper layer which is dried over calcium chloride and redistilled.

On the manufacturing scale, acetone is made by a suitable modification of the above process.

(2) Acetone is also prepared industrially by the catalytic decom-

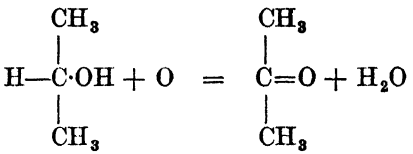
[1] See footnote, p. 129.

position of acetic acid vapour when passed over heated alumina or thoria:

$$CH_3{\cdot}CO{\cdot}OH + HO{\cdot}OC{\cdot}CH_3 = CH_3{\cdot}CO{\cdot}CH_3 + H_2O + CO_2.$$

(3) Some acetone is present in crude wood spirit (§ 48) from which it is extracted commercially.

(4) Acetone can be made by the oxidation of *iso*propyl alcohol:

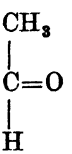


(5) Acetone is also made by the fermentation of starch (§ 50).

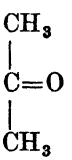
Purification of Acetone.—Very pure acetone is prepared from the commercial product by means of its additive compound with sodium iodide. Sodium iodide is dissolved in the minimum weight of acetone, and the solution is cooled in a freezing mixture to −8° C. Crystals of the compound $NaI{\cdot}3C_3H_6O$ separate. These are drained from the mother liquor, at once transferred to a dry distilling flask, and heated. Very pure acetone distils over.

110. Physical Properties of Acetone.—Acetone is a colourless mobile liquid with a peculiar and not unpleasant peppermint-like odour. It boils at 57·5° C. and has sp. gr. of 0·81/0° C. It is miscible with water but is readily salted out by means of calcium chloride, etc. Acetone is an excellent solvent, finding uses in the manufacture of cordite, celluloid, perfumes, etc. It is an excellent solvent for acetylene (*q.v.*, § 184).

111. Resemblance between Aldehydes and Ketones.—The properties of the ketones are remarkably like those of the aldehydes in almost all respects except their reaction with oxidising agents. Thus, both ketones and aldehydes form numerous addition products, are reduced to alcohols, and give a dichloride with phosphorus pentachloride. On the other hand, ketones are oxidised only with difficulty and do not readily polymerise. The key to the difference lies in the presence of a single hydrogen atom in aldehydes. This is readily oxidised to hydroxyl, and is readily shifted in the rearrangements required in polymerisation. The ketones have in place of this



Acetaldehyde.



Acetone.

hydrogen atom the stable methyl group. Thus aldehydes and

ketones are closely alike in the reactions which affect only the carbonyl group, but in other respects differ widely.

112. Chemical Properties of Acetone.—Acetone burns with a pale flame. It is not easily oxidised, but powerful oxidising agents such as potassium dichromate and sulphuric acid slowly convert it into acetic acid and carbon dioxide:

$$\begin{array}{l} CH_3 \\ | \\ CO + 4O \\ | \\ CH_3 \end{array} \quad = \quad \begin{array}{l} CH_3 \\ | \\ CO{\cdot}OH \end{array} \quad + \quad CO_2 + H_2O.$$

Since it is only oxidised with difficulty, acetone does not act as a reducing agent.

Acetone is readily reduced by nascent hydrogen to *iso*propyl alcohol:

$$\begin{array}{l} CH_3 \\ | \\ CO + 2H \\ | \\ CH_3 \end{array} \quad = \quad \begin{array}{l} CH_3 \\ | \\ H{\cdot}C{\cdot}OH \\ | \\ CH_3 \end{array}$$

This reaction should be compared with the reduction of aldehyde to ethyl alcohol (§ 70).

Phosphorus pentachloride substitutes two chlorine atoms for the oxygen atom:

$$\begin{array}{l} CH_3 \\ | \\ CO + PCl_5 \\ | \\ CH_3 \end{array} \quad = \quad \begin{array}{l} CH_3 \\ | \\ Cl{-}C{-}Cl \\ | \\ CH_3 \end{array} + POCl_3$$

forming $\beta\beta$-dichloropropane, often called acetone chloride. The halogens form substituted ketones such as trichloroacetone $CCl_3{-}CO{-}CH_3$. Acetone reacts with the halogens in presence of alkalis, forming chloroform, bromoform and iodoform (see § 61).

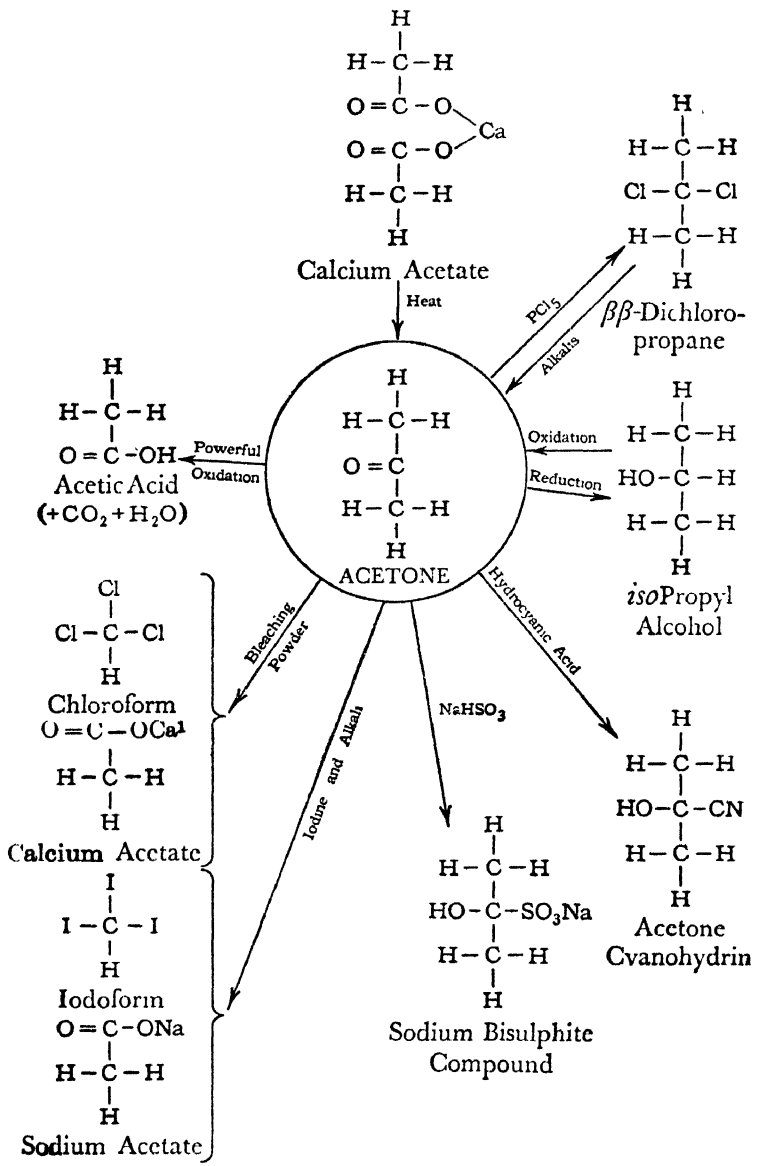
The ketones resemble the aldehydes (§ 70) in forming numerous addition products. They do not polymerise.

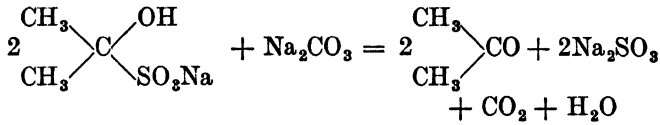
Addition compounds are formed with sodium bisulphite. Acetone, but not all the higher ketones, forms a compound with this reagent.

$$\begin{array}{l} CH_3 \\ | \\ CO + NaHSO_3 \\ | \\ CH_3 \end{array} \quad = \quad \begin{array}{l} CH_3 \\ | \\ HO{-}C{-}SO_3Na \\ | \\ CH_3 \end{array}$$

The bisulphite compound is reconverted into acetone by distillation with sodium carbonate solution:

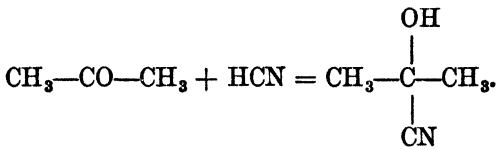
REACTIONS OF ACETONE





Expt. 36.—*To Prepare the Sodium Bisulphite Compound of Acetone.*—Make a *saturated* solution of sodium bisulphite by shaking the salt for some time with cold water.[1] To this add a quarter of its volume of acetone and cool under the tap. Colourless crystals of the bisulphite compound are produced. Dry these on blotting paper. Boil a portion with sodium carbonate solution. Acetone vapour is evolved and may be ignited at the mouth of the test-tube.

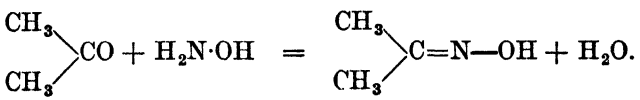
With hydrocyanic acid acetone gives a cyanohydrin



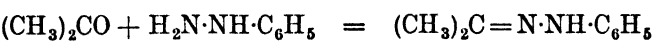
Acetone reacts with ammonia but no compound corresponding to aldehyde-ammonia is formed. Various *acetonamines* are produced, the oxygen of the carbonyl group and a part of the hydrogen of the ammonia being eliminated as water.

The ketones, like the aldehydes, form oximes, phenylhydrazones, and semicarbazones. The formation of the last compounds is discussed under the heading of semicarbazide (§ 313).

Acetone and hydroxylamine give acetoxime

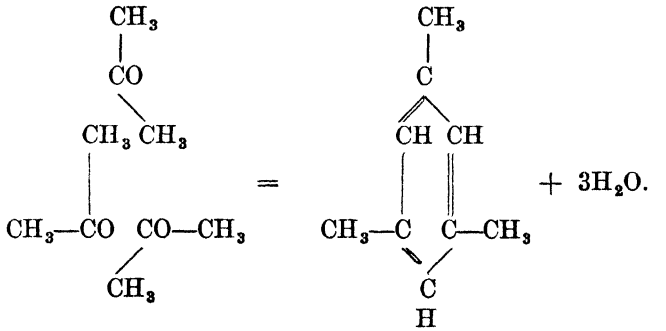


Acetone and phenylhydrazine give acetone phenylhydrazone:



The ketones, though they do not form polymerides, readily produce condensation products. Thus three molecules of acetone will condense, yielding (besides other products) mesitylene, trimethylbenzene. This reaction is interesting as a synthesis of an aromatic compound from an aliphatic compound (§ 336).

[1] Sodium bisulphite often becomes altered when stored. A suitable solution may be made by covering sodium carbonate crystals with water and saturating with sulphur dioxide till an apple-green colour develops.



Expt. 37.—*Reactions of Acetone.*—(1) Show that acetone is not affected by cold $KMnO_4$ solution, but is slowly oxidised on boiling.

(2) Show that acetone gives the iodoform reaction (Expt. 4).

(3) To 1 c.c. acetone add 3 c.c. saturated sodium bisulphite solution. Shake and cool. Crystals of bisulphite compound separate (Expt. 36).

(4) Dissolve some sodium nitroprusside in water to form a strong solution. Add a drop of acetone, then caustic soda drop by drop. A red coloration develops. The method is used for testing for acetone in urine.

Uses.—Acetone is used as a solvent for nitrocellulose, celluloid, etc. It also finds a use as a substitute for the much more expensive alcohol used in perfumery. It is used also in the manufacture of dissolved acetylene (§ 184) and in the manufacture of chloroform and iodoform (§§ 61, 63).

113. The Higher Ketones.—*Nomenclature.*—The ketones are commonly named from the alkyl groups present and the word *ketone*. They are also named from the hydrocarbon of the alkyl radical having the same number of carbon atoms as the ketone and the suffix—*one*. The position of the carbonyl group is indicated by a number or Greek letter.

Thus we speak of the compound $CH_3{\cdot}CO{\cdot}CH_3$ as acetone, dimethyl ketone or propanone. The compound $C_2H_5{\cdot}CO{\cdot}C_3H_7$ would be called ethyl propyl ketone or hexan-3-one.

It is hardly necessary to give a list of the higher ketones as very few are of importance. They may be prepared by the heating of the calcium salts of fatty acids (§ 109), the oxidation of secondary alcohols (§ 52), and the action of zinc alkyls or Grignard reagents on acyl chlorides (§§ 161, 163).

Their properties are similar to those of acetone.

QUESTIONS

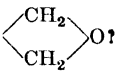
(1) What is a ketone? In what respects do ketones (*a*) resemble and (*b*) differ from aldehydes?

(2) How can acetone be converted into (i) an alcohol; (ii) a halide; (iii) an acid? Write equations for the changes in question.

(3) How can acetone be made in the laboratory? How can very pure acetone be made from the crude product?

(4) What addition products are formed by ketones? How far is their behaviour in this respect similar to that of aldehydes?

(5) The formula of acetone is C_3H_6O. How would you establish its structure and prove that its formula was not (*a*) $CH_2=CH—CH_2OH$, or (*b*) $CH_3 \cdot CH_2 \cdot CHO$

or (*c*) 

(6) What is the effect of reduction and oxidation on acetone? How does it resemble and differ from aldehyde and alcohol in this respect?

CHAPTER X

AMIDES, AMINES AND NITRO-PARAFFINS

114. Amides and Amines.—Both amides and amines are substituted ammonias, that is to say, they may be regarded as ammonia, NH_3, in which one or more hydrogen atoms are replaced by organic radicals.

Amides are compounds in which the hydrogen of ammonia is partly replaced by an *acyl* group. Their general formula is therefore $R—\overset{\overset{O}{\|}}{C}—NH_2$.

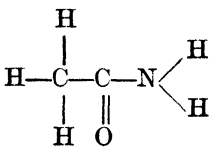
Amines are compounds in which the hydrogen of ammonia is partly or wholly replaced by hydrocarbon radicals, *e.g.*, alkyl groups. Their general formulæ are:

$R—NH_2$ (primary amine)

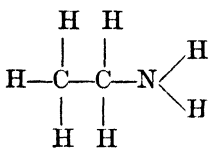
$\begin{matrix} R \\ \quad\diagdown \\ \quad\quad NH \\ \quad\diagup \\ R' \end{matrix}$ (secondary amine)

$\begin{matrix} R \\ \quad\diagdown \\ R' — N \\ \quad\diagup \\ R'' \end{matrix}$ (tertiary amine).

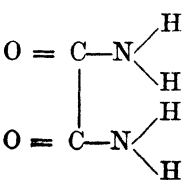
The formulæ of typical examples of amides and amines are shown below.



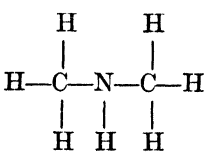
Acetamide.



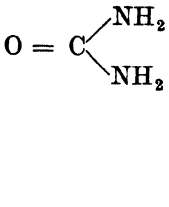
Ethylamine.



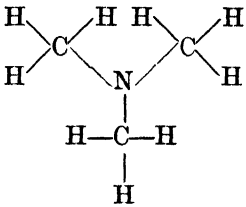
Oxamide.



Dimethylamine.



Carbamide (urea).
AMIDES.



Trimethylamine.
AMINES.

Amides and amines are alike in being substituted ammonias, but the conjunction of the basic amino-group with the acidic carbonyl to form an amide, and with the alkyl groups to form an amine, produces compounds differing in many of their properties.

AMIDES

As a typical amide we may study acetamide, which is of importance as the source of some of the simplest organic nitrogen derivatives.

115. Acetamide, $CH_3CO{\cdot}NH_2$.—Acetamide may be prepared by the action of ammonia on acetyl chloride or acetic anhydride (§§ 85, 86) but is ordinarily prepared by the decomposition of ammonium acetate when heated. The reaction is reversible:

$$CH_3{\cdot}CO{\cdot}O{\cdot}NH_4 \rightleftharpoons CH_3{\cdot}CO{\cdot}NH_2 + H_2O,$$

and therefore proceeds to completion only if one product of the reaction, in this case water, is removed as soon as formed. The use of ordinary dehydrating agents is inadmissible, as they react with ammonium acetate, so the water is removed by distilling it off.

A side reaction, which is troublesome, is the decomposition of the ammonium acetate to acetic acid and ammonia, which escapes on heating:

$$CH_3{\cdot}CO{\cdot}O{\cdot}NH_4 \rightleftharpoons CH_3{\cdot}CO{\cdot}OH + NH_3.$$

This decomposition is largely prevented by adding an excess of acetic acid, thus reducing the concentration of ammonia to a minimum. The method described in Expt. 38 gives good results.

Expt. 38.—*Preparation of Acetamide.*—The apparatus shown in Fig. 29 is set up. In the flask are placed 50 g. of ammonium acetate and 50 g. of glacial acetic acid. The flask is then heated so that a few drops per minute of liquid (water and acetic acid) distil. The residue remaining in the flask after about 4 hr. consists of acetamide and acetic acid. It is transferred to a distilling flask with air condenser (Fig. 30) and distilled, the

portion boiling between 213° C. and 230° C. being collected. The liquid solidifies to a mass of nearly pure acetamide.

Recrystallisation.—The acetamide may be purified by recrystallisation from alcohol. To the solid contained in a beaker is added about twice its weight of alcohol and the mixture heated

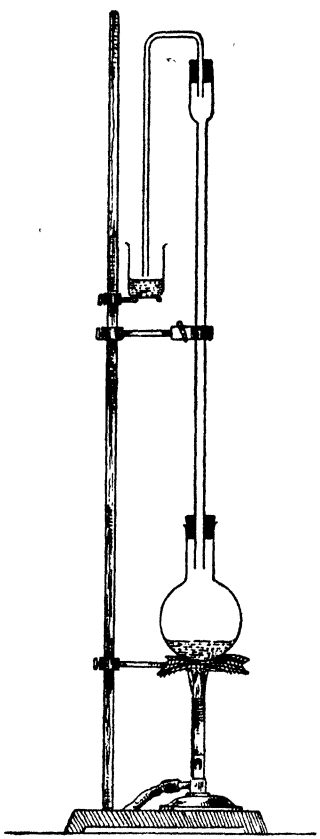


FIG. 29.—Preparation of Acetamide.

on the water-bath until the amide has dissolved. On cooling, colourless needles of acetamide separate. These may be sucked dry on the Buchner funnel and stored in a well-stoppered bottle.

Physical Properties.—Acetamide is a colourless solid with a strong odour of mice, probably due to traces of impurity. It melts at 82° C. and boils at 223° C. It is very soluble in water, alcohol and ether.

Chemical Properties.—Acetamide and most other amides, unlike the other compounds containing the $-NH_2$ group (*e.g.*, amines, amino-acids, etc.), do not form stable salts with acids.

When boiled with excess of water or dilute acids, acetamide is decomposed, giving ammonium acetate (which may be decomposed by any acid present):

$$CH_3{\cdot}CO{\cdot}NH_2 + H_2O \rightleftharpoons CH_3{\cdot}CO{\cdot}ONH_4.$$

With alkalis an acetate and ammonia result:

$$CH_3{\cdot}CO{\cdot}NH_2 + KOH = CH_3{\cdot}CO{\cdot}OK + NH_3.$$

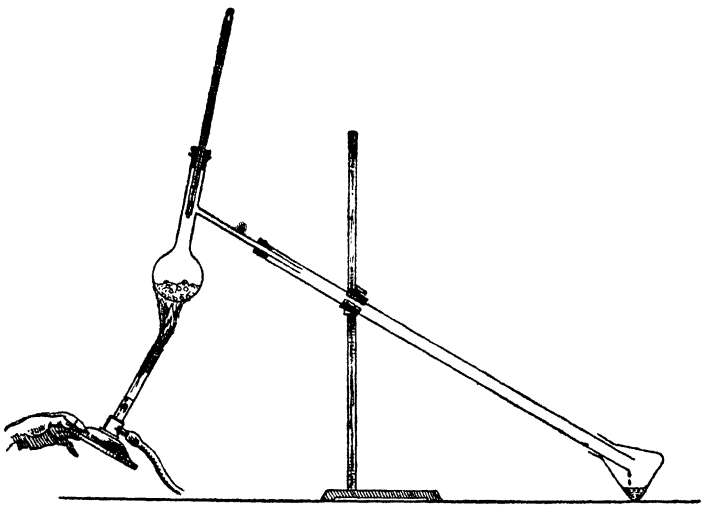


FIG. 30.—Distillation of Acetamide.

Acetamide is not readily oxidised. It can be reduced by nascent hydrogen (from sodium and amyl alcohol) to ethylamine:

$$CH_3{\cdot}CO{\cdot}NH_2 + 4H = CH_3{\cdot}CH_2{\cdot}NH_2 + H_2O.$$

The action of nitrous acid on compounds containing the $-NH_2$ group is usually to replace it by a hydroxyl group and liberate free nitrogen.[1] It converts acetamide in this way into acetic acid:

$$\begin{matrix} CH_3{\cdot}CO{\cdot}NH_2 \\ \qquad\qquad\quad = CH_3{\cdot}CO{\cdot}OH + N_2 + H_2O. \\ + HO{\cdot}NO \end{matrix}$$

Powerful dehydrating agents, such as phosphorus pentoxide, convert it into methyl cyanide, a reaction of value in making many cyanogen compounds (cf. § 144):

$$CH_3{\cdot}CO{\cdot}NH_2 = CH_3{-}C \equiv N + H_2O.$$

[1] But see under aromatic amines (§§ 382, 395).

The action of bromine in presence of alkalis upon acetamide yields first *N*-bromoacetamide, $CH_3{\cdot}CO{\cdot}NHBr$, and then methylamine, and this important reaction is discussed under the heading of the latter substance (§ 120).

Expt. 39.—*Reactions of Acetamide.*—(1) Heat the solid with lime, and the solution with NaOH. Ammonia evolved in each case.

(2) To a few crystals add 2 drops bromine and then an excess of caustic potash solution. Warm. Methylamine is evolved, recognised by alkaline reaction and fishy ammoniacal smell.

116. Other Amides.—*Formamide*, $H{\cdot}CO{\cdot}NH_2$, is a liquid which is of interest as being, like water, an ionising solvent (*v.* p. 110).

The higher amides much resemble acetamide in general properties, but are less soluble in water.

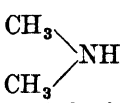
THE AMINES

117. Primary, Secondary and Tertiary Amines.—The amines may be regarded as ammonia, NH_3, in which one or more hydrogen atoms are replaced by hydrocarbon radicals. It follows, then, that three different types of amine will exist, according as one, two or three hydrogen atoms are replaced. These are called primary, secondary and tertiary amines.

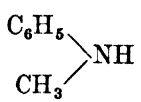
Primary amines contain the group $-NH_2$. Examples are:

$CH_3{\cdot}NH_2$ — Methylamine. $\qquad$ $C_6H_5{\cdot}NH_2$ — Aniline.

Secondary Amines.—These contain the group $=NH$. Examples are:

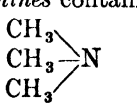


Dimethylamine.

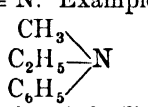


Methylaniline.

Tertiary amines contain the group $\equiv N$. Examples are:



Trimethylamine.



Methylethylaniline.

Quaternary Alkyl-ammonium Compounds.—Nitrogen forms the apparently quinquevalent ammonium salts, such as $[NH_4]^+Cl^-$. The hydrogen in these may be completely substituted by alkyl radicals, forming stable salts and bases. As examples of these we may take tetramethylammonium hydroxide,

$$[N(CH_3)_4]OH,$$

and tetramethylammonium chloride,

$$[N(CH_3)_4]Cl.$$

Just as no compound NH_5 can exist, so no alkyl compound NR_5 is known; and as NH_4-, ammonium, is not known in the free condition, so free substituted ammoniums of the type NR_4 do not normally exist.

118. Nomenclature of Amines.—The amines are usually named from the radicals composing them and the word *amine*. They are also named from the prefix *amino-* and the name of the substance in which it is substituted for hydrogen.

Thus the compound $C_4H_9{\cdot}NH_2$ is called *butylamine* or more rarely amino-butane.

119. The Primary Amines.—A few of the most important of these are tabulated below.

Name.	Formula.	State.	B.P.	Solubility in water.
Methylamine .	CH_3NH_2	Gas	-6° C.	1150 : 1 vol./12·5° C.
Ethylamine .	$C_2H_5NH_2$	Liquid	19–20° C.	Miscible
n-Propylamine .	$C_3H_7{\cdot}NH_2$	Liquid	49° C.	Miscible
n-Butylamine .	$C_4H_9{\cdot}NH_2$	Liquid	77·8° C.	Miscible

The first members of the series—methylamine and ethylamine—will be considered first as being typical of the group.

120. Methylamine, Monomethylamine, $CH_3{\cdot}NH_2$.—*Preparation.*—(1) Monomethylamine is prepared, together with the other methylamines, by the action of methyl iodide on a concentrated solution of ammonia.

The first reaction is the formation of methylamine hydriodide (methylammonium iodide):

$$CH_3I + NH_3 = [CH_3{\cdot}NH_3]I.$$

The excess ammonia liberates methylamine from this

$$[CH_3{\cdot}NH_3]I + NH_3 = CH_3{\cdot}NH_2 + NH_4I.$$

This methylamine, by a similar reaction, may then form dimethylamine:

$$CH_3I + CH_3{\cdot}NH_2 = [(CH_3)_2NH_2]I,$$
$$[(CH_3)_2{\cdot}NH_2]I + NH_3 = (CH_3)_2NH + NH_4I.$$

By similar reactions trimethylamine $N(CH_3)_3$ and tetramethylammonium iodide $N(CH_3)_4I$ are produced. It is not by any means simple to separate any of the above compounds in a pure state from the reaction mixture, but various methods depending on the different solubilities of the sulphonamides of the bases in alkali (§ 351) are commonly employed.

When the methylammonium salt has been isolated it is heated with an alkali and methylamine is evolved:

$$CH_3{\cdot}NH_3I + KOH = CH_3{\cdot}NH_2 + H_2O + KI.$$

The methylamine, which is a gas much resembling ammonia, is collected by absorbing it in water.

(2) A very much better way of obtaining methylamine is by the action of bromine and caustic potash on acetamide. *N*-Bromoacetamide is first formed:

$$CH_3{\cdot}CO{\cdot}NH_2 + Br_2 = CH_3{\cdot}CO{\cdot}NHBr + HBr,$$

and is then decomposed by caustic potash, giving potassium carbonate, potassium bromide and methylamine:

$$CH_3{\cdot}CO{\cdot}NHBr + 3KOH = CH_3{\cdot}NH_2 + K_2CO_3 + KBr + H_2O$$

The above is known as Hofmann's reaction.

(3) Methylamine is also obtained by the action of a solution of formaldehyde on ammonium chloride. Methylamine hydrochloride is produced which is then converted into methylamine. Some dimethylamine and trimethylamine hydrochloride are also produced and have to be removed by recrystallisation:

$$NH_4Cl + 2CH_2O = CH_3{\cdot}NH_3Cl + CH_2O_2.$$

(4) The action of caustic potash solution on methyl *iso*cyanate (§ 149) yields methylamine:

$$\begin{matrix} CH_3 - N = C = O \\ \qquad\qquad + H_2O \end{matrix} = CH_3{\cdot}NH_2 + CO_2.$$

Expt. 40.—*Preparation of Methylamine from Acetamide.*—Set up the apparatus shown in Fig. 31. In the flask, which is kept cool by immersion in water, place 12·5 g. of acetamide (previously well dried by rubbing between filter papers) and add 11·5 c.c. of bromine and then dilute caustic potash (20 g. in 175 c.c. of water) a little at a time, shaking well, until the liquid is of a golden-yellow colour. A strong warm solution of caustic potash (40 g. in 75 c.c. water) is now introduced through the tap-funnel and the liquid carefully heated to 70° C. and kept at that temperature, care being taken that the evolution of heat does not cause the temperature to rise. After a quarter of an hour, the liquid is distilled and the gaseous methylamine is absorbed in dilute hydrochloric acid contained in some form of apparatus designed to prevent liquid being sucked back into the reaction vessel.

The acid is evaporated on the water-bath and leaves a white residue containing methylamine hydrochloride and some ammonium chloride. This residue is extracted with 95 per cent alcohol and the solution obtained is evaporated on the water-bath, leaving methylamine hydrochloride.

Portions of the product may be (*a*) warmed with concentrated alkali, giving methylamine as a gas which is alkaline, smells of ammonia and burns with a yellow flame; (*b*) treated with nitrous acid, when nitrogen is evolved (§ 122).

121. Physical Properties of Methylamine.—Methylamine is a colourless gas with a powerful smell much resembling that of ammonia but distinguished from it by a certain fishiness. It is exceedingly soluble in water (1 c.c. of water dissolves 1,150 c.c. of the gas at 12·5° C.), and both it and the other alkylamines are usually sold as a 33 per cent. aqueous solution. When strongly cooled it condenses to a colourless liquid boiling at −6·5° C.

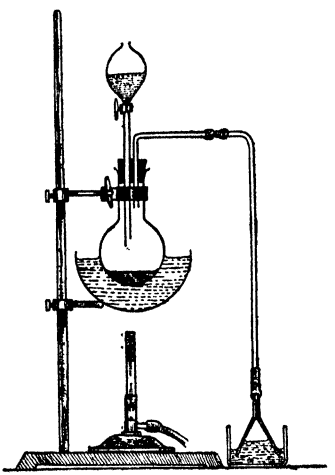


FIG. 31.—Preparation of a Solution of Methylamine.

122. Chemical Properties of Methylamine.—Methylamine burns in air with a yellow flame, this property being the readiest way of distinguishing it from ammonia, which in all other respects it much resembles. Both the gas and its solution are alkaline to litmus. Methylamine acts as a base in a manner entirely analogous to the behaviour of ammonia. Thus its solution in water conducts electricity, precipitates hydroxides from solutions of metallic salts and gives all the usual reactions of an alkali. It must therefore contain the hydroxyl ion. It is believed that methylamine and water give methylammonium hydroxide, which ionises to the methylammonium ion and hydroxyl ion:

$$CH_3{\cdot}NH_2 + H_2O \rightleftharpoons CH_3{\cdot}NH_3OH \rightleftharpoons [CH_3{\cdot}NH_3]^+ + OH^-.$$

With acids, methylammonium salts closely resembling the ammonium salts are formed. Thus with hydrochloric acid methylamine gives methylammonium chloride, more usually known as methylamine hydrochloride:

$$CH_3{\cdot}NH_2 + HCl = [CH_3{\cdot}NH_3]Cl.$$

The formula is sometimes written as $CH_3{\cdot}NH_2{\cdot}HCl$, but there is no more justification for doing this than for writing the formula of ammonium chloride as $NH_3{\cdot}HCl$.

The amines are not readily oxidised and cannot be reduced.

The action of nitrous acid on primary amines yields nitrogen and an alcohol:

$$\left.\begin{matrix} CH_3\cdot NH_2 \\ \\ +\ HO\cdot N:O \end{matrix}\right\} = CH_3OH + N_2 + H_2O.$$

Secondary and tertiary amines (§§ 126, 127) behave differently.

Primary amines when warmed with chloroform and alcoholic potash yield an *iso*cyanide. Thus methylamine warmed with these reagents gives methyl *iso*cyanide, also known as methyl carbylamine:

$$CH_3\cdot N\begin{matrix}H\\H\end{matrix} + \begin{matrix}Cl\\Cl\end{matrix}C\begin{matrix}H\\Cl\end{matrix} + 3KOH = CH_3\cdot N\overset{\rightarrow}{:}C + 3KCl + 3H_2O.$$

The *iso*cyanides have a very unpleasant and powerful smell and their formation by the above reaction, therefore, forms an excellent means of recognising primary amines.

Ex. t. 41.—*Reactions of Methylamine and its Salts.*—(1) Heat solid methylamine hydrochloride with excess of soda-lime. Note alkaline reaction and fishy ammoniacal odour of methylamine evolved. Note that it is inflammable.

(2) Add a solution of methylamine to a solution of an aluminium salt. The hydroxide is precipitated, but dissolves in excess.

(3) To a solution of sodium nitrite in cold dilute hydrochloric acid, add methylamine or a salt of it. Nitrogen is evolved.

(4) Perform the *iso*cyanide reaction (Expt. 86) with methylamine (or its hydrochloride) instead of aniline. The odour perceived is that of methyl *iso*cyanide.

123. Methylamine hydrochloride, $CH_3\cdot NH_3Cl$, may be taken as typical of the salts formed by these amines. It bears a strong resemblance to ammonium chloride, but, unlike it, is soluble in alcohol and is hygroscopic. When heated with alkalis it yields methylamine.

124. Ethylamine is prepared by modifications of methods (1), (2) and (4) given for methylamine but cannot be prepared by method (3). Thus it may be made:

(1) By the action of ethyl chloride on ammonia (§ 58).
(2) By the action of bromine and caustic potash (§ 120) on propionamide.
(3) By the action of caustic potash on ethyl *iso*cyanate (§ 149).
(4) Ethylamine can also be made by the reduction of methyl cyanide (§ 144):

$$CH_3-C\equiv N + 4H = CH_3\cdot CH_2\cdot NH_2.$$

In its properties it closely resembles methylamine.

125. Higher primary amines are made by methods similar to the above. They are not of practical importance.

SECONDARY AMINES

As typical of a secondary amine we may take dimethylamine $(CH_3)_2NH$.

126. Dimethylamine, $(CH_3)_2NH$.—*Preparation.*—The action of methyl iodide on ammonia forms mono-, di- and tri-methylamine. These are difficult to separate. This can, however, be done by fractional crystallisation of the hydrochlorides.

Properties.—Dimethylamine resembles methylamine in its basic properties—formation of a hydrochloride, etc.

It differs from it in its reaction with nitrous acid, and in its failure to form an *iso*cyanide with chloroform and alcoholic potash.

With nitrous acid it forms dimethyl-nitrosoamine, a yellow oil, boiling at 148° C.

$$(CH_3)_2NH + NO{\cdot}OH = (CH_3)_2N-N=O + H_2O$$

TERTIARY AMINES

Tertiary amines may be regarded as ammonia in which all three hydrogen atoms are replaced by hydrocarbon radicals. Examples of tertiary amines are $N(CH_3)_3$, trimethylamine, and $C_6H_5{\cdot}N(CH_3)_2$, dimethylaniline.

The first of these will be described as being a typical and important tertiary amine.

127. Trimethylamine, $(CH_3)_3N$.—Trimethylamine is a common product of the decomposition of nitrogenous plant or animal substances. Herring brine contains a notable proportion of it, as also does the plant, *Chenopodium vulvaria*, the "stinking goose-foot."

Preparation.—The action of methyl iodide on ammonia yields trimethylamine together with the other two methylamines.

$$3CH_3I + 4NH_3 = (CH_3)_3N + 3NH_4I.$$

The separation of trimethylamine from the other two methylamines presents some difficulty and depends on the fact that trimethylamine does not react with ethyl oxalate while the other amines do so.

Properties.—Trimethylamine is a colourless gas which condenses to a liquid boiling at 3·5° C. It has a most unpleasant smell, at once fishy and ammoniacal. Like the other amines it is extremely soluble in water.

Trimethylamine resembles methylamine in its basic properties. It reacts with nitrous acid in the same way as with any other acid, a salt being formed: this property distinguishes it from methylamine and dimethylamine.

When treated with methyl iodide it forms a crystalline salt, tetramethylammonium iodide,

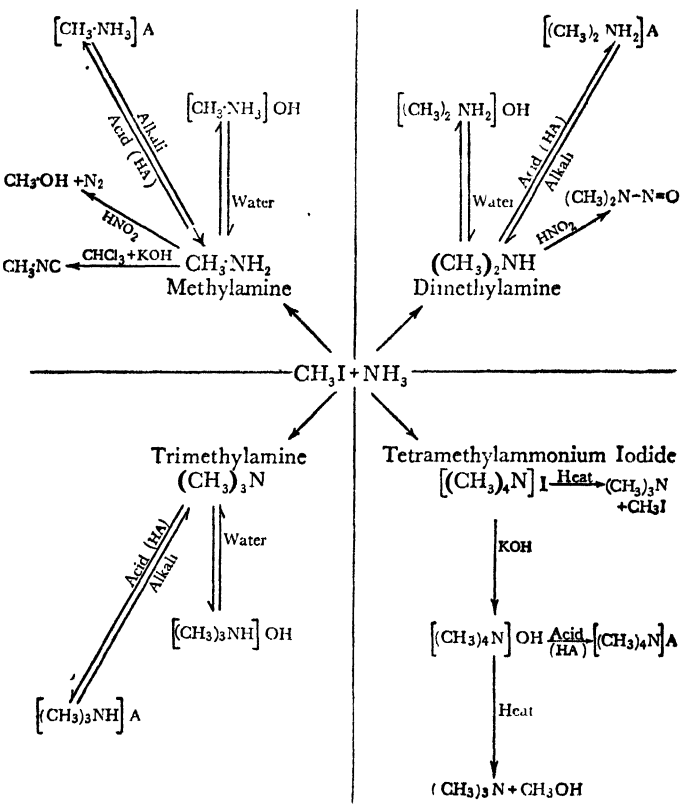
$$N(CH_3)_3 + CH_3I = N(CH_3)_4I.$$

QUATERNARY AMMONIUM COMPOUNDS, $[NR_4]X$.

128. Tetramethylammonium Compounds.—When trimethylamine is treated with methyl iodide or when ammonia is heated with an excess of methyl iodide, the salt tetramethylammonium iodide is formed:

$$NH_3 + 4CH_3I = N(CH_3)_4I + 3HI.$$

REACTIONS OF THE AMINES



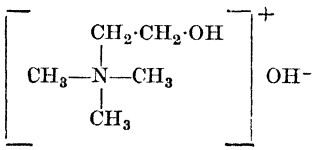
When this salt is treated with alcoholic potash a stable tetramethylammonium hydroxide $N(CH_3)_4OH$ is formed. This is a remarkable substance resembling the caustic alkalis, potassium and sodium hydroxide, in many ways. It is hygroscopic and forms a strongly alkaline solution, which absorbs carbon dioxide from the air.

The tetramethylammonium compounds decompose when heated, forming trimethylamine and a methyl compound:

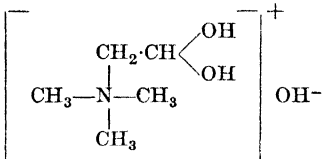
$$N(CH_3)_4I = N(CH_3)_3 + CH_3I.$$

Certain of the quaternary ammonium hydroxides are of physiological importance.

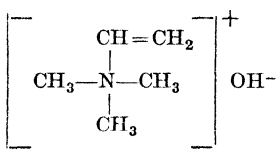
Choline, found in bile, many fungi, and numerous animal tissues, is trimethyl-β-hydroxyethylammonium hydroxide.



Muscarine, the poisonous principle of the toadstool *Agaricus muscarius*, is obtained from choline by oxidation. Its formula is



Muscarine.



Neurine.

Neurine frequently found in putrefying protein substances is trimethyl-vinylammonium hydroxide.

It is very poisonous. All these bases resemble tetramethylammonium hydroxide in being strong alkalis and in being readily decomposed.

129. Distinction between Primary, Secondary and Tertiary Amines.—The simplest method is treatment with nitrous acid. Primary amines evolve gaseous nitrogen and leave an alcohol:

$$CH_3NH_2 + HNO_2 = CH_3OH + N_2 + H_2O.$$

Secondary amines form a yellow oily nitrosoamine,

$$(CH_3)_2NH + HO{\cdot}NO = (CH_3)_2N{-}N{=}O + H_2O.$$

Tertiary amines merely form a nitrite:

$$(CH_3)_3N + HNO_2 = [(CH_3)_3NH]NO_2.$$

Primary amines also give the *iso*cyanide reaction with chloroform and alcoholic potash.

Expt. 42.—*To distinguish a Primary, Secondary and Tertiary Amine.*—Methylamine, dimethylamine or monomethylaniline, and trimethylamine may be used. The amine or its salt is dissolved in hydrochloric acid and a solution of sodium nitrite is slowly added. From methylamine nitrogen will be evolved. With the secondary amine the yellow oily nitrosoamine is produced, while with trimethylamine nothing is noticed.

NITRO-COMPOUNDS

130. Nitro-compounds and Nitrites.—Two series of compounds of the formula R – NO_2 are known. They are the alkyl nitrites (already considered in §§ 95, 96) and the nitro-paraffins.

The nitrites are formed by the action of a nitrite and an acid on an alcohol. Presumably nitrous acid is liberated and then reacts in the same way as any other acid with the alcohol. Nitrous acid has the structural formula HO – N=O, and the reaction is therefore probably

$$C_2H_5{\cdot}OH + H{\cdot}O-N=O \;=\; C_2H_5-O-N=O + H_2O.$$

The nitro-compounds of the higher paraffins and of the aromatic hydrocarbons can be formed by the action of nitric acid on the hydrocarbon, water being eliminated. Since nitric acid is usually formulated as HO – $N\langle^{O}_{O}$ or at least as HO – NO_2, the nitro-paraffin is probably formed by a reaction such as

$$R-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-\overset{\cdots}{H} + HO-N\langle^{O}_{O} = R-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-NO_2 + H_2O.$$

Apart from any question as to the structure of the nitro-group, it is evident that in the nitrites the alkyl group is attached to oxygen and in the nitro-compounds to nitrogen. The action of reducing agents on them confirms this. The nitrites yield an alcohol, ammonia and water.

$$C_2H_5-O-N=O + 6H \;=\; C_2H_5OH + NH_3 + H_2O.$$

The primary nitro-paraffins yield a primary amine and water,

$$C_2H_5-N\langle^{O}_{O} + 6H = C_2H_5NH_2 + 2H_2O.$$

This shows that the carbon of the alkyl radical is attached to oxygen (C_2H_5OH formed) in the nitrites, and to nitrogen ($C_2H_5NH_2$ formed) in the nitro-paraffins.

131. Diazomethane, CH_2N_2, $H_2C=N\rightleftharpoons N$ is prepared by treating methylamine hydrochloride with bleaching powder, so obtaining the volatile and explosive methyldichloroamine, $CH_3{\cdot}NCl_2$. This is treated in ethereal solution with hydroxylamine hydrochloride and sodium methoxide.

$$[CH_3{\cdot}NH_3]Cl + 2HOCl = CH_3{\cdot}NCl_2 + 2H_2O + HCl$$

$$CH_3{\cdot}NCl_2 + H_2N{\cdot}OH = CH_2N_2 + H_2O + 2HCl.$$

An ethereal solution of diazomethane distils over.

The most convenient method is to treat an ethereal solution of nitrosomethylurethane with alkali $CH_3{-}N(NO)CO_2Et \xrightarrow{KOH} CH_3{-}N{=}N{-}OK \xrightarrow{H_2O} CH_2N_2 + KOH + EtOH + K_2CO_3$.

It is a yellow, odourless, very poisonous and corrosive gas which may readily be liquefied. The liquid boils near 0° C.

Its ethereal solution affords an excellent means of inserting a methyl group. Thus it converts hydrocyanic acid into methyl cyanide, nitrogen

$$CH_2{:}N_2 + HCN = CH_3CN + N_2$$

being liberated. With water it gives methyl alcohol,

$$CH_2{:}N_2 + H{\cdot}OH = CH_3OH + N_2.$$

Its general reaction is $CH_2N_2 + HX = CH_3X + N_2$. Its properties should be compared with those of the aromatic azo- and diazo-compounds (Ch. XXV).

132. The Nitro-paraffins.—These compounds are of small importance compared with the very useful and commercially valuable nitro-compounds of the aromatic hydrocarbons (Ch. XXIII).

The lower members of the series are prepared by the reaction of an alkyl iodide with silver nitrite, which apparently has the structure of a nitro-compound:[1]

$$CH_3I + AgNO_2 = CH_3{\cdot}NO_2 + AgI.$$

The use of any other metallic nitrite yields the alkyl nitrite, not the nitro-paraffin; the silver salt yields both.

The higher hydrocarbons containing more than six carbon atoms can be *nitrated* directly with fuming nitric acid:

$$C_{10}H_{22} + HNO_3 = C_{10}H_{21}{\cdot}NO_2 + H_2O.$$

On the commercial scale nitro-paraffins are made by the reaction of hydrocarbons with nitric acid vapour at *c.* 400° C.

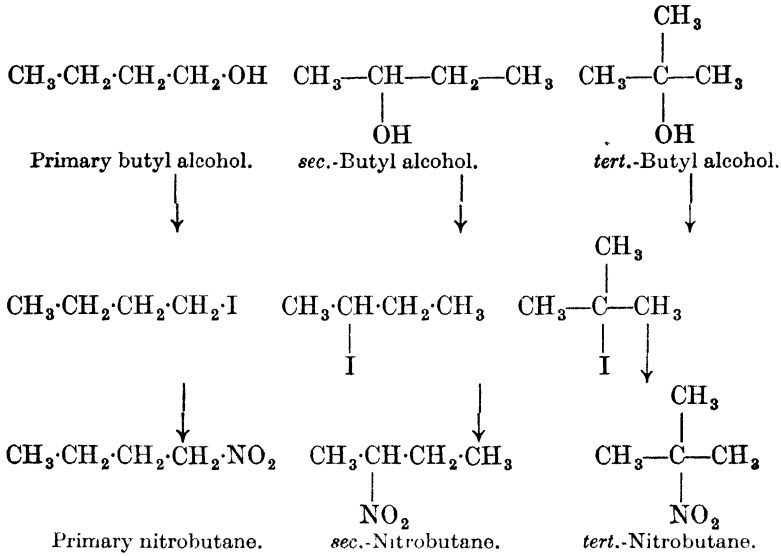
The nitro-paraffins are liquids which boil at temperatures from 100° C. upwards. Their most important reactions are their behaviour with reducing agents and with nitrous acid. In the first case amines are produced:

$$CH_3{\cdot}NO_2 + 6H = CH_3{\cdot}NH_2 + 2H_2O.$$

In the second case a different product is obtained according to whether the nitro-group is attached to the group $-CH_2-$, $=CH-$ or $\equiv C-$. This reaction can be used if we desire to distinguish between primary, secondary and tertiary alcohols. These may be

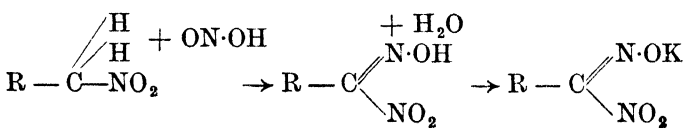
[1] Cf. formation of nitriles and *iso*cyanides (§ 142).

converted easily into nitro-paraffins by (*a*) conversion into the iodide (§ 56), (*b*) treatment of this with silver nitrite, as illustrated below:



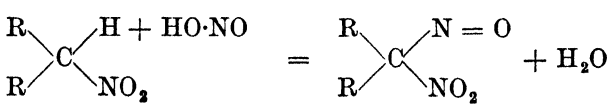
A primary, secondary or tertiary alcohol will form a primary, secondary or tertiary nitro-paraffin. These latter are distinguished readily by treating them first with nitrous acid and then with an alkali.

A primary nitro-paraffin gives a nitrolic acid which forms an intensely *red* salt:



Red *nitrolate.*

A secondary nitro-paraffin forms a pseudo-nitrol which dissolves with a blue colouration:



Blue pseudo-nitrol.

Tertiary nitro-paraffins are not affected.

133. Other Nitrogen Compounds.—The *iso*cyanides and cyanides are treated in the next chapter. The hydrogen in hydrazine, N_2H_4, and hydroxylamine, $NH_2{\cdot}OH$, may be substituted by alkyl groups, and such compounds as

methylhydrazine, $CH_3 \cdot NH \cdot NH_2$, and *N*-methylhydroxylamine, $CH_3 \cdot NH \cdot OH$, are formed. These are not of importance, though the aromatic compounds phenylhydrazine (§ 409) and phenylhydroxylamine are well-known substances.

QUESTIONS

(1) Compare the properties of the $-NH_2$ group in an amide and an amine.

(2) How is acetamide ordinarily prepared? What steps are taken to secure the maximum yield, and why?

(3) How does acetamide react with acids, alkalis, halogens, nitrous acid, phosphorus pentoxide? Outline the reactions by which ethyl alcohol could be converted into acetamide.

(4) Describe the preparation of methylamine, dimethylamine, and trimethylamine. How would you detect the presence of the first of these in a specimen of the last?

(5) Compare the properties of methylamine with those of ammonia. What tests can be used to distinguish these substances?

(6) How would you convert trimethylamine into tetramethylammonium hydroxide? What remarkable features does the latter compound present?

(7) What are primary, secondary and tertiary amines? How would you attempt to classify an unknown amine?

(8) How can methyl alcohol be converted into ethyl alcohol and *vice versa*?

(9) Distinguish between nitrites and nitro-compounds. How would you attempt, making use of the nitro-compounds, to classify an alcohol as primary, secondary, or tertiary? How could you confirm the conclusions so reached?

(10) 1·18 G. of a compound treated by Kjeldahl's method yielded enough ammonia to neutralise 20 c.c. of normal acid. The same weight of the compound in a combustion analysis yielded 1·76 g. of CO_2 and 0·90 g. water. The substance did not contain halogen or sulphur. Calculate its formula.

CHAPTER XI

ALKYL CYANIDES AND RELATED COMPOUNDS

134. The Cyanogen Radical.—The organic compounds containing the grouping CN are of considerable importance in organic syntheses. As cyanogen, $(CN)_2$, and hydrocyanic acid and the cyanides, from which the organic cyanogen derivatives are derived, are usually regarded as organic compounds, these will first be considered.

The radical $-CN$ shows some analogy to an atom of a halogen such as $-Cl$, and the cyanogen compounds were among the earliest in which the behaviour of a radical or group of atoms was seen to be analogous to that of a single atom. We may compare the sequence of compounds, Cl_2 chlorine, HCl hydrochloric acid, CH_3Cl methyl chloride, with $(CN)_2$ cyanogen, HCN hydrocyanic acid, CH_3CN methyl cyanide. In their chemical behaviour, however, the reactions of cyanogen bear but a superficial resemblance to those of a halogen.

CYANOGEN, HYDROCYANIC ACID AND ITS SALTS

135. Cyanogen, $(CN)_2$.—*Preparation.*—(1) The gas cyanogen is usually prepared by the action of heat upon mercuric cyanide. Needless to say, every precaution must be taken to avoid breathing the gas, which is intensely poisonous. The mercuric cyanide decomposes to cyanogen and mercury, leaving behind a little of a brown solid polymeride of cyanogen, known as paracyanogen:

$$Hg(CN)_2 = Hg + (CN)_2.$$

Silver cyanide may also be used.

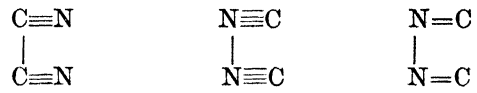
(2) The gas may also be prepared by heating cupric sulphate solution with potassium cyanide:

$$CuSO_4 + 2KCN = Cu(CN)_2 + K_2SO_4,$$
$$2Cu(CN)_2 = Cu_2(CN)_2 + (CN)_2.$$

(3) The action of phosphorus pentoxide on oxamide (§ 210) yields the gas:

$$\begin{array}{l} CO{\cdot}NH_2 \\ | \\ CO{\cdot}NH_2 \end{array} = \begin{array}{l} CN \\ | \\ CN \end{array} + 2H_2O.$$

Structure.—The density and composition of the gas show it to have the formula C_2N_2. This might be formulated in several ways, as for example:

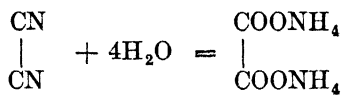


I. II. III.

The first of these formulæ is probably correct as is shown by its preparation from oxamide. The structure of the $-CN$ group is further discussed in § 147.

Properties.—Cyanogen is a colourless gas of an unpleasant almond-like odour and is intensely poisonous. It is fairly soluble in water (4 vols : 1 vol.).

Cyanogen burns with a beautiful peach-blossom-coloured flame. In solution it breaks up, giving a variety of products, including ammonium oxalate and a brown complex powder, 'azulmic acid.'



In its reactions it shows some analogy to a halogen. Thus it combines directly with potassium to form potassium cyanide:

$$2K + (CN)_2 = 2KCN,$$

and with caustic potash gives a cyanide and a cyanate (cf. chlorine which gives a chloride and hypochlorite):

$$2KOH + (CN)_2 = KCN + KCNO + H_2O.$$

136. Hydrocyanic Acid, Hydrogen Cyanide, HCN (Prussic Acid)—
—The cyanides of the alkali metals are the source of hydrocyanic acid. Their preparation is outlined below (§ 137).

(1) Hydrocyanic acid is prepared by distilling potassium cyanide or ferrocyanide with moderately diluted sulphuric acid:

$$KCN + H_2SO_4 = KHSO_4 + HCN.$$

Concentrated acid converts the acid into ammonium sulphate and carbon monoxide and therefore cannot be used.

Considerable care is necessary owing to its volatility and the extreme deadliness of the vapour; the preparation must be conducted out of doors or in a fume-cupboard with a good draught, and only skilled persons should attempt it.

(2) Hydrocyanic acid is formed by the action of dehydrating agents on ammonium formate:

$$NH_4 \cdot O \cdot CO \cdot H = HCN + 2H_2O.$$

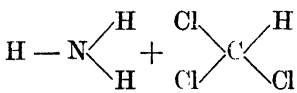
(3) Several plants contain glucosides (compounds of glucose with

organic substances) which by the action of hydrolysing agents liberate hydrogen cyanide. The commonest of these is *amygdalin*, found in bitter almonds. This, by the action of water and an enzyme (§ 273) known as 'emulsin' (which is also contained in bitter almonds), is converted into hydrocyanic acid, benzaldehyde and glucose:

$$C_{20}H_{27}O_{11}N + 2H_2O = HCN + C_6H_5{\cdot}CHO + 2C_6H_{12}O_6.$$

Oil of bitter almonds therefore contains hydrocyanic acid. The young shoots of the common cherry-laurel when bruised evolve small amounts of hydrogen cyanide.

(4) If the *iso*cyanide reaction described in § 146 be performed with chloroform alcoholic potash and ammonia (under pressure) instead of with an amine, hydrogen cyanide is formed. This is of interest as indicating the *iso*cyanide formula HNC, while reaction (2) above indicates the cyanide formula HCN (*v.* § 147):



$$+ 3KOH = HNC + 3KCl + 3H_2O.$$

Properties.—Hydrogen cyanide is a colourless liquid with a sickly and repellent odour. It is one of the most violent of poisons, often producing death within thirty seconds. No remedy is of value unless instantly administered. Freshly prepared ferrous hydroxide made by mixing solutions of ferrous sulphate and ammonia is the best antidote. Hydrogen peroxide is also of value. The vapour is exceedingly poisonous and every precaution is required in handling it. Hydrogen cyanide boils at 26° C. and is therefore extremely volatile. It is ordinarily kept in solution in water, with which it is miscible in all proportions.

Hydrocyanic acid slowly decomposes in solution, the main product being ammonium formate:

$$HCN + 2H_2O = H{\cdot}CO{\cdot}ONH_4.$$

It is a very weak acid indeed. Its salts are strongly hydrolysed and are decomposed even by carbon dioxide.

On reduction it gives methylamine,

$$HCN + 4H = CH_3{\cdot}NH_2.$$

With aldehydes and ketones it gives cyanohydrins (§ 70). It is detected by the formation of Prussian blue (§ 4).

Hydrocyanic acid is manufactured on a large scale for the destruction of insect pests on trees. The tree is surrounded by a sort of tent, and a small quantity of hydrocyanic acid is pumped in and at once evaporates. Alternatively, potassium or sodium cyanide may be dropped into moderately concentrated sulphuric acid, thus liberating

the poisonous gases. It has also been used for the destruction of rats in ships and bugs in dwelling-houses.

137. The Cyanides.—The metallic cyanides belong perhaps rather to Inorganic Chemistry than to Organic Chemistry, but a short account may be of value. Potassium and sodium cyanides are manufactured industrially on a large scale as they are of use in the extraction of gold from its ores. The chief method used in their preparation is the action of sodamide on red-hot charcoal.

Sodium is melted and treated with ammonia gas at 300–400° C. and the sodamide so formed is then run on to red-hot charcoal. It first reacts with the carbon forming sodium cyanamide, which itself then reacts with carbon forming sodium cyanide:

(1) $2Na + 2NH_3 = 2NaNH_2 + H_2$.

(2) $2NaNH_2 + C = Na_2N{\cdot}CN + 2H_2$.

(3) $Na_2N{\cdot}CN + C = 2NaCN$.

A good deal of sodium and potassium cyanide is made from the hydrocyanic acid present in crude coal-gas.

Both sodium and potassium cyanides are white salts, easily fusible and readily soluble in water. They are intensely poisonous. Being salts of a very weak acid they are much hydrolysed in solution and their solutions smell of hydrocyanic acid and are strongly alkaline:

$$KCN + H_2O \rightleftharpoons KOH + HCN.$$

Potassium cyanide finds uses in organic chemistry for preparing the nitriles (§ 144), and for the preparation of aromatic diketones (§ 481). When oxidised by lead dioxide, etc., it forms potassium cyanate KCNO (§ 149), and when fused with sulphur it gives potassium thiocyanate KCNS (§ 150).

138. Potassium ferrocyanide, $K_4Fe(CN)_6$, is usually prepared from coal-gas. In the laboratory it may be prepared by adding pure ferrous sulphate solution to potassium cyanide solution till a small permanent precipitate remains. The solution is filtered and evaporated: potassium ferrocyanide crystallises out in fine yellow tabular crystals:

$$FeSO_4 + 6KCN = K_4Fe(CN)_6 + K_2SO_4.$$

When distilled with dilute sulphuric acid it gives hydrocyanic acid: with concentrated sulphuric acid it forms carbon monoxide.

139. Potassium Ferricyanide, $K_3Fe(CN)_6$.—When potassium ferrocyanide is oxidised with chlorine, permanganates, etc., potassium ferricyanide is produced.

Expt. 43.—*To prepare Potassium Ferricyanide.*—Dissolve 13 g. of powdered potassium ferrocyanide in 100 c.c. of cold

water and add 4 c.c. of concentrated hydrochloric acid. Dissolve 1 g. of potassium permanganate in 150 c.c. of water and add the solution, a few c.c. at a time, till the solution no longer gives a blue colour, when a drop is mixed with a drop of ferric chloride solution. The solution is evaporated on the water-bath to 15 c.c. On cooling, potassium ferricyanide crystallises out:

$$KMnO_4 + 8HCl + 5K_4Fe(CN)_6 = 6KCl + MnCl_2 + 5K_3Fe(CN)_6 + 4H_2O.$$

Potassium ferricyanide forms mahogany-red crystals readily soluble in water.

140. Prussian Blue.—The reactions of the ferricyanides and ferrocyanides with iron salts are of importance for the detection of the latter and for the industrial preparation of the pigment Prussian blue. There are at least five different blue compounds, all ferrocyanides of ferric iron or double ferrocyanides of ferric iron and potassium. The best known of these is *Insoluble Prussian Blue*, which is made by adding an acid solution of a ferric salt to a solution of a ferrocyanide:

$$4FeCl_3 + 3K_4Fe(CN)_6 + 10H_2O = Fe_4[Fe(CN)_6]_3 \cdot 10H_2O + 12KCl.$$

It forms a very stable and insoluble powder of a deep blue tint. Other forms of Prussian blue are obtained by oxidising the white ferrous ferrocyanide, by using neutral solutions of ferric salts and ferrocyanides, etc.

The action of a ferrous salt on a ferricyanide also yields Prussian blue, ferric ferrocyanide being produced instead of ferrous ferricyanide as might be expected.

141. Sodium nitroprusside, $Na_2[FeNO(CN)_5] \cdot 2H_2O$, is formed when potassium ferricyanide is boiled with dilute nitric acid (1 : 1) and the solution made alkaline with sodium hydroxide. It is a red crystalline salt, solutions of which give a deep purple colouration with soluble sulphides, for which it is employed as a test (cf. use in Lassaigne's test, § 4).

ALKYL CYANIDES AND *ISO*CYANIDES

142. The Esters of Hydrocyanic Acid.—It is possible to prepare from the cyanides two different alkyl compounds. Thus, from ethyl iodide and potassium cyanide there is obtained a compound which when purified has a pleasant odour, while from ethyl iodide and silver cyanide a liquid of repulsive and intolerable odour is produced. These liquids both have the formula, C_3H_5N, and it is presumed from their formation and reactions that one has the formula C_2H_5CN, and

the other the formula C_2H_5NC. The evidence for these formulæ will be commented on in studying their formation and reactions.

143. Alkyl Cyanides or Nitriles.—The nitriles will be shown to have the general formula R·CN. They are named from the acid with the same number of carbon atoms and the word *nitrile* or from the alkyl radical and the word *cyanide*. Thus the compound C_2H_5CN is called *propionitrile* or *ethyl cyanide*.

144. Methyl Cyanide, Acetonitrile, CH_3CN.—(1) Methyl cyanide can be made by heating an alcoholic solution of potassium cyanide with methyl iodide, or by heating methyl hydrogen sulphate with potassium ferrocyanide, but in absence of direct evidence as to whether potassium cyanide is KCN or KNC this method of formation throws no light on its structure:

$$CH_3I + KCN = CH_3CN + KI.$$

(2) Methyl cyanide is made by the action of phosphorus pentoxide on acetamide:

$$CH_3-\underset{\underset{O}{\|}}{C}-NH_2 = CH_3CN + H_2O.$$

This reaction marks it out as definitely of the structure CH_3CN and not CH_3NC.

Properties.—Methyl cyanide is a colourless liquid with a not unpleasant ethereal odour, and is not particularly poisonous. It boils at 82° C. It is miscible with water.

Methyl cyanide and other nitriles are reactive substances. When they are hydrolysed by acids, alkalis or superheated water, the ammonium salt of a fatty acid results,

$$CH_3{\cdot}CN + 2H_2O = CH_3{\cdot}CO{\cdot}ONH_4.$$

This again is evidence that the carbon of the cyanide group is attached to the carbon of the alkyl radical. The reaction is a valuable one for synthesising organic acids.

When reduced by nascent hydrogen (sodium and alcohol) the nitriles form amines. Thus methyl cyanide gives ethylamine:

$$CH_3{\cdot}CN + 4H = CH_3{\cdot}CH_2{\cdot}NH_2.$$

This again shows the structure of the cyanide group to be $-CN$ not $-NC$. The reaction is of value for obtaining derivatives of a hydrocarbon from those of a hydrocarbon with one less carbon atom in the molecule (*e.g.*, ethyl compounds from methyl compounds) (§ 152).

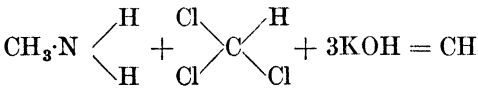
145. *iso*Cyanides (*iso*Nitriles, Carbamines, Carbylamines).—T*iso*cyanides or carbylamines are isomeric with the nitriles: that *i*

say, they have the same empirical formula. They will be shown to have the formula RNC, the nitrogen being attached to the alkyl radical and the single carbon atom to the nitrogen atom.

146. Methyl *iso*Cyanide, $CH_3{\cdot}NC$.—(1) Methyl *iso*cyanide can be made by heating silver cyanide with methyl iodide:

$$CH_3I + AgNC = CH_3NC + AgI.$$

(2) The usual method of preparation is the action of chloroform and alcoholic potash on a primary amine. Since the nitrogen in the amine is attached to the alkyl carbon atom, presumably the same is true of the nitrogen atom in the *iso*cyanide, which therefore has the formula $CH_3 - NC$.



$$CH_3{\cdot}N\begin{matrix}H\\H\end{matrix} + \begin{matrix}Cl\\Cl\end{matrix}C\begin{matrix}H\\Cl\end{matrix} + 3KOH = CH_3NC + 3KCl + 3H_2O.$$

Properties.—Methyl *iso*cyanide is a colourless liquid with an unbearable heavy and putrid odour. It is poisonous. The *iso*cyanides are only slightly soluble in water.

The *iso*cyanides differ from the nitriles in the effect of hydrolysis upon them and in the effect of reducing agents.

When they are hydrolysed with dilute acids, an amine and formic acid are produced. Thus methyl *iso*cyanide gives methylamine and formic acid:

$$CH_3NC + 2H_2O = CH_3NH_2 + H{\cdot}CO{\cdot}OH.$$

Strong reducing agents convert them into secondary amines, a reaction which also helps to demonstrate their structure:

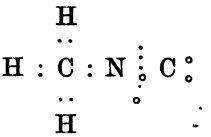
$$CH_3NC + 4H = \underset{\text{Dimethylamine.}}{CH_3{\cdot}NH{\cdot}CH_3}.$$

147. Structure of the Cyanide and *iso*Cyanide Groups.—The cyanide group is usually represented as having the formula $-C \equiv N$ and this agrees well with its reactions.

The *iso*cyanide group, $-NC$, presents more difficulty. The formula $-N \equiv C$ does not appear possible as nitrogen never shows a covalency of five, which would require a ring of ten electrons round the nitrogen atom, while eight electrons seem to be the greatest number possible for the atoms of the elements of the first period of the periodic table. The formula $-N=C$ suggested by Nef involves the conception of bivalent carbon and while this is not impossible, the *iso*cyanides are perhaps hardly reactive enough to justify it.

The development of the electronic theory of valency has suggested a third possibility expressed by the formula $-N \rightrightarrows C$. The carbon atom shares two pairs of electrons with the nitrogen atom and

receives a share of a pair of electrons from it. The formula given below



shows the electronic arrangement, the electrons originally possessed by the isolated C atom being shown thus °.

This theory is supported by the physical properties of the *iso*-cyanides. Measurements of the parachor and the dipole moment of the *iso*cyanides and of the C – N distance (by long X-rays) are in agreement with the latter formula and not with the formula – N=C or any other yet suggested.

148. Structure of Hydrocyanic Acid.—Hydrocyanic acid reacts both as a nitrile and as an *iso*cyanide.

Thus it is formed from ammonium formate (nitrile structure indicated) and from ammonia, chloroform and alcoholic potash (*iso*cyanide structure). Its hydrolysis is inconclusive, as ammonium formate would be produced from both H – N → C and H – C ≡ N. It is probable that it is a tautomeric substance (§ 257) and consists of an equilibrium mixture of both forms,

$$H - C \equiv N \rightleftharpoons H - N \rightarrow C.$$

CYANIC ACID, THIOCYANIC ACID AND THEIR COMPOUNDS

149. Cyanic Acid, Cyanuric Acid and Fulminic Acid.—These acids all have the empirical formula HCNO. As will be seen below, their formulæ are probably:

Cyanic acid, N≡C—OH or possibly H—N=C=O,

Cyanuric acid, $(HCNO)_3$,

Fulminic acid, H—O—N→C.

Cyanuric acid, $C_3N_3O_3H_3$, is obtained by heating urea (§ 312). When the acid is distilled and the vapour condensed in a vessel cooled by a freezing mixture, cyanic acid, CONH, condenses as a liquid of a pungent odour.

It rapidly polymerises to cyanuric acid and cyamelide, which have the same formula $C_3N_3O_3H_3$. The structure of cyanic acid is probably N ≡ C – OH, but it may have the *iso*cyanate formula H – N = C = O.

Potassium cyanate is prepared by oxidising well-cooled potassium cyanide solution with potassium permanganate or by fusing potassium cyanide with lead monoxide or peroxide, or by oxidising potassium ferrocyanide with potassium dichromate.

Ammonium cyanate, NH_4CNO, is of interest as being very readily

changed to urea $(NH_2)_2CO$, which is isomeric with it. The preparation of potassium cyanate and urea is described in § 309, Expt. 70.

By analogy with the cyanides, two different series of alkyl cyanates might be expected to exist. The *normal cyanates* would have the structure $N{\equiv}C-O-R$ while the iso*cyanates* would have the structure $O{=}C{=}N-R$.

There are no normal alkyl cyanates, but *ethyl* iso*cyanate* $C_2H_5-N{=}C{=}O$ is obtained by the action of potassium cyanate on ethyl iodide:

$$C_2H_5I + K-N{=}C{=}O \quad = \quad C_2H_5-N{=}C{=}O + KI.$$

It is a colourless liquid with a suffocating smell. When hydrolysed it gives ethylamine and carbon dioxide, which indicates its structure to be $C_2H_5-N{=}C{=}O$ and not $C_2H_5-O-C{\equiv}N$,

$$C_2H_5{-}N{=}C{=}O \quad = \quad C_2H_5NH_2 + CO_2.$$
$$+ H_2O$$

Fulminic acid is very unstable in the free condition and rapidly polymerises. Its mercury and silver salts are readily prepared, the former being of practical value as a detonating explosive.

Mercury fulminate, $Hg(CNO)_2$, is made by dissolving mercury in nitric acid of suitable concentration, and adding alcohol to the resulting solution of mercuric nitrate in nitric and nitrous acids. A violent reaction ensues and mercury fulminate crystallises out. The preparation is unsuitable for the student.

Mercury fulminate crystallises from hot water in lustrous prisms. It is very sensitive to shock and explodes when heated or struck. The explosion is exceedingly rapid and is most effective in bringing about the detonation of less sensitive explosives such as nitrocellulose or picric acid (§§ 290, 377), and mercury fulminate is therefore much used in percussion caps and detonators.

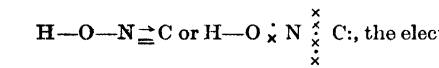
Silver fulminate, Ag·ONC, is made in an analogous manner and is an even more sensitive and dangerous explosive.

The structure of the fulminates has long given rise to dispute. The acid was at first thought to be $H_2O_2N_2C_2$, but several of its reactions indicate the formula HONC to be correct. Conductivity determinations carried out on its solutions show that it is monobasic. For many years the formula HO—N=C, was adopted, the presence of bivalent carbon being assumed. The arguments adduced made it clear that the atoms had the *order* HONC. Thus its formation from the mercury salt of nitromethane:

$$(H_2C{=}NO{\cdot}O)_2Hg \rightarrow (C{=}N-O)_2Hg + H_2O,$$

and several other reactions indicated this formula.

Much doubt has recently been cast on the existence of bivalent carbon. The *iso*cyanides and carbon monoxide, formerly believed to contain bivalent carbon, are now regarded as containing co-ordinate linkages (§ 19) In the same way, it has recently been argued that fulminic acid has the formula



H—O—N⇉C or H—O—N⁝C:, the electrons originally belonging to the nitrogen atom being denoted by ×. This formula explains all the reactions which led to the formula H—O—N=C, and avoids the necessity for postulating bivalent carbon.

150. Thiocyanic Acid and its Derivatives.—*Thiocyanic Acid*, HSCN.—The acid has been isolated but is very unstable.

Potassium thiocyanate, KSCN, is made by fusing potassium cyanide with sulphur. The product is dissolved in alcohol, which leaves behind potassium sulphate, etc., as an insoluble residue.

The thiocyanate is purified by recrystallisation. It forms colourless crystals which are exceedingly soluble in water.

Acids do not liberate thiocyanic acid from it but instead produce oxides of carbon, carbonyl sulphide, sulphur, etc. With ferric salts it forms a deep red solution containing ferric thiocyanate. The reaction is a sensitive test for iron.

Ammonium thiocyanate, $NH_4 \cdot SCN$, can be made by the action of carbon disulphide on ammonia in presence of alcohol:

$$CS_2 + NH_3 = SCNH + H_2S$$
$$SCNH + NH_3 = NH_4 \cdot SCN.$$

It is a very soluble salt much resembling the potassium compound. When heated it behaves analogously to ammonium cyanate, forming thiourea (§ 324):

$$NH_4SCN = NH_2—CS—NH_2.$$

151. Alkyl Thiocyanates and *iso*Thiocyanates—Two series of alkyl compounds of the general formula RCNS exist. The normal thiocyanates have the formula $R-S-C\equiv N$ and the *iso*thiocyanates the formula $R-N=C=S$.

Ethyl thiocyanate, $C_2H_5-S-C\equiv N$, is obtained by the action of potassium ethylsulphate on potassium thiocyanate:

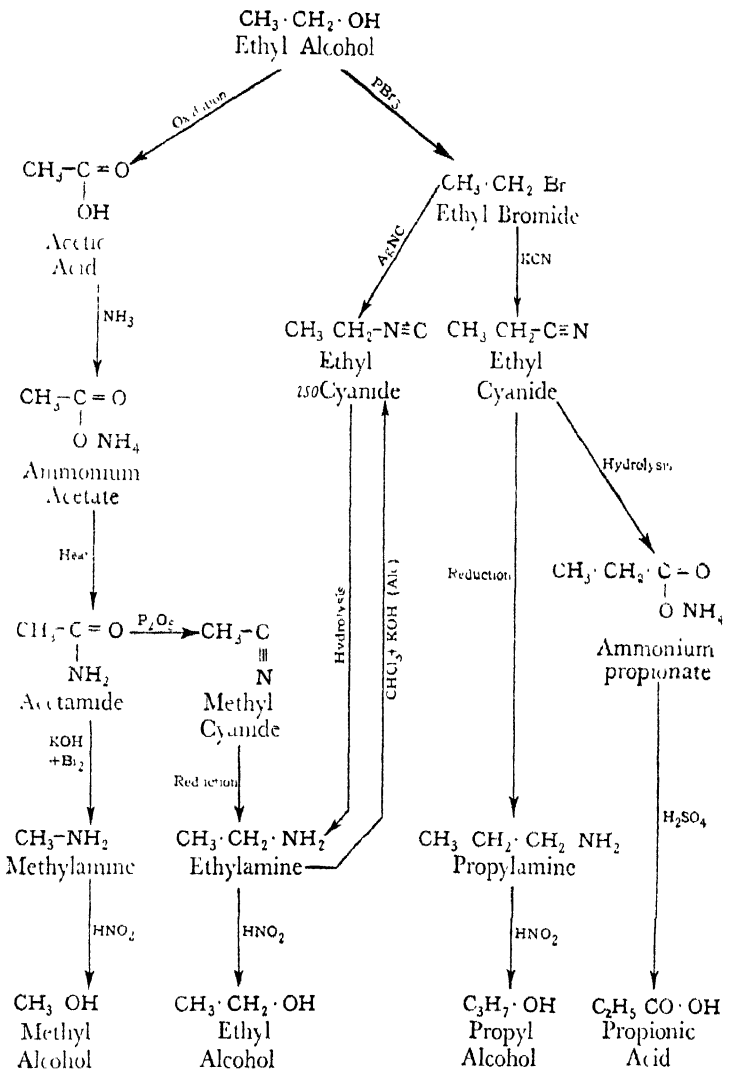
$$KSCN + K(C_2H_5)SO_4 = K_2SO_4 + C_2H_5SCN.$$

It is a liquid with a powerful odour of leeks. Its reduction to ethyl sulphide shows that its formula is $C_2H_5-S-C\equiv N$ and not $C_2H_5-N=C=S$,

$$C_2H_5SCN + 2H = C_2H_5SH + HCN.$$

Ethyl iso*thiocyanate* is obtained by the action of carbon disulphide

SYNTHETIC USE OF NITROGEN COMPOUNDS



on ethylamine, the intermediate compound first formed being decomposed with silver nitrate or mercuric chloride:

$$C_2H_5NH_2 + CS_2 + H_2N{\cdot}C_2H_5 = [C_2H_5{\cdot}NH{\cdot}CS{\cdot}S]^- [H_3N{\cdot}C_2H_5,]^+$$
$$[C_2H_5NH{\cdot}CS{\cdot}S]^- [H_3N{\cdot}C_2H_5]^+ + 2AgNO_3 = C_2H_5NCS + Ag_2S$$
$$+ C_2H_5NH_2 + 2HNO_3.$$

This reaction shows its structure. It has a powerful odour of mustard.

The true mustard oil is *allyl* iso*thiocyanate*, $CH_2{=}CH-CH_2{\cdot}NCS$, and is discussed among the allyl compounds.

152. Use of Nitrogen Compounds in Synthetic Reactions.—The amides, amines and cyanides afford a ready means of converting compounds of a particular alkyl radical (*e.g.*, ethyl) into the compounds of the alkyl radical containing one carbon atom more or less (*e.g.*, propyl or methyl).

Thus, to pass to a higher alcohol from a lower, we may form the halide, convert this into the cyanide, reduce this to the amine and treat this with nitrous acid, thus forming the next higher alcohol.

$$\mathbf{3C_2H_5OH} + PI_3 = 3C_2H_5I + P(OH)_3,$$
$$C_2H_5I + KCN = C_2H_5CN + KI,$$
$$C_2H_5CN + 4H = C_2H_5{\cdot}CH_2{\cdot}NH_2,$$
$$C_2H_5{\cdot}CH_2{\cdot}NH_2 + HO{\cdot}NO = \mathbf{C_2H_5{\cdot}CH_2OH} + N_2 + H_2O.$$

To pass to a lower alcohol we may oxidise the alcohol to an acid, convert this into the amide, treat this with bromine and caustic potash and treat the amine so produced with nitrous acid:

$$\mathbf{C_2H_5{\cdot}OH} + 2O = CH_3{\cdot}CO{\cdot}OH + H_2O,$$
$$CH_3{\cdot}CO{\cdot}OH + NH_3 = CH_3{\cdot}CO{\cdot}O{\cdot}NH_4,$$
$$CH_3{\cdot}CO{\cdot}ONH_4 = CH_3{\cdot}CO{\cdot}NH_2 + H_2O,$$
$$CH_3{\cdot}CO{\cdot}NH_2 + Br_2 + 4KOH = CH_3{\cdot}NH_2 + K_2CO_3 + 2KBr + 2H_2O,$$
$$CH_3{\cdot}NH_2 + HNO_2 = \mathbf{CH_3{\cdot}OH} + N_2 + H_2O.$$

These and other relations between the nitrogen compounds are set out in the diagram on p. 158.

By repeating these series of reactions, it is theoretically possible to make any alkyl compound from any other, but in practice the fact that the yield of product is rarely more than about 70 per cent. of the theoretical makes it difficult and expensive to carry out an extended series of such reactions with the same material.

At this stage it may be well to refer back to the synthetic methods of preparing the paraffins given in § 28, and so to review the methods available for building up any desired alkyl compound.

QUESTIONS

(1) How are cyanogen, hydrocyanic acid and methyl cyanide prepared? How far is the cyanogen radical analogous to a halogen?

(2) What is the relationship between the cyanides and *iso*cyanides? How are acetonitrile and methylcarbylamine prepared, and in what respects do they differ?

(3) What formulæ have the cyanates and *iso*cyanates, the thiocyanates and *iso*thiocyanates? To which of the latter classes do the 'mustard-oils' belong? On what evidence is your opinion based?

(4) How can the nitriles and *iso*cyanides be employed to make:—

(i) Acetic acid from methyl alcohol?

(ii) Ethylamine from acetic acid?

(iii) Ethyl alcohol from methyl alcohol?

(iv) Methyl alcohol from ethyl alcohol?

(5) Explain how the reaction by which *iso*cyanides may be prepared from amines may be used as a test. What class of amines respond to this test?

(6) Explain the reactions used for the detection of cyanides through the formation of Prussian blue.

(7) What are the formulæ of potassium thiocyanate, ferrocyanide, ferricyanide and nitroprusside? Briefly outline their preparation. How can they be distinguished by simple tests?

CHAPTER XII

ALKYL COMPOUNDS OF SULPHUR AND SOME OTHER ELEMENTS

153. Alkyl Compounds containing Sulphur.—The analogy between oxygen and sulphur, the first two members of the sixth group of the Periodic Table, might lead us to expect that a number of the organic compounds which contain oxygen might have analogues containing sulphur. We find in fact that this is the case. Among such compounds are:

Thio-alcohols or mercaptans . . .	R—S—H
Thio-ethers	R—S—R
Thio-ketones	R—CS—R
Thio-acids	R—CS—OH R—CO—SH R—CS—SH
Thio-amides	R—CS—NH_2

The first two of the above classes are of some practical importance.

MERCAPTANS, R—S—H.

Mercaptans may be regarded as thio-alcohols R—S—H, or as hydrogen sulphide in which an alkyl group is substituted for one hydrogen atom.

Just as hydrogen sulphide differs considerably from hydrogen oxide—water—so the mercaptans differ widely from the alcohols.

As an example of a mercaptan we may take ethyl mercaptan, C_2H_5SH.

154. Ethyl Mercaptan, C_2H_5SH, is made by the action of an alcoholic solution of potassium hydrogen sulphide on an ethyl halide:

$$C_2H_5Br + KSH = C_2H_5SH + KBr.$$

This reaction is evidence that the formula C_2H_5SH is the correct one. It can also be made by heating phosphorus pentasulphide with alcohol.

Expt. 44.—*Formation of Ethyl Mercaptan.*—Heat a piece of sulphur the size of a pea, with half as much red phosphorus, in a narrow test-tube. When the residue has solidified add a little

alcohol and heat. The unpleasant smell of ethyl mercaptan is at once apparent.

Properties.—Ethyl mercaptan is a volatile liquid with an exceedingly unpleasant smell recalling both onions and hydrogen sulphide. It boils at 36° C. and is slightly soluble in water.

The mercaptans resemble hydrogen sulphide in that they are very weak acids. They form salts known as mercaptides. Thus, with mercuric oxide ethyl mercaptan forms a white crystalline salt, mercuric mercaptide $Hg(SC_2H_5)_2$. The name mercaptan is derived from the Latin *mercurio aptum*, 'readily combining with mercury.'

Oxidation converts mercaptans into sulphonic acids. Thus nitric acid oxidises ethyl mercaptan to ethane-sulphonic acid (ethyl-sulphonic acid) $C_2H_5{\cdot}SO_3H$:

$$C_2H_5{\cdot}S{\cdot}H + 3O = \begin{matrix} C_2H_5 \\ HO \end{matrix}\!\!>\!S\!<\!\!\begin{matrix} O \\ O \end{matrix}$$

The latter must be distinguished from ethyl-sulphuric acid (ethyl hydrogen sulphate, $C_2H_5{\cdot}HSO_4$, cf. § 93), and also from ethyl hydrogen sulphite, $C_2H_5HSO_3$, with which it is isomeric. Ethane-sulphonic acid differs from the other two in that it is not an ester and is not hydrolysed by solutions of caustic potash.

$C_2H_5{\cdot}O$, HO, S, O, O

Ethyl sulphuric acid.

C_2H_5, HO, S, O, O

Ethane-sulphonic acid.

$C_2H_5{\cdot}O$, HO, S → O

Ethyl hydrogen sulphite.

THIO-ETHERS, R—S—R′.

The thio-ethers may be regarded as ethers in which oxygen is replaced by sulphur, or as hydrogen sulphide in which both hydrogen atoms have been replaced by alkyl groups.

Ethyl sulphide $(C_2H_5)_2S$ may be taken as typical.

155. Ethyl Sulphide, $(C_2H_5)_2S$, is made by the action of ethyl halides on normal potassium sulphide (*v.* Expt. 10 (4)).

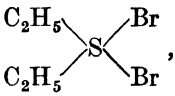
$$2C_2H_5Br + K_2S = (C_2H_5)_2S + 2KBr,$$

or by the action or phosphorus pentasulphide on ethers.

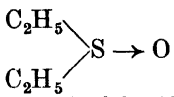
Ethyl sulphide is a liquid of an exceedingly penetrating odour, onion-like and sulphurous. It boils at 91° C. and is almost insoluble in water.

As might be expected the thio-ethers do not show acidic properties. Since sulphur can show a greater valency than two they are readily oxidised.

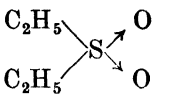
Bromine and ethyl sulphide give a dibromide,



while nitric acid can give two compounds, a *sulphoxide* and a *sulphone*.



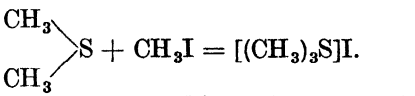
Diethyl sulphoxide.



Ethyl sulphone.

Some of the sulphones are of importance owing to their hypnotic properties (*v.* Sulphonal, *below*).

With the alkyl halides the thio-ethers behave in a similar manner to the tertiary amines (§ 128) forming salts of a *sulphonium base*:

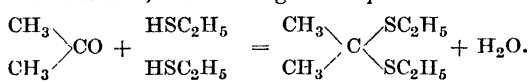


Trimethylsulphonium iodide.

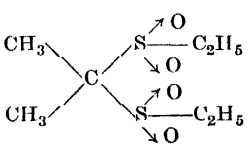
By treating this salt with silver oxide, the very remarkable compound, trimethylsulphonium hydroxide $[(CH_3)_3S]OH$, which is a strong base much resembling caustic potash, is obtained.

Dichlorodiethyl sulphide, $(CH_2Cl{\cdot}CH_2)_2S$, attained importance in the war of 1914–1918 as *mustard-gas*. It is a heavy and not very volatile liquid, the vapour of which causes most violent irritation of the skin, eyes, and lungs.

156. Sulphonal is made by treating a mixture of acetone and mercaptan with hydrochloric acid, thus forming a *mercaptol*:



This latter product is then oxidised by means of potassium permanganate to sulphonal.



It is an excellent hypnotic. The methyl groups may be replaced successively by ethyl, giving the hypnotics *trional* and *tetronal*.

ALKYL COMPOUNDS OF OTHER NON-METALS

Alkyl groups may replace the hydrogen atoms of the hydrides of any of the non-metals. Thus we have the alkyl compounds given in the table below:—

Alkyl compounds.			Corresponding to the hydride.
Primary	Alkyl Phosphines	$PH_2 \cdot CH_3$	PH_3
Secondary		$PH(CH_3)_2$	
Tertiary		$P(CH_3)_3$	
Tertiary Alkyl Arsines		$As(CH_3)_3$	AsH_3
Tertiary Alkyl Stibines		$Sb(CH_3)_3$	SbH_3
Alkyl Silicanes		$Si(CH_3)_4$	SiH_4
Alkyl Boranes		$B(CH_3)_3$	
Alkyl Selenides		$SeH(CH_3)$	SeH_2
		$Se(CH_3)_2$	
Alkyl Tellurides		$TeH(CH_3)$	TeH_2
		$Te(CH_3)_2$	

Few of these are of importance, and only the phosphorus and arsenic compounds require mention here.

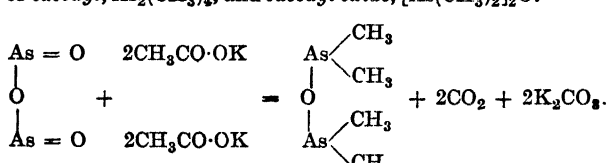
157. Alkyl Phosphines do not resemble the amines very closely, as might be expected from the considerable differences between phosphine and ammonia.

Thus the alkyl phosphines are only very feebly basic. Since phosphorus forms quinquevalent compounds much more readily than does nitrogen, the alkyl phosphines are readily oxidised, forming compounds such as $(CH_3)_3PO$. The alkyl phosphines are highly inflammable liquids of a very powerful stupefying odour.

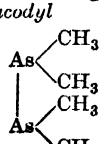
158. Alkyl Arsines.—Several of the organic compounds of arsenic are of value in medicine, but the alkyl arsines and arsonium compounds are all intensely nauseous and poisonous. True primary arsines, *e.g.*, $AsH_2(CH_3)$, are not known, but the compounds $AsCl_2(CH_3)$ and $AsCl(CH_3)_2$ exist.

Trimethyl arsine, $As(CH_3)_3$, is a fuming liquid readily oxidised to a compound $(CH_3)_3As - O$.

159. Cacodyl Compounds.—When a mixture of potassium acetate and arsenic trioxide is distilled, there passes over a spontaneously inflammable fuming liquid, intensely poisonous and of horribly nauseous odour. This is a mixture of *cacodyl*, $As_2(CH_3)_4$, and *cacodyl oxide*, $[As(CH_3)_2]_2O$.



This liquid, when treated with caustic potash solution, gives cacodyl oxide, This compound behaves like a basic oxide, giving salts such as cacodyl chloride, $As(CH_3)_2Cl$. Zinc reduces it to *cacodyl*



a colourless liquid of intensely poisonous character. It is spontaneously inflammable.

Cacodylic acid, $(CH_3)_2As(=O)OH$, is obtained by careful oxidation of cacodyl oxide. It is very much less poisonous than the other cacodyl compounds. Its salts have been used medicinally.

160. Alkyl Compounds of the Metals.—Most of the metals form alkyl compounds which are in most cases volatile and highly reactive liquids. One of them, tetraethyl lead, $Pb(C_2H_5)_4$, has found commercial use as an anti-detonating agent (anti-knock) in petrol, while methylzinc, $Zn(CH_3)_2$, and the alkylmagnesium halides, such as $CH_3{\cdot}Mg{\cdot}I$, are valuable reagents for the synthesis of many organic substances.

161. Methylzinc, zinc methyl, $Zn(CH_3)_2$, is made by the direct action of zinc upon methyl iodide:

$$Zn + CH_3I = CH_3{\cdot}Zn{\cdot}I$$
$$2CH_3{\cdot}Zn{\cdot}I = Zn(CH_3)_2 + ZnI_2.$$

The reaction does not take place very readily. Since zinc methyl inflames spontaneously in air the reaction has to be carried out in an atmosphere of an inert gas. Methyl iodide is heated with zinc filings and sodium amalgam in a flask fitted with a reflux condenser which is isolated from the outer air by a tube dipping under mercury. After 36 hr. the methylzinc is distilled off on an oil-bath. It forms a colourless liquid of very unpleasant odour. It is spontaneously inflammable. Methylzinc reacts with water giving zinc hydroxide and methane:

$$Zn(CH_3)_2 + 2H_2O = Zn(OH)_2 + 2CH_4.$$

Zinc methyl and zinc ethyl (which is made in a similar manner) were formerly much used in organic syntheses, but are now almost entirely replaced by the alkylmagnesium halides or Grignard reagents.

Zinc alkyls may be used to prepare secondary alcohols, tertiary alcohols and ketones, but all these are better prepared by the use of the Grignard reagent, as described below.

GRIGNARD REAGENTS

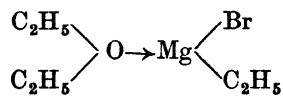
162. Alkylmagnesium Halides.—The alkylmagnesium halides, known as the Grignard reagents (R—Mg—*Ha*), are probably the group of compounds most useful to the organic chemist for the synthesis of new substances.

They are prepared by the action of magnesium ribbon on a

solution of an alkyl halide in ether, all the reagents being very dry. Thus magnesium and ethyl bromide give ethylmagnesium bromide:

$$C_2H_5Br + Mg = C_2H_5—Mg—Br.$$

The ethylmagnesium bromide forms a co-ordinated compound with the ether, probably,



Expt. 45.—*Preparation of Methylmagnesium Iodide.*[1]—Some ether (150 c.c.) is very thoroughly purified and dried. It is best shaken with half its volume of water to remove traces of alcohol, etc., and then left to stand overnight over granulated calcium chloride. The ether is poured into a dry flask fitted with a cork and calcium chloride tube which serves to allow the escape of hydrogen without the entry of moisture. Thin slices of *clean* sodium are dropped into the ether, which is then left till no more gas is evolved. It is then distilled over sodium into a well-dried flask from which moisture is excluded by means of a calcium chloride tube. Some methyl iodide is dried by standing over calcium chloride and then distilled over fresh calcium chloride in the same apparatus as was used for the ether. Magnesium ribbon is made absolutely clean and bright by rubbing first with fine emery paper, then with filter paper and cut into inch lengths. 4 g. of this ribbon are weighed out and put in a flask fitted with reflux condenser; the flask, condenser and cork being thoroughly dry. 25 g. of methyl iodide and 15 c.c. of the dry ether are mixed and poured on to the magnesium. A brisk reaction should occur within a short time. If it does not do so, a small crystal of iodine may be added. The flask may require cooling at first to moderate the reaction, and later may be heated until the whole of the magnesium has dissolved. When this has taken place, add 50 c.c. of dry ether.

The flask now contains a solution of methylmagnesium iodide in ether which should be used at once for Expt. 46: *Synthesis of tertiary butyl alcohol.*

163. Properties of Alkylmagnesium Halides.—The alkylmagnesium halides, as obtained by distillation of their ethereal solutions, are white solids. They are, however, almost always employed in ethereal solution.

[1] This experiment and Expt. 46 which follows from it are best postponed till the student has had a fair experience of practical organic chemistry.

Expt. 46.—*Preparation of Tertiary Butyl Alcohol.*—Dry some acetone over calcium chloride and redistil it in a well-dried apparatus and add to it an equal volume of dry ether. Place the solution of methylmagnesium iodide (prepared in Expt. 45) in a flask and add the acetone-ether mixture to it gradually, shaking occasionally. Let the mixture stand overnight. Add to the resulting solution an equal volume of dilute sulphuric acid and shake well. The solution separates into an upper ethereal layer and a lower aqueous layer, both of which contain the butyl alcohol. Distil the ethereal layer on the water-bath and add any butyl alcohol to the aqueous layer.

Distil this in steam (see § 381, Fig. 53), and collect the first 50 c.c. of distillate. Saturate this with solid potassium carbonate. The tertiary butyl alcohol separates as an upper layer and may be drawn off by means of a separating funnel, dried over quick-lime and redistilled.

The action of carbon dioxide on the Grignard reagent yields a product which with dilute sulphuric acid, gives an *acid*:

$$C_2H_5{\cdot}MgBr + CO_2 = C_2H_5CO{\cdot}O{\cdot}MgBr,$$

$$2C_2H_5CO{\cdot}OMgBr + H_2SO_4 = 2C_2H_5CO{\cdot}OH + MgSO_4 + MgBr_2.$$

164. Tetraethyl lead, $Pb(C_2H_5)_4$ has recently become of importance on account of its antidetonating action on mixtures of inflammable gases and air.

The compressed charge of petrol vapour and air in the cylinders of an internal combustion engine has a tendency to detonate, *i.e.*, explode suddenly and violently, instead of burning steadily and progressively as is desirable. This tendency becomes greater the more highly the charge is compressed. It is, however, desirable to compress the charge highly, for thereby an engine of given cylinder capacity is enabled to take in more fuel and so produce more power. The harmful detonation which would be occasioned by this high compression is prevented by the presence of a small proportion of tetraethyl lead, $Pb(C_2H_5)_4$ (known commercially as ethyl); a small proportion of this (1 : 1000) together with ethylene dibromide, etc. is dissolved in the petrol.

On the commercial scale tetraethyl lead is made by the action of heated and compressed gaseous ethyl chloride on a powdered alloy of sodium and lead:

$$4C_2H_5Cl + 4Na + Pb = Pb(C_2H_5)_4 + 4NaCl.$$

In the laboratory it may be made by the action of ethylmagnesium bromide on lead chloride or bromide:

$$4C_2H_5MgBr + 2PbBr_2 = Pb(C_2H_5)_4 + 4MgBr_2 + Pb.$$

It is a heavy colourless liquid which slowly decomposes when exposed

to light. It is very poisonous, but the fears at first expressed as to the danger of its use in petrol seem to have been unnecessary.

165. Other Metallic Alkyls.—Most metals form alkyl compounds, and the action of the Grignard reagents upon the halide of the metal is the usual method of preparing them.

$$nC_2H_5MgBr + MBr_n = M(C_2H_5)_n + nMgBr_2.$$

Cadmium dimethyl, prepared as above, has gained importance as a more stable substitute for zinc dimethyl.

QUESTIONS

(1) Show how the alkyl groups can replace the hydrogen in the hydrides of most elements. How far do the resulting alkyl-elements resemble the analogous hydrides?

(2) Compare the organic compounds of oxygen and sulphur.

(3) What is sulphonal and how is it prepared commercially?

(4) How are the Grignard reagents prepared and how do they react with water, alcohols, aldehydes and ketones?

(5) How can (1) alcohols (primary, secondary and tertiary), (2) ketones, and (3) hydrocarbons be synthesised by the use of the Grignard reagents?

(6) What is tetraethyl lead? How is it manufactured, and for what purposes is it used?

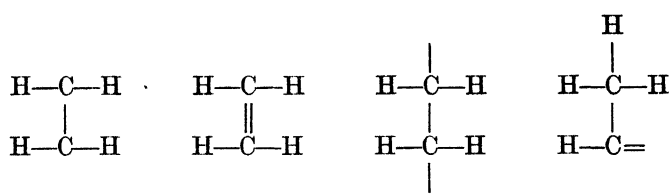
CHAPTER XIII

THE OLEFINE HYDROCARBONS

The series of hydrocarbons known as the paraffins is by no means the only one. Members of another important series—the Olefines—can be obtained from petroleum, by the action of heat on mixtures of alcohols and sulphuric acid, and by several other methods.

These olefine hydrocarbons are found to have the general formula C_nH_{2n}. The simplest is ethylene C_2H_4; no compound CH_2 is known.

166. Structure of the Olefines.—A study of the formulæ of the isomeric paraffin hydrocarbons (*e.g.*, the pentanes), as given in the table in § 23, will convince the student that these exhaust the possibilities of linking quadrivalent carbon and univalent hydrogen in open chains by means of single bonds. The only ways in which we can write the structural formula of ethylene are (*a*) by representing carbon as tervalent or (*b*) by joining the two carbon atoms by a double bond or (*c*) by considering the carbon atoms to have one or more free valency bonds.

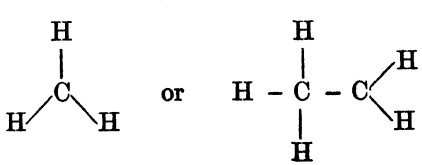


I. Carbon tervalent. II. Double linkage. III., IV. Free valencies.

Possible Structures of Ethylene

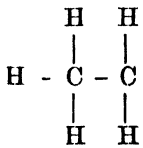
The arguments which lead to accepting Formula II are the following:

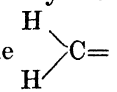
(1) If carbon could be tervalent as well as quadrivalent we should expect compounds such as CH_3 or C_2H_5



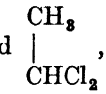
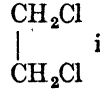
These do not exist. The phenomenon which allows carbon to combine with fewer hydrogen atoms than we should expect from its valency of four, *always affects two carbon atoms at once.* This is not accounted for by the supposition of a possible tervalency for carbon, and Formula I may be ruled out.

The same argument applied to Formula III, for there is no apparent reason why compounds such as

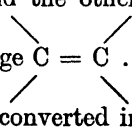
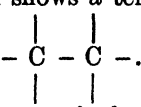


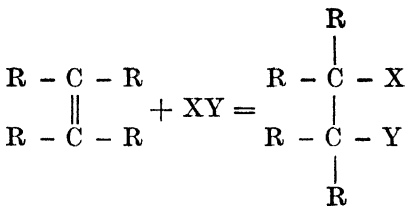
should not exist, if unsaturation is due to the existence of free valencies. In the same way if Formula IV were the true one, we should expect methylene  to exist.

(2) A valency of three is not found in any of the other elements of Group IVB of the Periodic Table, and is therefore unlikely in carbon. This is also an argument against Formula I.

(3) Formula IV would lead us to expect that the reaction of, say, chlorine with ethylene would yield a compound  , ethylidene chloride (§ 60), whereas in fact ethylene chloride  is produced. This rules out Formula IV.

(4) The isomerism of unsaturated compounds, *e.g.*, fumaric and maleic acid (*q.v.*, § 217), is accounted for by the double linkage formula but not by the hypothesis of tervalent carbon or the free valency theory.

It is believed, then, that ethylene and the other 'unsaturated' compounds allied to it, contain the linkage  . This grouping is reactive and shows a tendency to be converted into the normal single linkage  . This can be brought about by combination with two univalent atoms or groups, and accordingly the characteristic reactions of the unsaturated compounds are additive. In general terms their chief reaction is:



Unsaturated. Saturated.

The term 'unsaturated,' applied to the olefines and their derivatives and some other compounds, implies that the carbon atoms in them are not exerting all their power of combination with other elements, and that consequently the compound containing them can combine with other elements or compounds *additively*.

Thus we call carbon monoxide unsaturated because it can take up chlorine directly and additively, $CO + Cl_2 = COCl_2$. We call methane saturated because it will not add on any other atoms, but must react by *substitution*, one atom being removed to make room for another:

$$CH_4 + Cl_2 = CH_3Cl + HCl.$$

167. The Olefines. List and Nomenclature.—The olefine hydrocarbons are given the name of the paraffin hydrocarbon having the same number of carbon atoms, with the substitution of the termination *-ene* for *-ane*. Thus the hydrocarbon $C_{10}H_{20}$ is called *decene*. The lower members are also given names compounded of the corresponding alkyl radical and the termination *-ene*. Thus the hydrocarbon C_3H_6 is commonly called *propylene* and not *propene*.

The various isomerides with the same number of carbon atoms are distinguished by a number preceding the name and indicating which bond, counting from one end, is doubled. Branches are indicated by the alkyl group they contain, and a number indicating the carbon atom from which they branch. Thus the hydrocarbon

$$\overset{1}{CH_3} - \overset{2}{CH_2} - \overset{3}{CH} = \overset{4}{CH} - \overset{5}{CH_2} - \overset{6}{CH_3}$$

is called 3-hexene. In a branched-chain compound, the longest carbon chain is always taken as the fundamental hydrocarbon from which the systematic name is derived.

$$\overset{1}{CH_3} - \overset{2}{CH_2} - \overset{3}{CH}\begin{cases} \overset{4}{CH_2} - \overset{5}{CH} = \overset{6}{CH} - \overset{7}{CH_2} - \overset{8}{CH_3} \\ CH_2 \cdot CH_3 \end{cases}$$

is called 3-ethyl-5-octene, or sometimes 3-ethyl-Δ^5-octene, the Greek letter Δ indicating the double linkage.

Greek letters may also replace the numbers. Thus the hydrocarbon mentioned above might be called γ-ethyl-ϵ-octene.

The following table shows the formulæ, names and boiling points of a few typical olefine hydrocarbons:—

C_2H_4	Ethylene	Ethene	.. b.p.	−103° C.
C_3H_6	Propylene	Propene	.. „	48°
C_4H_8	Butylene	Butene	.. „	−5°
C_5H_{10}	Amylene	Pentene	.. „	39°
$C_{10}H_{20}$	Decylene	Decene	.. „	172°
$C_{30}H_{60}$	Melene	Tricosene	.. m.p.	62°

The possibilities of isomerism among them are very similar to those of the paraffin series. Thus we can theoretically have five different pentenes of formula C_5H_{10}.

1-pentene . . . . $CH_2 = CH - CH_2 - CH_2 - CH_3$

2-pentene . . . . $CH_3 - CH = CH - CH_2 - CH_3$

2-methyl-2-butene . . $(CH_3)_2C = CH - CH_3$

2-methyl-1-butene . . $CH_2 = C(CH_3) - CH_2 - CH_3$

3-methyl-1-butene . . $CH_3 - CH(CH_3) - CH = CH_2$

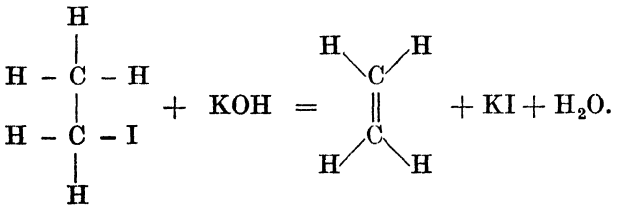
As typical of the olefine series of hydrocarbons we may take the gas ethylene, C_2H_4.

168. Ethylene, C_2H_4.—Ethylene may be prepared:

(1) By the action of dehydrating agents on alcohols. Sulphuric acid and phosphoric acid are commonly used as dehydrating agents (Expt. 47), while passing the vapour over heated alumina or thoria is also effective:

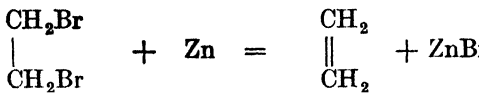
$$C_2H_6O = C_2H_4 + H_2O.$$

(2) By the action of alcoholic potash on an ethyl halide. Aqueous alkalis convert alkyl halides into alcohols (§ 58), but alcoholic potash appears to remove a molecule of halogen acid without substituting hydroxyl. Thus ethyl iodide and alcoholic potash give ethylene:

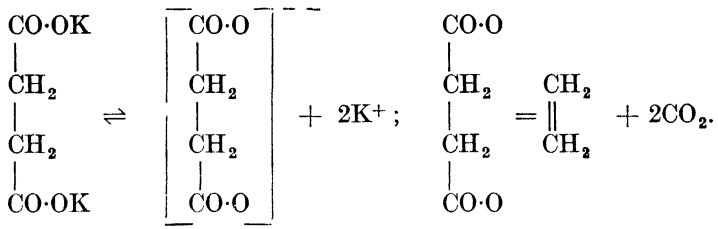


This is a valuable method for making all substances containing a double linkage.

(3) Pure ethylene may be prepared by warming an alcoholic solution of ethylene dibromide with granulated zinc:



(4) The electrolysis of salts of succinic acid yields ethylene. The method is analogous to the preparation of ethane by electrolysis of acetates.



(5) Ethylene is used commercially for preparing ethylene chlorohydrin (§ 190) and glycol (§ 188). It is obtained from natural gas, from alcohol or by the cracking of petroleum.

Expt. 47.—*Preparation of Ethylene from Alcohol and Sulphuric Acid.*—A capacious flask (1½—2 litres) is fitted with a thermometer and tap-funnel and supported on a sand-bath. An exit tube is connected to a wash bottle containing concentrated potash; from this a delivery tube passes to a pneumatic trough (Fig. 32). 50 c.c. of ethyl alcohol are mixed with 100 c.c. of concentrated sulphuric acid and 7·5 g. of anhydrous aluminium sulphate are added. The latter substance checks the frothing which is otherwise troublesome and much increases the yield of ethylene. On heating to 160° C. ethylene is formed, together with a good deal of sulphur dioxide, ether vapour, etc. The passage of the gas through concentrated potash removes sulphur dioxide, carbon dioxide, etc. The gas is collected over water in the usual manner. If more gas is required, a mixture of equal volumes of alcohol and concentrated sulphuric acid is added from the dropping funnel.

Several jars full of the gas should be collected. The gas in one should be burned and the bright smoky flame noted. To another, two or three drops of bromine may be added and the jar closed. In the course of some minutes the colour of the bromine will disappear and a few drops of a heavy liquid insoluble in water (ethylene dibromide) will be produced. A third jar may be shaken with acidified potassium permanganate solution when the gas will be seen to be oxidised. Note that none of these reactions was given by methane in Expt. 1.

Physical Properties of Ethylene.—Ethylene is a colourless gas with a faint sweetish smell. It acts as an anæsthetic and has been used for this purpose. Ethylene is of almost the same density as air. It is sparingly soluble in water.

Chemical Properties.—Ethylene burns in air with a bright smoky flame. It burns also in chlorine with a reddish flame, forming

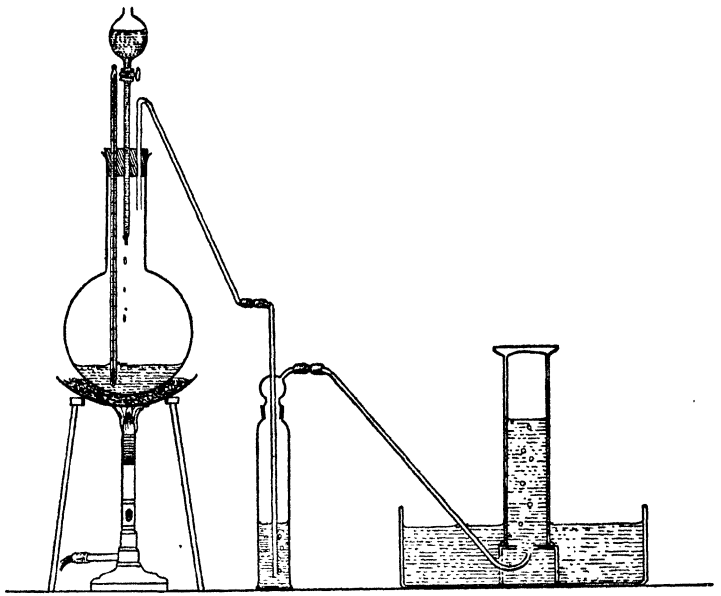


FIG. 32.—Preparation of Ethylene.

hydrogen chloride and free carbon. The most important reactions of ethylene are *additive* and of the type

$$\begin{matrix} H-C-H \\ \| \\ H-C-H \end{matrix} + AB = \begin{matrix} CH_2A \\ | \\ CH_2B \end{matrix}$$

Thus it reacts additively with hydrogen in presence of a suitable catalyst, with chlorine, bromine, hydrogen iodide and fuming sulphuric acid. Similar behaviour is shown by all substances containing the double bond.

With hydrogen, ethane is formed in presence of suitable catalysts.

$$\begin{matrix} CH_2 \\ \| \\ CH_2 \end{matrix} + H_2 = \begin{matrix} CH_3 \\ | \\ CH_3 \end{matrix}$$

If a mixture of ethylene and hydrogen is passed over heated

metallic nickel or spongy platinum, the ethylene is completely converted into ethane. Nickel is peculiarly active and has been used for bringing about many reductions with hydrogen which could hardly be accomplished otherwise (cf. § 170a).

Chlorine and bromine react directly with ethylene. If chlorine be mixed with ethylene and the mixture exposed to light, drops of a colourless oily liquid, ethylene chloride, 'Dutch liquid,' are deposited. The original but now obsolete name for ethylene—'olefiant gas'—was taken from this property.

$$\begin{matrix}CH_2\\\|\\CH_2\end{matrix} + Cl_2 = \begin{matrix}CH_2Cl\\|\\CH_2Cl\end{matrix}$$

The preparation of ethylene bromide

$$\begin{matrix}CH_2Br\\|\\CH_2Br\end{matrix}$$

by passing ethylene into bromine is described in Expt. 48.

Hydrogen chloride reacts hardly at all with ethylene, and hydrogen bromide but slowly. Hydrogen iodide readily forms ethyl iodide:

$$\begin{matrix}CH_2\\\|\\CH_2\end{matrix} + HI = \begin{matrix}CH_3\\|\\CH_2I\end{matrix}$$

Fuming sulphuric acid forms various products with ethylene, chief of which is ethyl hydrogen sulphate:

$$\begin{matrix}CH_2\\\|\\CH_2\end{matrix} + H_2SO_4 = \begin{matrix}CH_3\\|\\CH_2{\cdot}HSO_4\end{matrix}$$

The latter reaction is used in gas analysis for separating unsaturated hydrocarbons from saturated hydrocarbons, which are not affected by cold fuming sulphuric acid.

Ethylene is at once oxidised by dilute potassium permanganate and gives a *dihydric* alcohol, glycol.

$$\begin{matrix}CH_2 + H_2O\\\|\\CH_2 + O\end{matrix} = \begin{matrix}CH_2OH\\|\\CH_2OH\end{matrix}$$

Glycol.

169. Ethylene dibromide, $C_2H_4Br_2$, has been mentioned in Chapter IV, § 60. Its preparation is, however, more conveniently described here.

Expt. 48.—*Preparation of Ethylene Dibromide.*—Ethylene dibromide is prepared by passing ethylene into liquid bromine.

For this experiment the ethylene may be conveniently prepared from alcohol and phosphoric acid.

The apparatus shown in Fig. 33 is set up. In a capacious flask (1 litre) is placed 120 g. of syrupy phosphoric acid previously heated in an evaporating dish to 220° C. in order to remove water. The tap-funnel, which has its stem drawn to a point, contains alcohol. The stem is filled with alcohol by sucking the latter up from a porcelain dish. The Woulff's bottle contains concentrated potash, and in each of the two wash bottles are placed about 25 c.c. of bromine covered by about 1 cm. depth of water.

The flask is heated, and when the thermometer reaches 210°

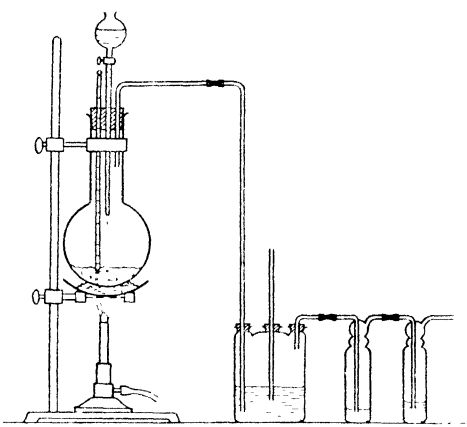


FIG. 33.—Preparation of Ethylene Dibromide.

—220° C. the alcohol is allowed to drop in a little at a time. The ethylene is bubbled through the bromine until the colour of the latter has almost disappeared (*ca.* 4 hr.). The ethylene bromide left in the wash bottles is purified by the method adopted for ethyl bromide in Expt. 7.

Properties.—Ethylene dibromide is a colourless liquid with a pleasant smell, boiling at 131·6° C. It is heavier than water (sp. gr. 2·21 0°/4° C.), in which it is almost insoluble.

Ethylene dibromide has most of the properties of a paraffin halide (§ 58). When heated with water under pressure to 150°—160° C., or when boiled with dilute potassium carbonate it yields glycol (§ 188):

$$\begin{matrix} CH_2{\cdot}Br \\ | \\ CH_2{\cdot}Br \end{matrix} + 2H_2O = \begin{matrix} CH_2OH \\ | \\ CH_2OH \end{matrix} + 2HBr.$$

The action of zinc gives ethylene [§ 168 (3)]. Alcoholic potash removes HBr and forms first vinyl bromide, then acetylene:

$$\begin{array}{l} CH_2{\cdot}Br \\ | \\ CH_2{\cdot}Br \end{array} + KOH = \begin{array}{l} CH_2 \\ \| \\ CHBr \end{array} + KBr + H_2O,$$

$$\begin{array}{l} CH_2 \\ \| \\ CHBr \end{array} + KOH = \begin{array}{l} CH \\ \| \\ CH \end{array} + KBr + H_2O.$$

The action of alcoholic potassium cyanide gives ethylene cyanide:

$$\begin{array}{l} CH_2{\cdot}Br \\ | \\ CH_2{\cdot}Br \end{array} + 2KCN = \begin{array}{l} CH_2{\cdot}CN \\ | \\ CH_2{\cdot}CN \end{array} + 2KBr.$$

170. The Higher Olefine Hydrocarbons.—These may be prepared by modifications of the same methods as are used for ethylene. The higher members are liquids or solids but in their chemical properties they are very similar to ethylene.

Amylene is readily obtained by the action of zinc chloride or somewhat diluted sulphuric acid on commercial amyl alcohol. It has been used for making tertiary amyl alcohol.

170a. Hydrogenation.—Almost every unsaturated compound can be made to combine with hydrogen and form the corresponding saturated compound:

$$X-CH=CH-Y + H_2 = X-CH_2-CH_2-Y$$

This very important reaction may be brought about:—

(1) By passing a mixture of hydrogen and the vapour of the substance over finely divided nickel, which acts as a catalyst. (Sabatier-Senderens reaction, cf. § 333.)

(2) By passing hydrogen, either at atmospheric or higher pressure, into a mixture of the liquid or dissolved substance with a metallic catalyst—nickel, palladium black, platinum black. The latter two catalysts are usually effective at atmospheric pressure (cf. § 196).

UNSATURATED COMPOUNDS

The *vinyl* and *allyl* compounds are considered in this chapter, also oleic acid. The important unsaturated alcohols and aldehydes geraniol, citral, etc., are considered in Chapter XXIX, with the terpenes from which they are derived.

171. Vinyl Compounds.—Numerous other compounds besides hydrocarbons contain a double linkage between carbon atoms. If an atom of hydrogen in ethylene is replaced by a univalent atom or group A, we obtain a compound $\begin{array}{l} H-C-A \\ \| \\ H-C-H \end{array}$. The radical C_2H_3- or $CH_2=CH-$ is called *vinyl*. Vinyl halides,

such as vinyl chloride, $\begin{matrix}CHCl\\ \|\\ CH_2\end{matrix}$, are known, also vinyl ethyl ether $CH_2=CH-O-C_2H_5$, but vinyl alcohol $\begin{matrix}CH(OH)\\ \|\\ CH_2\end{matrix}$ does not exist, and all the reactions which might be expected to yield it give acetaldehyde $\begin{matrix}CHO\\ |\\ CH_3\end{matrix}$ which is isomeric with it.

Alcohols of the type $R-CH=CH(OH)$ are not known, though many alcohols exist in which a double bond links carbon atoms which are not linked to hydroxyl, *e.g.*, allyl alcohol, $CH_2=CH-CH_2OH$.

Vinyl bromide, $CH_2=CHBr$, may be made by the regulated action of alkalis on ethylene dibromide

$$\begin{matrix}CH_2Br\\ |\\ CH_2Br.\end{matrix} + KOH = \begin{matrix}CH_2\\ \|\\ CHBr\end{matrix} + KBr + H_2O.$$

172. Allyl Compounds.—Several important compounds are derived from the radical $-CH_2-CH=CH_2$, known as *allyl*. Thus we have

$\begin{matrix}CH_3\\ |\\ CH\\ \|\\ CH_2\end{matrix}$ Allene (Propylene). $\quad$ $\begin{matrix}CH_2Br\\ |\\ CH\\ \|\\ CH_2\end{matrix}$ Allyl bromide. $\quad$ $\begin{matrix}CH_2\cdot OH\\ |\\ CH\\ \|\\ CH_2\end{matrix}$ Allyl alcohol. $\quad$ $\begin{matrix}CHO\\ |\\ CH\\ \|\\ CH_2\end{matrix}$ Allyl aldehyde (Acrolein).

$\begin{matrix}CO\cdot OH\\ |\\ CH\\ \|\\ CH_2\end{matrix}$ Acrylic acid. $\quad$ $\begin{matrix}CH_2-S-CH_2\\ |\quad\quad |\\ CH\quad\quad CH\\ \|\quad\quad \|\\ CH_2\quad\quad CH_2\end{matrix}$ Allyl sulphide (Oil of garlic). $\quad$ etc.

The name *Propenyl* is given to the isomeric radical $-CH=CH-CH_3$. Propenyl compounds are not however of much importance.

173. Allyl Alcohol, C_3H_6O.—Allyl alcohol is usually made by the action of glycerol on oxalic acid or formic acid at 220° C. A little ammonium chloride is usually added.

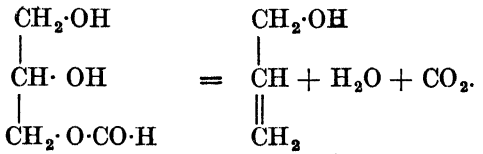
It will be remembered that formic acid is made by the action of oxalic acid on glycerol at about 100—110° C. In both reactions the first two stages are the same—the formation of glycerol mono-oxalate and its decomposition to glycerol monoformate.

$$CH_2(OH)-CH(OH)-CH_2\cdot OH + H_2C_2O_4 = CH_2(OH)-CH(OH)-CH_2-HC_2O_4 + H_2O$$

Glyceryl mono-oxalate.

$$CH_2(OH)-CH(OH)-CH_2\cdot O\cdot CO\cdot CO\cdot OH = CH_2(OH)-CH(OH)-CH_2\cdot O\cdot CO\cdot H + CO_2$$

Glyceryl formate.

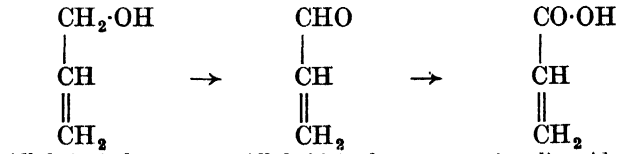


Allyl alcohol.

Expt. 49.—*Preparation of Allyl Alcohol.*—A distilling flask is connected to a Liebig condenser and receiver, and a thermometer (0—360° C.) is so arranged as to dip into the liquid contents. In the flask are placed 200 g. of glycerol, 50 g. of powdered crystallised oxalic acid and 0·5 g. of ammonium chloride. The mixture is distilled slowly. The liquid distilling between 200° C. and 260° C. is collected. It is redistilled from a small flask, the portion boiling below 105° C. being collected. It is allowed to stand first over potassium carbonate and then over solid caustic potash. It is then finally redistilled. Yield, about 7 g. The product may be compared with ordinary alcohol and will be found to differ in its ready decolorisation of bromine.

Properties.—Allyl alcohol is a colourless mobile liquid with an unpleasant suffocating odour. It boils at 97° C. It is miscible with water.

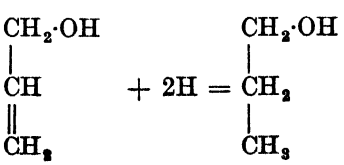
Allyl alcohol has the properties both of a primary alcohol and of an unsaturated compound. Thus it yields esters with acids and when vigorously oxidised gives an aldehyde (acrolein) and finally an acid. Since it can give an aldehyde it must have the hydroxyl group at the end of the chain of carbon atoms.



Allyl alcohol. Allyl aldehyde (Acrolein). Acrylic acid.

The above reactions are typical of a primary alcohol. Allyl alcohol behaves as an unsaturated compound in its reactions with hydrogen, chlorine and bromine.

When the vapour of allyl alcohol is mixed with hydrogen and passed over heated metallic nickel, normal propyl alcohol is formed:



With bromine dibromopropyl alcohol is produced:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH \\ \| \\ CH_2 \end{array} + Br_2 = \begin{array}{l} CH_2{\cdot}OH \\ | \\ CHBr \\ | \\ CH_2Br \end{array}$$

Expt. 50.—*Reactions of Allyl Alcohol.*—(1) Note smell.

(2) To 2 drops of allyl alcohol add 2 c.c. acidified potassium dichromate solution. Warm. Acrolein is evolved with an irritating odour of burnt fat.

(3) To a drop of allyl alcohol add bromine water, which is instantly decolorised.

(4) Pour ½ c.c. of allyl alcohol on a little powdered phosphorus pentasulphide (if not available, see Expt. 44). Heat. Note powerful odour of garlic, due to allyl sulphide.

174. Allyl halides are not prepared by the methods adopted for the ethyl halides, for the allyl compounds are converted into propyl derivatives by halogens (except iodine) and hydrogen halides (except hydrogen chloride). Allyl iodide is made by the action of phosphorus and iodine on glycerol.

175. Allyl sulphide, $(C_3H_5)_2S$, is an important substance as being the essential flavouring and odoriferous matter in onions and garlic. It can be made synthetically from allyl iodide and potassium sulphide (cf. § 154).

176. Allyl *iso*thiocyanate, $C_3H_5{\cdot}NCS$, is *oil of mustard*. Mustard seeds contain a glucoside (§ 273), sinigrin, which is apparently a compound of potassium hydrogen sulphate, glucose and allyl *iso*thiocyanate. Thus the seeds do not contain free mustard oil. When the seeds are crushed and moistened, an enzyme *myrosin* brings about the decomposition of the sinigrin, and the pungent oil is liberated:

$$KS_2NC_{10}H_{18}O_{10} = KHSO_4 + C_6H_{12}O_6 + C_3H_5{\cdot}NCS.$$

Allyl mustard oil is a liquid of the strong odour and taste familiar in mustard. It raises blisters on the skin.

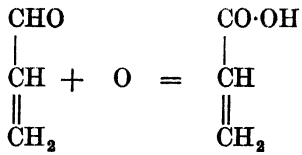
'Mustard gas' is not a mustard oil but is dichlorodiethyl sulphide (§ 155): the name was given to the substance on account of its mustard-like odour.

177. Acrolein, Allyl aldehyde, $CH_2{=}CH-CHO$. Acrolein is readily prepared by the action of heat upon glycerol. If glycerol is distilled with anhydrous magnesium sulphate or potassium hydrogen sulphate, a good yield is obtained:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}OH \end{array} = \begin{array}{l} CHO \\ | \\ CH \\ \| \\ CH_2 \end{array} + 2H_2O.$$

It may also be made by oxidising allyl alcohol

Acrolein is a colourless liquid of unpleasant and pungent odour. Its vapour is painful to the eyes. The unpleasant odour of burnt fat is due to acrolein. The fat contains glycerol (§ 192) and the decomposition of this yields acrolein. It is a volatile substance boiling at 52° C. It has the usual reactions of an aldehyde (§ 70), and also those of an unsaturated compound. Oxidation converts it into acrylic acid:



It readily polymerises to a white substance 'disacryl.'

178. Acrylic acid, $CH_2{=}CH-CO{\cdot}OH$, much resembles propionic acid. It reacts, however, with bromine in the usual manner of unsaturated compounds. Nascent hydrogen reduces it to propionic acid.

179. Oleic Acid.—A large number of unsaturated acids are known, but the only one of any considerable importance is oleic acid $C_{18}H_{34}O_2$, which has the structural formula

$$CH_3-(CH_2)_7-CH{=}CH-(CH_2)_7-CO_2H.$$

Oleic acid is important because its glyceryl ester, glyceryl trioleate, $C_3H_5(C_{18}H_{33}O_2)_3$, is the chief constituent of fatty oils, *e.g.*, olive oil almond oil, and is also contained in the softer fats, lard, etc.

Oleic acid is best made from tallow by boiling with caustic potash and so obtaining a solution of a soap—potassium oleate (§ 198). Lead acetate is added, thus giving insoluble lead oleate together with the lead salts of other fatty acids. The lead oleate is dissolved in ether in which the lead salts of other fatty acids are insoluble. The lead salt is then decomposed by hydrochloric acid, giving lead chloride and oleic acid.

It forms a colourless, tasteless and odourless liquid which freezes below 14° C. It is readily oxidisable in air, forming a yellow liquid of unpleasant 'rancid' odour. It may be reduced to stearic acid (§ 192) by the action of hydrogen and finely divided metallic nickel. This important process is known as the *hydrogenation* of oils, and is discussed in § 196.

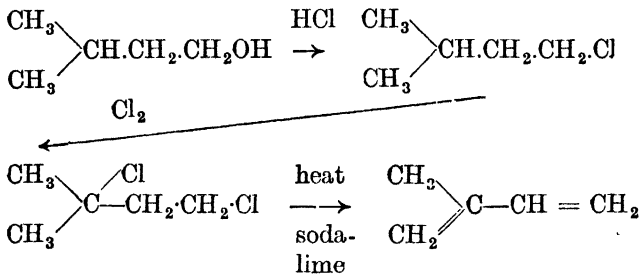
OTHER HYDROCARBONS CONTAINING DOUBLE LINKAGES

Many of the cyclic hydrocarbons, such as benzene, naphthalene, etc., contain double linkages. These are discussed in Part II.

Straight-chain hydrocarbons containing more than one double bond are known. An example of these which is of interest is *isoprene* C_5H_8, β-methylbutadiene:

$$CH_2 = \overset{\displaystyle CH_3}{\overset{|}{C}} - CH = CH_2.$$

180. Isoprene, C_5H_8.—This hydrocarbon can be made by distilling rubber, or synthetically. Its chief interest is that, on keeping, it polymerises to a mass identical in composition with and very closely resembling pure rubber Isoprene is commonly made from fusel-oil, *iso*Amyl alcohol (§ 51), by treatment with hydrogen chloride, chlorinating the product and treating with soda-lime



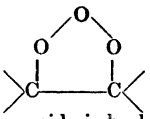
Isoprene when heated with sodium polymerises to a mass of the synthetic rubber known as buna-rubber.

Chloroprene, *B*-chlorbutadiene, polymerises about 700 times as fast as isoprene, giving a rubber-like product which has advantages over natural rubber in that it does not perish through oxidation, is not permeable to gases and is not dissolved or swelled by petrol. It is made by polymerising acetylene by passing it over a calcium chloride and ammonia catalyst and treating the product with hydrogen chloride.

$$2HC \equiv CH \longrightarrow CH_2 = \underset{\displaystyle H}{\overset{|}{C}} - C \equiv CH \xrightarrow{HCl} CH_2 = CH - \underset{\displaystyle Cl}{\overset{|}{C}} = CH_2$$

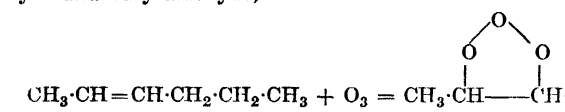
Several other types of synthetic rubber are in production. Synthetic rubbers, alone or mixed with natural rubber, are harder wearing and more chemically resistant than the latter, though in normal times more costly.

Isoprene is also to be regarded as the parent substance of the group of *terpenes*, considered in Chapter XXIX.

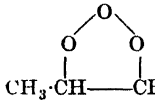
181. Ozonides.—The formation of an ozonide by ethylene has already been mentioned. All compounds with ethylenic linkages $\rangle C = C \langle$ form ozonides  , which are usually solid explosive compounds. When an ozonide is hydrolysed it breaks at the linkage to which the oxygen atoms are attached, usually forming two aldehydes and hydrogen peroxide.

By identifying these aldehydes, the position of the double bond can be ascertained.

Thus β-hexene would give an ozonide which would break up into acetaldehyde and butyraldehyde,

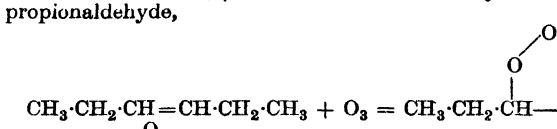


$$CH_3{\cdot}CH{=}CH{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3 + O_3 = CH_3{\cdot}CH\text{——}CH{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3.$$

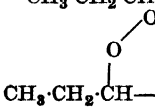


$$CH_3{\cdot}CH\text{——}CH{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3 + H_2O =$$
$$CH_3{\cdot}CHO + CHO{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3 + H_2O_2.$$

On the other hand, γ-hexene treated in this way would give two molecules of propionaldehyde,



$$CH_3{\cdot}CH_2{\cdot}CH{=}CH{\cdot}CH_2{\cdot}CH_3 + O_3 = CH_3{\cdot}CH_2{\cdot}CH\text{——}CH{\cdot}CH_2{\cdot}CH_3$$



$$CH_3{\cdot}CH_2{\cdot}CH\text{——}CH{\cdot}CH_2{\cdot}CH_3 + H_2O =$$
$$CH_3{\cdot}CH_2{\cdot}CHO + CHO{\cdot}CH_2{\cdot}CH_3 + H_2O_2.$$

THE ACETYLENE SERIES OF HYDROCARBONS C_nH_{2n-2}

182. Structure of Acetylene.—The gas acetylene, which is made from calcium carbide and water, has the formula C_2H_2. For reason similar to those which have led to the adoption of the formula $H_2C{=}CH_2$ for ethylene, the formula $H-C{\equiv}C-H$ has been given to acetylene.

Compounds containing the group $-C{\equiv}C-$ show the phenomena of unsaturation even more definitely than those containing the double bond $-C{=}C-$, and in addition to their unsaturated character they are markedly unstable.

183. Nomenclature of the Acetylene Hydrocarbons.—The systematic name of these hydrocarbons is derived from that of the paraffin hydrocarbon with the same number of carbon atoms by substituting the termination *-ine* for *-ane*. Thus acetylene C_2H_2 would be called *ethine* on this system. The position of the triple

linkage is indicated by a number or a Greek letter. The only hydrocarbon of importance containing a triple linkage is acetylene itself.

184. Acetylene, Ethine, C_2H_2.—*Preparation.*—(1) Acetylene has been synthesised by striking an electric arc between carbon poles in an atmosphere of hydrogen; it is also formed when hydrocarbons burn in a poor supply of air. The smell of acetylene is readily perceptible when a Bunsen burner 'strikes back' and the gas burns in the tube.

(2) The method ordinarily employed is the action of water upon calcium carbide, CaC_2. The latter substance is made by heating coke and lime in an electric furnace:

$$CaO + 3C = CaC_2 + CO$$
$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2.$$

These reactions afford us one of the few methods available for making organic compounds directly from carbon.

In the laboratory the apparatus shown in Fig. 34 is conveniently used. A layer of sand is placed on the bottom of a conical flask and on this rest lumps of calcium carbide. Water is allowed to drip slowly on to this, and acetylene, contaminated with a little phosphine, hydrogen sulphide, etc., is evolved. It may be washed with an *acid* solution of cupric sulphate, which removes both of the above impurities. Though somewhat soluble, the gas may be collected over water.

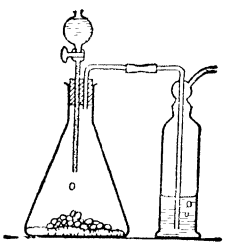


FIG. 34.—Preparation of Acetylene.

On the commercial scale acetylene is also prepared from calcium carbide, but more elaborate generators are employed in which the carbide falls into a large excess of water, or in which the water rises to meet the carbide (as in a Kipp's apparatus). The impurities are removed by various purifying agents, such as acidified copper salts, hypochlorites, etc.

(3) Acetylene can also be made by the action of alcoholic potash on ethylene dibromide:

$$\begin{matrix} CH_2Br \\ | \\ CH_2Br \end{matrix} + 2KOH = \begin{matrix} CH \\ \| \\ CH \end{matrix} + 2KBr + 2H_2O.$$

Physical Properties.—Acetylene is a colourless gas, which when impure has a strong and unpleasant garlic-like smell. When the gas is purified the smell becomes less objectionable. It is somewhat poisonous and has been used as an anæsthetic.

Acetylene is liquefied without difficulty by cooling and pressure. The liquid is explosive (*v. supra*) and the liquefied gas cannot be stored safely. For storage purposes it is dissolved under pressure in acetone, which is contained in steel cylinders packed with some porous material.

Chemical Properties.—Acetylene is an *endothermic* compound. A molecule of acetylene has considerably more energy than the molecules of carbon and hydrogen of which it is composed. Accordingly it is very easily decomposed and very reactive. Thus the violent shock brought about by exploding silver fulminate in the gas is enough to cause its decomposition. The liquid or the compressed gas is still more readily decomposed and several dangerous explosions have resulted from their use. The violence of the explosion is only due to the heat energy liberated and not to volume change:

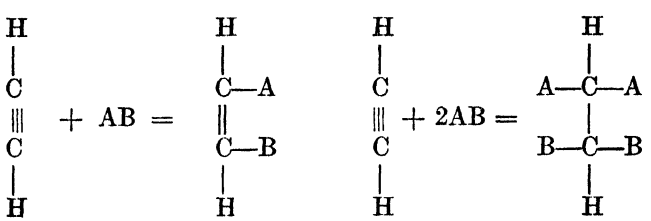
$$\underset{1\text{ vol.}}{C_2H_2} = 2C + \underset{1\text{ vol.}}{H_2} + 56{,}000\text{ cals.}$$

When acetylene is passed through a red-hot glass tube, benzene is formed, $3C_2H_2 = C_6H_6$, and when it is heated in presence of finely divided metals a great number of different hydrocarbons, ethylene ethane, benzene, etc., are produced.

Acetylene burns in air or oxygen with a very bright and smoky flame. It is occasionally used as an illuminating gas, and for that purpose is burned at jets designed at once to draw air into the flame and to give a very thin flame which presents a large surface to the air. In this way the carbon is completely burned to carbon dioxide and no smoke is evolved.

Industrially, much acetylene is used in the oxy-acetylene blowpipe for welding. This type of blowpipe is so constructed that it is easy to regulate the supply of the two gases in such a way as to obtain an intensely hot flame, which in its interior has an excess of acetylene and therefore has reducing powers—a most valuable property for the purpose of welding metals.

Acetylene combines additively with hydrogen, the halogens, hydrogen halides, oxidising agents, etc., forming both (I) ethylene and (II) ethyl compounds:



I. II.

When a mixture of acetylene and hydrogen is passed through a heated tube containing certain finely divided metals (nickel, copper iron, etc.) it is reduced to ethylene, ethane, and other hydrocarbons:

$$\begin{matrix}CH\\|||\\CH\end{matrix} + H_2 = \begin{matrix}CH_2\\\|\\CH_2\end{matrix}, \qquad \begin{matrix}CH\\|||\\CH\end{matrix} + 2H_2 = \begin{matrix}CH_3\\|\\CH_3\end{matrix}$$

A mixture of chlorine and acetylene ignites spontaneously, often with explosion, hydrogen chloride and carbon being produced.

With bromine acetylene combines less vigorously. When acetylene is passed into bromine water, the compound acetylene dibromide is produced.

$$\begin{matrix}CH\\|||\\CH\end{matrix} + Br_2 = \begin{matrix}CHBr\\\|\\CHBr\end{matrix}$$

When acetylene is passed into bromine the main product is acetylene tetrabromide:

$$\begin{matrix}CH\\|||\\CH\end{matrix} + 2Br_2 = \begin{matrix}CHBr_2\\|\\CHBr_2\end{matrix}$$

With hydrobromic acid it forms vinyl bromide:

$$\begin{matrix}CH\\|||\\CH\end{matrix} + HBr = \begin{matrix}CH_2\\\|\\CHBr\end{matrix}$$

and with hydriodic acid it forms ethylidene iodide:

$$\begin{matrix}CH\\|||\\CH\end{matrix} + 2HI \qquad \begin{matrix}CH_3\\|\\CHI_2\end{matrix}$$

Acetylene combines directly with water in presence of mercuric salts forming acetaldehyde (*q.v.*, § 67, and Expt. 16):

$$\begin{matrix}CH\\|||\\CH\end{matrix} + H_2O = \begin{matrix}CH_3\\|\\CHO\end{matrix}$$

The compounds of acetylene with the metals are of interest. When it is passed into an ammoniacal solution of cuprous chloride, a red precipitate of cuprous acetylide is produced:

$$Cu_2Cl_2 + C_2H_2 + H_2O = Cu_2C_2{\cdot}H_2O + 2HCl.$$

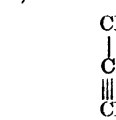
The formation of this red precipitate affords a useful test for acetylene. Silver produces a yellowish-white precipitate of a similar structure.

These acetylides, when dry, explode if struck or heated. When treated with dilute acids they evolve acetylene once more, and this reaction has been used for preparing pure acetylene. Copper acetylide seems to be formed when acetylene remains in contact with copper or brass and moisture for long periods. Several explosions which have occurred when old acetylene generators have been broken up, have been attributed to the formation of this substance.

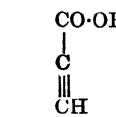
185. Other Hydrocarbons of the Acetylene Series.—Allylene (*Propine*), $CH_3-C \equiv CH$, much resembles acetylene. *Dipropargyl*, C_6H_6, $CH \equiv C-CH_2-CH_2-C \equiv CH$, is of interest as being isomeric with the important compound benzene. It bears little or no resemblance to benzene (*v.* § 338).

Hexa-$\Delta^{\alpha\epsilon}$*-diene-*Δ^{γ}*-inene*, $H_2C = CH-C \equiv C-CH = CH_2$, is also isomeric with benzene. It has the properties of both an olefine and an acetylene hydrocarbon.

186. Derivatives of the Acetylene Hydrocarbons.—Alcohols, acids, etc., derived from acetylene and its homologues are known. They have the properties of unsaturated substances and also of their characteristic groups (alcohols, acids, etc.). As examples we may mention



Propargyl alcohol.



Propiolic acid.

They have no practical importance.

QUESTIONS

(1) What is the meaning of the term *unsaturated* as applied to an organic compound? What reactions are characteristic of such compounds?

(2) What structural formula do we assign to ethylene? What alternative formulæ could be written and in what respects are they unsatisfactory?

(3) How many compounds are there of formula C_5H_{10}? Suggest methods by which a given specimen of a pure liquid hydrocarbon of the above formula could be identified as one of the above compounds.

(4) Describe the preparation of a specimen of pure ethylene. How would you distinguish your product from (1) ethane; (2) acetylene?

(5) How is allyl alcohol made? What evidence is there (1) that it contains a double linkage; (2) that it is a primary alcohol?

(6) How is pure acetylene made? What are its most important chemical properties and uses?

(7) Compare the reactions of ethane, ethylene and acetylene with the common non-metallic elements.

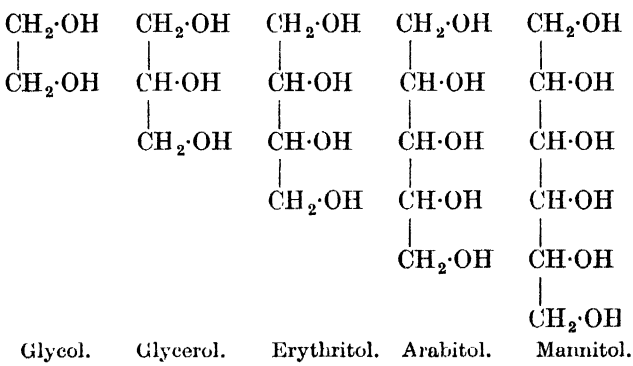
(8) Limonene, a cyclic hydrocarbon of formula $C_{10}H_{16}$, reacts with bromine without evolution of HBr and forms a bromide containing 70·2 per cent. bromine. How many ethylenic linkages are present in a molecule of limonene?

(9) What methods are available for (*a*) introducing, (*b*) removing double or treble linkages in an organic compound? How may the number and positions of such linkages be ascertained?

CHAPTER XIV

POLYHYDRIC ALCOHOLS

187. List and Nomenclature.—In addition to the alcohols containing one hydroxyl group and already discussed in Chapter III and §§ 33–53, compounds are known which contain from two to six hydroxyl groups substituted in a paraffin hydrocarbon residue. These are called polyhydric alcohols. As examples we may mention:



Glycol. Glycerol. Erythritol. Arabitol. Mannitol.

The most important of these is the second, glycerol.

The examples given all have special names, but systematic names are also given, based on the hydrocarbon from which they are derived, with numbers showing the positions of the hydroxyl groups, and prefix showing number of hydroxyl groups and the termination *-ol*, denoting an alcohol. Thus the compound

$CH_3 \cdot CH_2 \cdot CH(OH) \cdot CH_2 \cdot OH$ called butane-1 : 2-diol.

DIHYDRIC ALCOHOLS

The only dihydric alcohol which need be considered here is

ethylene glycol or ethanediol, $\begin{matrix} CH_2 \cdot OH \\ | \\ CH_2 \cdot OH \end{matrix}$

188. Glycol, Ethylene Glycol, Ethanediol, $\begin{matrix} CH_2 \cdot OH \\ | \\ CH_2 \cdot OH \end{matrix}$ **.**—*Preparation*—

Glycol is made in the laboratory by the action of water or alkaline solutions on ethylene dibromide (§ 169):

$$\begin{array}{l}CH_2{\cdot}Br\\ |\\ CH_2{\cdot}Br\end{array} + 2H_2O \rightleftharpoons \begin{array}{l}CH_2{\cdot}OH\\ |\\ CH_2{\cdot}OH\end{array} + 2HBr.$$

The action is slow, and a more rapid method is to treat the dibromide with silver acetate and hydrolyse the di-ester with alkali under a reflux condenser.

$$\begin{array}{l}CH_2{-}Br\\ |\\ CH_2{-}Br\end{array} \xrightarrow{AgAc} \begin{array}{l}CH_2{-}O{\cdot}CO{\cdot}CH_3\\ |\\ CH_2{-}O{\cdot}CO{\cdot}CH_3\end{array} \xrightarrow{NaOH} \begin{array}{l}CH_2{\cdot}OH\\ |\\ CH_2OH.\end{array}$$

Ethylene bromide is heated under a reflux condenser with a 14 per cent solution of potassium carbonate. When the reaction is complete the solution is slowly evaporated and shaken with a mixture of alcohol and ether in which glycol is soluble. The solvents are distilled off, leaving the glycol.

Alternatively the ethylene bromide may be heated to 100° C. in a sealed tube with a considerable excess of water for a long period (five days) and the glycol recovered as above.

It is now prepared commercially. Ethylene, made from alcohol or from natural gas or by the cracking of petroleum, is treated with chlorine water, the ethylene being in excess. Ethylene chlorohydrin $HO{\cdot}CH_2{\cdot}CH_2{\cdot}Cl$ is thus formed. This is boiled with milk of lime and gives glycol and calcium chloride.

Physical Properties.—In its physical properties glycol is quite unlike the monohydric alcohols. It is a colourless and odourless liquid of a syrupy consistency. It has a sweet taste. Its boiling point is high, 197° C., and it is heavier than water (1·117, 15°/15°) with which it is miscible. It dissolves in alcohol but hardly at all in ether.

Chemical Properties.—Glycol resembles the ordinary monohydric alcohols in most of its properties.

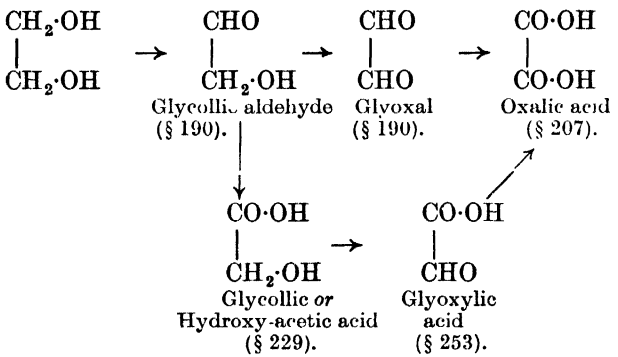
Acids convert it into esters, either one or both hydroxyl groups being replaced. Thus hydrochloric acid gives first ethylene chlorohydrin and then at higher temperatures ethylene dichloride:

$$\begin{array}{l}CH_2{\cdot}OH\\ |\\ CH_2{\cdot}OH\end{array} + HCl = \begin{array}{l}CH_2{\cdot}Cl\\ |\\ CH_2{\cdot}OH\end{array} + H_2O$$

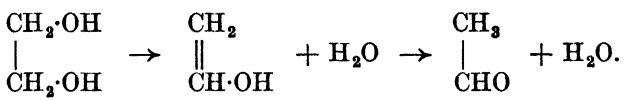
$$\begin{array}{l}CH_2{\cdot}Cl\\ |\\ CH_2{\cdot}OH\end{array} + HCl = \begin{array}{l}CH_2{\cdot}Cl\\ |\\ CH_2{\cdot}Cl\end{array} + H_2O.$$

In the same way a mono-acetate and di-acetate can be made. When it is treated with sodium, sodium glycols, exactly analogous to sodium ethoxide (§ 42), are formed.

Oxidation proceeds in the same way as with the monohydric alcohols, aldehydes and then acids being formed. But since each $-CH_2{\cdot}OH$ group can be oxidised separately five different compounds can be formed. The scheme below shows the oxidation products, and gives references to the paragraph of this book in which they are considered.



The action of some dehydrating agents (*e.g.*, zinc chloride) converts glycol into acetaldehyde. Possibly an unsaturated alcohol is first formed:



189. Structure of Glycol.—That glycol has the formula $\begin{matrix}CH_2{\cdot}OH\\|\\CH_2{\cdot}OH\end{matrix}$ is clear (1) from its reaction with phosphorus trichloride to form ethylene dichloride $\begin{matrix}CH_2{\cdot}Cl\\|\\CH_2{\cdot}Cl\end{matrix}$, (2) from its oxidation to hydroxyacetic acid, which is shown to be $\begin{matrix}CH_2{\cdot}OH\\|\\CO{\cdot}OH\end{matrix}$ by its formation from chloro-acetic acid $\begin{matrix}CH_2{\cdot}Cl\\|\\CO{\cdot}OH\end{matrix}$, obtained from acetic acid and chlorine.

190. Derivatives of Glycol.—*Glycol chlorohydrin*, $HO{\cdot}CH_2-CH_2{\cdot}Cl$, also known as ethylene chlorohydrin, is made by passing hydrogen chloride gas into warm glycol. It is a liquid boiling at 130° C.

In addition to having the reactions both of a halide and of an alcohol, it can be converted into the interesting *internal ether* ethylene oxide.

Ethylene Oxide.—When glycol chlorohydrin is distilled with caustic potash solution, ethylene oxide is evolved and may be condensed to a liquid boiling at 13·5° C:

$$\begin{matrix}CH_2\cdot OH\\ |\\ CH_2Cl\end{matrix} + KOH = \begin{matrix}H_2C\\ |\ \ \diagdown\\ H_2C\ \ \ O\end{matrix} + KCl + H_2O.$$

It is a reactive substance. With water, it slowly forms glycol:

$$\begin{matrix}CH_2\\ |\ \ \diagdown\\ CH_2\ \ \ O\end{matrix} + H_2O = \begin{matrix}CH_2\cdot OH\\ |\\ CH_2\cdot OH\end{matrix}$$

and with hydrochloric acid it gives the chlorohydrin.

Glycollic Aldehyde, $\begin{matrix}CHO\\ |\\ CH_2\cdot OH\end{matrix}$. When glycol is gently oxidised, glycollic aldehyde is first formed. It is a liquid which has the properties of an aldehyde and an alcohol.

Glyoxal, $\begin{matrix}CHO\\ |\\ CHO\end{matrix}$, is formed when acetaldehyde, ethylene or ethyl alcohol is gently oxidised by means of selenium dioxide. It is a yellowish-green gas which polymerises almost at once to a liquid trimeric form $\left[\begin{matrix}CHO\\ |\\ CHO\end{matrix}\right]_3$ Glyoxal is of interest as being the simplest coloured compound of carbon, hydrogen and oxygen.

Dimethylglyoxime, $\begin{matrix}CH_3-C=N\cdot OH\\ |\\ CH_3-C=N\cdot OH\end{matrix}$, is the oxime of 'dimethylglyoxal,' which is the diketone, diacetyl, $CH_3\cdot CO\cdot CO\cdot CH_3$. It is prepared by oxidising methyl ethyl ketone with nitrous acid and treating the product with hydroxylamine.

$$CH_3\cdot CH_2\cdot CO\cdot CH_3 \rightarrow CH_3-\underset{\underset{NOH}{\|}}{C}-CO-CH_3 \rightarrow CH_3-\underset{\underset{N\cdot OH}{\|}}{C}-\underset{\underset{N\cdot OH}{\|}}{C}-CH_3$$

Dimethylglyoxime is important as a reagent for nickel salts, with which gives a scarlet precipitate.

Glycol dinitrate, $\begin{matrix}CH_2\cdot NO_3\\ |\\ CH_2\cdot NO_3\end{matrix}$, has attained some importance as an explosive. It is obtained by the action of nitric acid upon glycol. It is similar in properties to 'nitroglycerine' (*q.v.* § 202), but is safer, since it does not readily freeze.

The ethylene dihalides have already been considered (§ 169). From them it is possible to prepare numerous compounds which may be regarded as derivatives of glycol, notably the *diamines*.

191. The diamines are compounds containing two amino-groups. Many of them are found in the products of animal putrefaction.

Ethylenediamine, $\begin{matrix}CH_2\cdot NH_2\\ |\\ CH_2\cdot NH_2\end{matrix}$, can be made by the action of ammonia on ethylene dibromide (cf. § 120). It is a liquid boiling at 123° C. It has the properties of a primary amine.

Tetramethylenediamine, $\begin{matrix}CH_2-CH_2-NH_2\\ |\\ CH_2-CH_2-NH_2\end{matrix}$, has been made by converting ethylene bromide into ethylene cyanide (cf. § 144), and reducing this with sodium and alcohol:

$$\begin{matrix}CH_2\cdot Br\\ |\\ CH_2\cdot Br\end{matrix} \xrightarrow{KCN} \begin{matrix}CH_2\cdot CN\\ |\\ CH_2\cdot CN\end{matrix} \xrightarrow{8H} \begin{matrix}CH_2\cdot CH_2\cdot NH_2\\ |\\ CH_2\cdot CH_2\cdot NH_2.\end{matrix}$$

It is contained in putrefying flesh, as is also *pentamethylenediamine*, $NH_2\cdot CH_2\cdot CH_2\cdot CH_2\cdot CH_2\cdot NH_2$. These and similar compounds are called ptomaines (*πτῶμα, ptoma*, a corpse). They arise from the action of bacteria on some of the aminoacids, of which the complex protein molecules of the body are built up. Thus *lysine* can lose carbon dioxide and form pentamethylene diamine

$$NH_2\cdot CH_2\cdot CH_2\cdot CH_2\cdot CH(NH)_2CO\cdot OH = NH_2\cdot CH_2\cdot CH_2\cdot CH_2\cdot CH_2\cdot NH_2 + CO_2.$$

They are not for the most part very poisonous, and the so-called ptomaine poisoning which follows the eating of bad tinned meat, etc., is caused by other poisonous bacterial products.

GLYCEROL, OILS, FATS AND SOAPS

Since glycerol is an essential constituent of and is chiefly made from fixed oils and fats, it is necessary to understand the nature of these important substances before considering the preparation and properties of glycerol.

192. Fixed Oils and Fats.—Fixed oils[1] and fats occur in the great majority of living organisms. The most notable sources are:

(1) *Seeds of plants* from which are derived such important oils as linseed oil, tung oil, cotton-seed oil, olive oil, castor oil, palm oil, coconut oil, cocoa-butter, etc.

(2) *Tissues of Animals.*—From marine animals oils of many kinds are derived, *e.g.*, fish oils, cod-liver oil, and most important, whale oil. From terrestrial animals solid fats are derived, notably lard, tallow, butter, etc.

All these substances have in common the property of being converted by the action of alkalis into glycerol and a soap, *i.e.*, the salt of an organic acid, usually of high molecular weight. This makes it clear that oils and fats are *esters of the alcohol glycerol.*

Glycerol can be shown (§ 200) to have the constitution $\begin{matrix}CH_2\cdot OH\\ |\\ CH\cdot OH\\ |\\ CH_2\cdot OH\end{matrix}$

[1] As distinguished from 'essential oils' (esters and terpenes), also from mineral oils (hydrocarbons).

and oils and fats therefore have the constitution $\begin{matrix}CH_2\cdot\bar{A}\\|\\CH\cdot\bar{A}\\|\\CH_2\cdot\bar{A}\end{matrix}$ where $\bar{A}$ is an organic acid radical.

Thus *tristearin*, one of the chief constituents of beef tallow, is the glyceryl ester of stearic acid $C_{17}H_{35}\cdot CO\cdot OH$, and has the formula:

$$\begin{matrix}CH_2\cdot O\cdot CO\cdot C_{17}H_{35}\\|\\CH\cdot O\cdot CO\cdot C_{17}H_{35}\\|\\CH_2\cdot O\cdot CO\cdot C_{17}H_{35}.\end{matrix}$$

In addition to the usual term tri-stearin, this fat may be called *glyceryl tri-stearate* or the *tri-glyceride of stearic acid.*

The three acid radicals attached to the glyceryl radical need not be identical. Thus di-palmito-stearin is a common constituent of fats:

$$\begin{matrix}CH_2\cdot O\cdot CO\cdot C_{15}H_{31}\\|\\CH\cdot O\cdot CO\cdot C_{15}H_{31}\\|\\CH_2\cdot O\cdot CO\cdot C_{17}H_{35}\end{matrix}$$

Dipalmitostearin.

The fats, then, are compounds of glycerol and various organic acids. These may be fatty acids or unsaturated acids. The glycerides of saturated acids are chiefly found in solid fats, while those of unsaturated acids are chiefly found in oils. A remarkable fact, not fully explained, is that the acids contained in these fats always have an even number of carbon atoms.

CHIEF COMPOUNDS CONTAINED IN OILS AND FATS

Glycerides of			Chiefly found in
Fatty acids	Lauric acid	$C_{11}H_{23}\cdot CO_2H$	Coconut oil.
	Palmitic acid	$C_{15}H_{31}\cdot CO_2H$	Solid animal fats.
	Stearic acid	$C_{17}H_{35}\cdot CO_2H$	,, ,, ,,
Unsaturated acids with one double bond.	Oleic acid	$C_{17}H_{33}\cdot CO_2H$	Olive oil and most other oils and soft fats.
	Erucic acid	$C_{21}H_{41}\cdot CO_2H$	Rape oil, fish oils.
Unsaturated acids with more than one double bond.	Linoleic acid	$C_{17}H_{31}\cdot CO_2H$	Linseed oil.
	Linolenic acid	$C_{17}H_{29}\cdot CO_2H$	, ,,

193. Waxes.—The waxes are a group of substances somewhat resembling the fats in physical properties. Their chief constituents are esters of the higher fatty acids with alcohols of high molecular weight. Thus beeswax contains a large proportion of the ester myricyl palmitate, $C_{30}H_{61}\cdot O\cdot CO\cdot C_{15}H_{31}$.

Spermaceti, obtained from the head of the sperm whale, is mainly cetyl palmitate, $C_{16}H_{33}\cdot O\cdot CO\cdot C_{15}H_{31}$.

Waxes are obtained from many plants and are of much use in making polishes, etc.

The waxes then are esters of higher primary alcohols, while the fats are esters of glycerol.

194. Extraction of Oils and Fats.—The sources, composition and uses of some of the most important oils and fats are described in the table given below. The composition of oils and fats is usually complex, so that the third column is only an indication of the chief glycerides present.

IMPORTANT OILS AND FATS

Oil or Fat.	Source.	Chief Constituents are Glycerides of	Uses.
Linseed	Seed of flax.	Linolenic acid (unsat.)	Paint, varnish, linoleum.
Cottonseed	Seeds of cotton plant.	P, O, Linoleic acid (unsat.)	Food, soap.
Arachis	Ground nuts.	O, Arachidic acid	Food, soap.
Olive	Olives.	O	Food, soap, lubricant.
Cocoa-butter	—	S, O, L, M, etc.	Chocolate.
Palm	Oil-palm kernels.	O, S, P, M, L, etc.	Candles, soap.
Coconut	Copra.	M, L, etc.	Food, soap, candles.
Cod-liver	Liver of codfish.	S, O, M, P, and others.	Medicine, leather.
Whale	Blubber of whale.	P, Clupanodonic acid (unsat.).	Burning, soap, hydrogenation for margarine.
Lard	Kidney fat of pig.	O, S, P	Food, soap.
Tallow	Fat of beef and mutton.	S, O, P	Food, soap, candles.
Butter	Milk fat.	P, O, Butyric acid, etc.	Food.

O = Oleic acid (unsat.).
L = Lauric acid.
M = Myristic acid.
P = Palmitic acid.
S = Stearic acid.

The oils and fats in an animal or plant tissue are contained in cells which prevent their escape. The various methods of extraction are designed to break the cell wall and cause the oil (or melted fat) to exude.

Oil-seeds are commonly ground to a rough meal, packed in linen bags and subjected to a pressure of 300 atmospheres or more in hydraulic presses. The best oil exudes at this stage, but a further yield of second-quality oil is obtained by heating the residue and again pressing it. More oil exudes and a 'cake' is left which is often used for feeding cattle.

The 'cake' retains some oil which may be extracted with a solvent.

Animal fats are usually obtained by 'rendering.' The fatty tissues are chopped into little pieces and boiled with water. The fat melts and floats to the top of the water while the membranous portions sink.

195. Milk and butter are exceptional in character. Milk consists of minute globules of fat suspended in a watery solution containing proteins (casein), salts, etc. When this is violently agitated, as in a

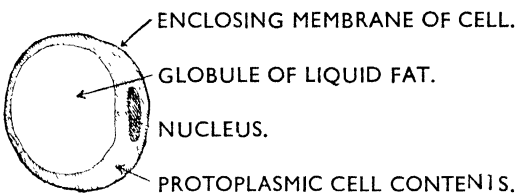


FIG. 35.—Fat Cell, diagrammatic.

churn, the globules of fat are brought into contact and form butter The watery solution is pressed from the fat as far as possible.

The fat of butter contains chiefly the glycerides of palmitic and oleic acid. It differs from other fats in containing a proportion of the glyceride of butyric acid, $C_3H_7{\cdot}CO_2H$. The genuineness of butter is commonly tested by the Reichert Wollney process, which consists in converting a known weight of it into a soap by heating it with caustic soda and distilling this soap with dilute sulphuric acid. Butyric acid passes over and is titrated, while non-volatile acids of high molecular weight remain behind. A deficiency of butyric acid is to be attributed to adulteration with other fats.

Margarine is a mixture of fats, etc., intended to simulate butter as nearly as possible. A fat is prepared which may contain some 25 per cent of hardened fat and 75 per cent of coconut oil, or may be compounded from animal fats. Skimmed milk is carefully soured to the desired extent and is violently churned with the melted fat. The emulsion is suddenly cooled and worked like butter to the desired consistency. Margarine is a valuable food, but lacks the vitamin content of butter unless vitamins have been added.

196. Properties and Uses of Fats and Oils.—*Physical Properties.*—Mixtures of glycerides which are liquid below 20° C. are called oils, and those solid above 20° C. are called fats. Oils and fats are usually light-coloured, and are colourless or white when pure. The oils and fats derived from saturated acids are tasteless; the characteristic flavours of fats being due, as a rule, to volatile non-fatty substances. Their melting points range from about 50° C. downwards but no natural oil or fat has a sharp melting point, for all are complex mixtures. None of them boils without decomposition at atmospheric pressure. They may, however, be distilled *in vacuo*.

Fats and oils are insoluble in water, but soluble in all ordinary organic solvents. Ether is much used in the laboratory as a solvent for fats. For dry-cleaning, which depends mainly on the removal of oils and fats, carbon tetrachloride or ligroin (petroleum ether) is used.

Chemical Properties.—When heated to about 300° C. oils and fats decompose, giving off irritating vapours which contain *acrolein* (§ 177).

The oils containing unsaturated acids, *e.g.*, linseed oil, are slowly oxidised in air and become converted into hard waterproof substances. These oils are valuable as a basis for paints. Compounds of certain metals, notably the borates of lead and manganese, catalyse the oxidation and are added to paints as *driers*.

In presence of moisture the fats are slowly decomposed, chiefly by the action of bacteria, which, like the animal digestive system, produce substances, *lipases*, capable of catalysing the hydrolysis of fats. Glycerol and free acids are produced and an unpleasant 'rancid' taste develops.

The fats containing unsaturated acids may be reduced to the saturated condition by the action of hydrogen in presence of metallic nickel. Unsaturated oils for which there may be no great demand and oils which are inedible on account of their unpleasant odour, may be thus converted into hard fats useful for margarine manufacture. The oil is mixed with finely divided metallic nickel and heated to 140–200° C. Hydrogen is passed through it and converts the double linkages into single ones:

$$\ldots\ldots - CH = CH - \ldots + H_2 = \ldots - CH_2 - CH_2 - \ldots\ldots$$

The nickel is recovered by filtration.

The action of water at high temperatures, of mineral acids and of alkalis hydrolyses fats (§ 197) to glycerol and acids. If the hydrolysis is carried out by boiling with alkali, the acids so produced react with it to form soaps. This process is of enormous industrial importance.

197. Saponification of Fats.—*Saponification* as a chemical term is used to denote the hydrolysis of any ester to an alcohol and a fatty acid or its salt. The term is derived from the Latin *sapo*, soap, and was originally applied to the conversion of a fixed oil or fat (ester of glycerol) into glycerol and a soap (salt of one of the higher acids).

Soaps.—The soaps are the salts of certain organic acids of high molecular weight. While soaps can be made from any metal, the sodium and potassium salts are the only soluble ones and therefore the only soaps useful for washing purposes. The sodium salts constitute hard soap and the potassium salts soft soap. The chief fats used in the manufacture of soap are coconut, olive and palm oil and various animal fats. The soaps prepared from these are mixtures containing sodium laurate, palmitate, stearate, oleate, etc.

The value of soaps for cleansing purposes depends on the peculiar character of their solutions. A solution of a soap is intermediate between a colloid and a crystalloid and appears to contain large aggregates of ions associated as a charged group known as a micelle. Its cleansing power seems to be due firstly to its low surface tension, which enables it to wet greasy surfaces, and possibly also to the formation of a 'colloidal adsorption compound' with the dirt which is thus kept suspended in solution.

The stearates, palmitates, oleates, etc., of most metals are insoluble and therefore useless for washing. Lead soaps, however, have found certain uses. Lead plaster, *emplastrum plumbi*, is made by heating oil with finely divided lead oxide and water. It forms an adhesive mass, used as a plaster in medicine. Magnesium oleate is dissolved in the inflammable solvents used in dry cleaning. Its relatively good conductivity prevents the accumulation of statical electricity induced by friction and thereby does away with the danger of the solvent being ignited by an electric spark. Other metallic soaps are used in varnishes.

198. Manufacture of Soap.—Three chief methods are in use, of which only one can here be considered in detail.

(1) Fats are hydrolysed to glycerol and fatty acid by means of steam in presence of a catalyst (lime, etc.). The melted fatty acids are then run into a strong solution of alkali.

$$C_3H_5(O{\cdot}CO{\cdot}C_{15}H_{31})_3 + 3H_2O = C_3H_5(OH)_3 + 3C_{15}H_{31}{\cdot}CO_2H$$
$$C_{15}H_{31}{\cdot}CO_2H + NaOH = C_{15}H_{31}{\cdot}CO_2Na + H_2O.$$

(2) Coconut oil (which is very easily saponified) is mixed with the exact quantity of warm 30 per cent. caustic soda needed to convert it into soap. Perfume, etc., is stirred in and the mass left to set.

The resulting soap contains the glycerol, which in this process cannot be recovered. The following equation for the process

$$C_3H_5(C_{11}H_{23}\cdot CO\cdot O)_3 + 3NaOH = 3C_{11}H_{23}\cdot CO_2\cdot Na + C_3H_5(OH)_3$$

represents coconut oil as the glyceride of lauric acid—one of its chief constituents. Soft soaps are made from caustic potash and fats by a similar process, though in this case boiling for a considerable time is required. Soft soap sets to a jelly and does not crystallise or form a true solid.

(3) The most important process consists of saponifying the fat with weak alkali, precipitating the soap with salt, drawing off the lyes containing the glycerol and boiling the soap once more with some strong caustic soda.

(i) The melted fats are run into a pan capable of holding 10—30 tons of material and a solution of 10 per cent. caustic soda is added. The mixture is boiled and agitated by means of steam, more alkali being added from time to time:

$$C_3H_5(O\cdot CO\cdot C_{17}H_{35})_3 + 3NaOH = C_3H_5(OH)_3 + 3C_{17}H_{35}\cdot CO_2Na.$$

(ii) The resulting mixture is boiled and salt is added. Soap, being insoluble in salt solution, separates and floats to the surface as a granular curdy mass. The remaining liquor, a solution of salt and glycerol, is drawn off, and the glycerol recovered from it (§ 199).

(iii) The separated soap still contains some fat and it is boiled with successive portions of strong caustic soda solution till saponification is complete. The soap, which is insoluble in cold concentrated alkalis, is then allowed to rise to the surface of the liquid. It may be used in this condition for household purposes, etc. If toilet soap is required, it is partly dried, mixed with colours, perfumes, glycerol, etc., and stamped into tablets.

Expt. 51.—*Preparation of Soap.*—Weigh out 30 g. of lard, melt it in a large evaporating dish and add 60 c.c. of 10 per cent. caustic soda solution. Heat on a sand tray, stirring well and boiling gently. Replenish the water evaporated and continue the heating till all the melted fat has disappeared. Pour the resulting solution into a beaker and add an equal volume of saturated salt solution. The soap will separate and form a cake on the surface of the liquid.

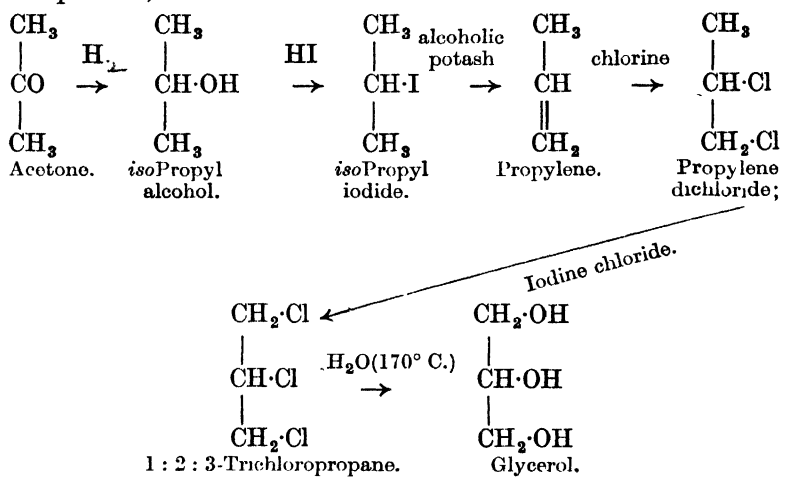
199. Manufacture of Glycerol.—(1) *Manufacture of Glycerol from Soap-lyes.*—The spent lyes obtained in soap manufacture contain 3—5 per cent. of glycerol together with some salt. They are simply concentrated by evaporation in a vacuum pan until they contain some 80 per cent of glycerol. Glycerol decomposes below its boiling point under atmospheric pressure. The liquors are therefore distilled

under greatly reduced pressure (3–5 mm. of Hg) in a current of superheated steam. The glycerol so obtained is pure enough for dynamite manufacture (§ 202) but for chemical and pharmaceutical purposes it is redistilled.

(2) *Glycerol from the Candle Industry.*—Candles are made from paraffin wax together with a certain proportion of stearic acid (*stearin*) which reduces the tendency to soften and collapse in a warm atmosphere. The stearin is obtained by heating a solid fat with water and a catalyst (lime, sulphuric acid, etc) under pressure. The fat separates into fatty acids and a solution of glycerol, which is concentrated and purified as already described.

(3) *Glycerol by Fermentation.*—If sugar is fermented in presence of certain salts, *e.g.*, sodium sulphite, the main product is glycerol (§ 301a). The process was used by Germany in the War of 1914–1918, when shortage of fats became acute.

200. Synthesis and Constitution of Glycerol.—Glycerol may be synthesised by the following reactions, which demonstrate its composition,



201. Properties of Glycerol.—*Physical Properties.*—Glycerol is a viscous colourless liquid. It is odourless, and has a sweet taste.

Glycerol solidifies, on cooling, to crystals which melt at 20° C. It boils at 290° C. with decomposition (*v. infra*) but can be distilled satisfactorily at much reduced pressure.

It mixes with water and alcohol in all proportions but it is insoluble in ether. It attracts moisture from the air.

Chemical Properties.—When glycerol is distilled it partly breaks up, giving some acrolein. In presence of dehydrating agents (*e.g.*, potassium hydrogen sulphate) the decomposition is complete:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}OH \end{array} = \begin{array}{l} CHO \\ | \\ CH \\ \| \\ CH_2 \end{array} + 2H_2O.$$

Glycerol is an alcohol and can therefore form esters. The esters of glycerol with the higher fatty and other organic acids are the fats and have already been discussed (§ 192). Esters are also formed with sulphuric, phosphoric, and nitric acids. Glyceryl trinitrate, incorrectly known as nitroglycerin, is a most important explosive and is discussed in § 202 below.

Glycerol also forms ethers such as triethylin:

$$\begin{array}{l} CH_2{\cdot}O{\cdot}C_2H_5 \\ | \\ CH{\cdot}O{\cdot}C_2H_5 \\ | \\ CH_2{\cdot}O{\cdot}C_2H_5. \end{array}$$

The oxidation of glycerol forms a variety of products as shown below:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2{\cdot}OH \end{array} \rightarrow \begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CO{\cdot}OH \end{array} \rightarrow \begin{array}{l} CO{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CO{\cdot}OH \end{array} \rightarrow \begin{array}{l} CO{\cdot}OH \\ | \\ CO \\ | \\ CO{\cdot}OH \end{array}$$

Glyceric acid. Tartronic acid (§ 240) Mesoxalic acid (§ 261).

Glycerol is a useful starting point for synthesising allyl and propyl derivatives. We have already seen that by dehydration it yields allyl aldehyde, acrolein. When heated with oxalic acid it yields allyl alcohol (§ 173) or formic acid (§ 79) according to conditions. When treated with yellow phosphorus and iodine it gives *iso*propyl iodide. Allyl iodide is first formed and then reduced:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH{\cdot}OH + 3HI \\ | \\ CH_2{\cdot}OH \end{array} = \begin{array}{l} CH_2I \\ | \\ CH \\ \| \\ CH_2 \end{array} + 3H_2O + I_2, \quad \begin{array}{l} CH_2I \\ | \\ CH + HI \\ \| \\ CH_2 \end{array} = \begin{array}{l} CH_3 \\ | \\ CHI + I \\ | \\ CH_3 \end{array}$$

Uses.—Glycerol is used in a great number of industries, notably for the manufacture of explosives, for medicinal purposes, as a preservative and for very numerous minor purposes where a water-soluble liquid which will not evaporate is needed. It is mixed with the water in the radiators of automobiles in order to avoid the danger of freezing in cold weather.

Expt. 52.—*Reactions of Glycerol.*—(1) Dissolve a portion in water: note sweet taste.

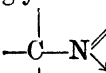
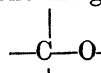
(2) Show that glycerol is insoluble in ether, but soluble in alcohol-ether mixture.

(3) Heat two drops glycerol with ½ g. potassium hydrogen sulphate. Irritating odour of acrolein.

(4) Warm two drops glycerol with 2 c.c. acidified potassium dichromate solution. CO_2 is evolved.

(5) Show that it reduces both alkaline and acid $KMnO_4$ solution.

(6) Powder about 5 g. of potassium permanganate. Form into a cone, hollow out the tip and pour in glycerol, which will in a short time burst into flame.

202. 'Nitroglycerin,' Glyceryl Trinitrate, $C_3H_5(NO_3)_3$.—Nitroglycerin is definitely not a *nitro-compound* containing the group  but a *nitrate* containing the group  It is the basis of many explosives, and its manufacture (which should *on no account* be attempted by the student) is of much industrial importance.

Glycerol is sprayed into a mixture of concentrated nitric and sulphuric acids, care being taken that the temperature does not rise above 25° C. The glycerol and nitric acid form glyceryl trinitrate,

$$C_3H_5(OH)_3 + 3HNO_3 = C_3H_5(NO_3)_3 + 3H_2O,$$

which rises to the surface as a yellow oil. It is then well washed with water to remove any excess of acid.

Nitroglycerin is an oily liquid, colourless when pure. It has no smell and is poisonous. It is employed medicinally in small quantities as a vasodilator. Its action resembles that of amyl nitrite.

Nitroglycerin freezes to white needles which melt at 11° C. It cannot be safely distilled as it may explode above about 45–50° C.

The main importance of nitroglycerin is its intense explosive power. It will burn without explosion for a short time but when the mass of the liquid becomes hot the whole explodes. It is sensitive to shock and a heavy blow from a hammer will detonate a drop of the liquid. In practice the explosion of the nitroglycerin is brought about by a detonator containing mercury fulminate, the explosion of which imparts to it a sudden and violent shock.

Nitroglycerin is an inconvenient explosive since, being an oily liquid, it is easily spilt. It is now obsolete and has been entirely replaced by dynamite and blasting gelatin.

Dynamite is a mixture of 75 per cent. nitroglycerin with 25 per cent. of the very porous siliceous earth known as *kieselguhr*. It is a putty-like mass, and is much safer and easier to handle than nitroglycerin.

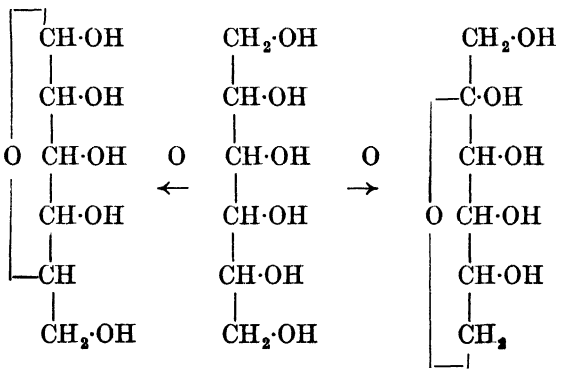
Blasting gelatine is a tough jelly-like mixture of guncotton (§ 290) and nitro glycerin, containing about 7 per cent. of the former. It is at once exceedingly powerful and not dangerously sensitive. The nitroglycerin explosives are admirably suited to the blasting of hard rocks, but are too sensitive for use in shells, and too shattering in effect for use as propellants in guns.

203. Other Polyhydric Alcohols.

Erythritol, $CH_2(OH)\,CH(OH)\cdot CH(OH)\cdot CH_2\cdot OH$, is a crystalline solid found in certain lichens and algæ.

Arabitol, $CH_2(OH)\cdot CH(OH)\cdot CH(OH)\cdot CH(OH)\cdot CH_2\cdot OH$, is made by reducing the sugar arabinose.

Mannitol $\begin{matrix}CH_2\cdot OH\\ |\\ (CH\cdot OH)_4\\ |\\ CH_2\cdot OH\end{matrix}$ is found in many plant products, particularly in manna, the dried juice of the manna-ash, a tree which grows in Southern Europe. It forms white needle-like crystals with a sweet taste. It is a mild aperient, suitable for children. It can be oxidised to the sugars, mannose and fructose.



Mannose.[1] Mannitol. Fructose.[1]

It is added to solutions of boric acid which are to be titrated. Boric acid is too weak to affect most indicators, but mannitoboric acid is stronger, and can be satisfactorily titrated.

Several alcohols, stereoisomeric (§ 232 ff) with mannitol are known, notably d-sorbitol, obtained by reduction of certain sugars.

QUESTIONS

(1) Compare the reactions of glycol with those of ethyl alcohol. How could the latter be converted into the former?

(2) What effect has oxidation on (*a*) glycol; (*b*) glycerol? What light do these reactions throw on the positions of the hydroxyl groups in the molecule?

[1] The stereoisomerism of these compounds is here ignored. But see Ch. XIX. §§ 275, 276.

(3) What are oils, fats, soaps and waxes? How could you convert a specimen of fat into soap on the laboratory scale?

(4) What peculiarities distinguish butter from most other fats? How could adulteration of butter with margarine be detected?

(5) Describe the commercial preparation of soap and glycerol from oils and fats.

(6) For what purposes is glycerol employed? What compounds are commonly made from it in the chemical laboratory?

(7) What evidence is there that glycerol contains three hydroxyl groups and that one of these differs from the other two?

(8) Distinguish between nitrates and nitro-compounds and discuss the uses of both of these in the explosive industry.

CHAPTER XV

THE DIBASIC ACIDS

204. List of Dibasic Acids of the Oxalic Acid Series.—The best-known series of dibasic acids is the oxalic series. These are saturated acids containing two carboxyl groups. The most important acids of the series are oxalic, malonic and succinic acid.

Name	Formula	M.P.
Oxalic acid . . .	$\begin{matrix}CO{\cdot}OH\\ \vert \\ CO{\cdot}OH\end{matrix}$	Sublimes
Malonic acid . . .	$CH_2\begin{matrix}\diagup CO{\cdot}OH\\ \diagdown CO{\cdot}OH\end{matrix}$	132°
Succinic acid . . .	$\begin{matrix}CH_2{-}CO{\cdot}OH\\ \vert \\ CH_2{-}CO{\cdot}OH\end{matrix}$	185°
Glutaric acid . . .	$(CH_2)_3\begin{matrix}\diagup CO{\cdot}OH\\ \diagdown CO{\cdot}OH\end{matrix}$	97·5°
Adipic acid . . .	$(CH_2)_4\begin{matrix}\diagup CO{\cdot}OH\\ \diagdown CO{\cdot}OH\end{matrix}$	149°
Pimelic acid . . .	$(CH_2)_5\begin{matrix}\diagup CO{\cdot}OH\\ \diagdown CO{\cdot}OH\end{matrix}$	105°
Suberic acid . . .	$(CH_2)_6\begin{matrix}\diagup CO{\cdot}OH\\ \diagdown CO{\cdot}OH\end{matrix}$	140°

205. Preparation of Dibasic Acids.—The acids of this series are prepared by methods analogous to those used to prepare the fatty acids.

These include,

(1) Oxidation of glycols or hydroxy-acids:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH_2{\cdot}OH \end{array} + 4O = \begin{array}{l} CO{\cdot}OH \\ | \\ CO{\cdot}OH \end{array} + 2H_2O$$

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CO{\cdot}OH \end{array} + 2O = \begin{array}{l} CO{\cdot}OH \\ | \\ CO{\cdot}OH \end{array} + H_2O$$

(2) Hydrolysis of di-cyanides and cyano-acids. Succinic acid may be made by converting ethylene bromide into ethylene cyanide and hydrolysing this (cf. § 144):

$$\begin{array}{l} CH_2{\cdot}Br \\ | \\ CH_2{\cdot}Br \end{array} \xrightarrow{KCN} \begin{array}{l} CH_2{\cdot}CN \\ | \\ CH_2{\cdot}CN \end{array} \xrightarrow{H_2O} \begin{array}{l} CH_2{\cdot}CO{\cdot}OH \\ | \\ CH_2{\cdot}CO{\cdot}OH \end{array}$$

Succinic acid.

Again, acetic acid may be converted into monochloroacetic acid, thence to cyanoacetic acid, which on hydrolysis gives malonic acid:

$$\begin{array}{l} CH_3 \\ | \\ CO{\cdot}OH \end{array} \xrightarrow{Cl_2} \begin{array}{l} CH_2{\cdot}Cl \\ | \\ CO{\cdot}OH \end{array} \xrightarrow{KCN} \begin{array}{l} CH_2{\cdot}CN \\ | \\ CO{\cdot}OH \end{array} \xrightarrow{H_2O} \begin{array}{l} CH_2{-}CO{\cdot}OH \\ | \\ CO{\cdot}OH \end{array}$$

Malonic acid.

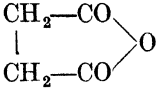
206. General Chemical Properties of Dibasic Acids.—The dibasic acids have similar properties to the fatty acids except as follows:

(1) They form two series of compounds, according to whether one or both carboxyl groups have reacted.

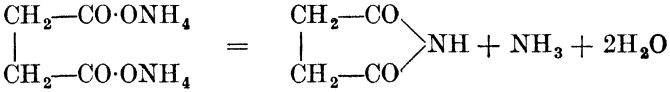
Thus we have the acid salts such as $\begin{array}{l} CO{\cdot}OH \\ | \\ CO{\cdot}ONa \end{array}$, acid esters such as $\begin{array}{l} CO{\cdot}OH \\ | \\ CO{\cdot}O{\cdot}C_2H_5 \end{array}$, acid amides such as $\begin{array}{l} CO{\cdot}NH_2 \\ | \\ CO{\cdot}OH \end{array}$; and also normal compounds such as the salt $\begin{array}{l} CO{\cdot}ONa \\ | \\ CO{\cdot}ONa \end{array}$, the ester $\begin{array}{l} CO{\cdot}O{\cdot}C_2H_5 \\ | \\ CO{\cdot}O{\cdot}C_2H_5 \end{array}$ and the amide $\begin{array}{l} CO{\cdot}NH_2 \\ | \\ CO{\cdot}NH_2 \end{array}$.

(2) Some of the higher members tend to form *internal anhydrides* by elimination of water. Just as *two* molecules of acetic acid $CH_3{\cdot}CO{\cdot}OH$ yield a molecule of acetic anhydride $\begin{array}{l} CH_3{-}CO \\ \quad\quad\quad O \\ CH_3{-}CO \end{array}$, so

one molecule of succinic acid forms a molecule of succinic anhydride



In the same way they can form *imides* where fatty acids would form *amides*. When ammonium succinate is heated succinimide is obtained:



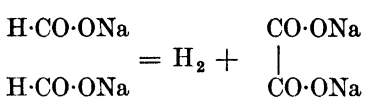
207. Oxalic Acid,  . $2H_2O$.—*Occurrence and Preparation.*—Salts of oxalic acid are common in many plants, notably sorrel, rhubarb, etc.

(1) Oxalic acid may be prepared by oxidising glycol or glycollic acid (*v.* §§ 188, 229). This reaction shows it to have the formula





(2) When sodium formate is rapidly heated it produces sodium oxalate:



(3) Oxalic acid is formed by oxidising most carbohydrates (§ 263), *e.g.*, sugar, starch, etc., with concentrated nitric acid. This affords a good laboratory method of making the acid.

Expt. 53.—*Preparation of Oxalic Acid from Sugar.*—Weigh out 50 g. of cane sugar and transfer to a capacious flask (2000 c.c.). Add 100 c.c. of ordinary concentrated nitric acid (sp. gr. 1·4) and if available 0·1 g. of vanadium pentoxide. Heat to boiling on the water-bath in the fume chamber, and as the reaction subsides add a further 300 c.c. of nitric acid in portions of 50 c.c. When the reaction has subsided evaporate the solution to a bulk of 60 c.c. Crystals of oxalic acid separate on cooling. Dry on blotting paper and recrystallise by dissolving them in twice their weight of boiling water and letting the solution cool slowly.

(4) On the commercial scale, oxalic acid is made by the action of sodium hydroxide on some form of cellulose, usually sawdust. Some sodium peroxide improves the yield. In one modification of the process the sawdust is impregnated with strong caustic soda solution and heated to a temperature of about 200°–300° in a current of hot air.

The mass is extracted with water, and lime is added to the liquors. The insoluble calcium oxalate is precipitated and on treatment with dilute sulphuric acid yields a solution from which oxalic acid can be crystallised.

Physical Properties.—Oxalic acid forms transparent monoclinic crystals containing two molecules of water of crystallisation. The anhydrous acid is obtained by heating these to 60°–70° C. for some time and forms a white powder which may be sublimed and then forms white needle-shaped crystals. Oxalic acid is odourless. It has a sharp taste and is very poisonous, about 1 g. being a fatal dose. The antidote is a calcium compound (best slaked lime or precipitated chalk) which produces the insoluble calcium oxalate.

It is soluble in cold water, 100 g. of which dissolve 8·78 g. of the anhydrous acid at 20° C. and 63·82 g. at 70° C. It is moderately soluble in alcohol, slightly soluble in ether and insoluble in most other organic solvents, *e.g.*, chloroform, benzene, etc.

Chemical Properties.—Oxalic acid is decomposed to some extent when heated above 160° C. It sublimes a little below this temperature and some of the vapour decomposes into carbon dioxide and formic acid:

$$\begin{matrix}\text{CO·OH}\\|\\\text{CO·OH}\end{matrix} = \text{CO}_2 + \begin{matrix}\text{H}\\|\\\text{CO·OH.}\end{matrix}$$

The same decomposition results in a more complex way when oxalic acid is heated with glycerol (§ 79).

Oxalic acid is a moderately strong acid, a good deal stronger than acetic acid, though weaker than the mineral acids. It has the usual properties of an acid, forming oxalates (§ 208) with bases and some metals, with carbonates, etc. With alcohols it readily forms esters (§ 209).

It is decomposed by dehydrating agents, notably sulphuric acid, carbon monoxide and carbon dioxide being evolved:

$$\begin{matrix}\text{CO·OH}\\|\\\text{CO·OH}\end{matrix} = \text{CO}_2 + \text{CO} + \text{H}_2\text{O}.$$

Oxalic acid is a reducing agent, being easily oxidised to carbon dioxide and water. Among the reagents which will oxidise it are

manganese dioxide, lead dioxide and acid potassium permanganate solution. These reactions are utilised in quantitative analysis. Nitric acid of sp. gr. $> 1{\cdot}4$ will also oxidise it.

Oxalic acid can be reduced by nascent hydrogen to hydroxyacetic acid:

$$\begin{matrix}\mathrm{CO{\cdot}OH}\\ |\\ \mathrm{CO{\cdot}OH}\end{matrix} + 4\mathrm{H} = \begin{matrix}\mathrm{CH_2{\cdot}OH}\\ |\\ \mathrm{CO{\cdot}OH}\end{matrix} + \mathrm{H_2O}.$$

When oxalic acid or ethyl oxalate is treated with phosphorus pentachloride oxalyl chloride $\begin{matrix}\mathrm{CO{\cdot}Cl}\\ |\\ \mathrm{CO{\cdot}Cl}\end{matrix}$ is formed.

Tests.—Oxalic acid is distinguished from other organic acids (1) by its giving carbon monoxide and carbon dioxide when heated with concentrated sulphuric acid without any blackening of the liquid; (2) by its giving a white precipitate with calcium chloride which, unlike other precipitates of organic calcium salts, is not soluble in acetic acid (*v.* § 252).

Oxalic acid is readily determined by titration with potassium permanganate.

Expt. 54.—*Reactions of Oxalic Acid.*—(1) Heat in a dry tube: note melting, evolution of water, and finally sublimation.

(2) Heat a solution with dilute sulphuric acid and potassium permanganate solution: note oxidation to CO_2.

(3) Heat solid with conc. H_2SO_4. Note evolution of CO and CO_2.

(4) Add solution to calcium chloride solution. Note white precipitate insoluble in acetic acid.

208. Salts of Oxalic Acid.—The oxalates, other than those of the alkali metals and ammonium, are insoluble in water. When heated they break up into carbonates and carbon monoxide. The carbonate may further break up into carbon dioxide and the oxide of the metal which may be partly or wholly reduced by the carbon monoxide.

Thus calcium oxalate, if gently heated, gives calcium carbonate and carbon monoxide:

$$\mathrm{CaC_2O_4} \rightarrow \mathrm{CaCO_3} + \mathrm{CO} \rightarrow \mathrm{CaO} + \mathrm{CO_2} + \mathrm{CO},$$

while stronger heating gives calcium oxide.

Lead oxalate, on the other hand, gives lead suboxide, Pb_2O:

$$2\mathrm{PbC_2O_4} = \mathrm{Pb_2O} + 3\mathrm{CO_2} + \mathrm{CO}.$$

Silver oxalate explodes when heated, giving metallic silver and carbon dioxide. Oxalates react with sulphuric acid and with calcium chloride solution in the same manner as does the free acid.

Sodium Oxalates.—Normal sodium oxalate $Na_2C_2O_4$ and sodium hydrogen oxalate $NaHC_2O_4$ are known. The normal salt is sparingly soluble (*ca.* 3 per cent.).

Potassium Oxalates.—Three salts are known. Normal potassium oxalate $K_2C_2O_4 \cdot 2H_2O$ is readily soluble in water. Acid potassium oxalate KHC_2O_4 is found in various plants and is sparingly soluble in water. Potassium quadroxalate $KHC_2O_4 \cdot H_2C_2O_4 \cdot 2H_2O$ is formed when caustic potash or potassium oxalate is crystallised with the correct quantity of oxalic acid. It is sparingly soluble, dissolving in about twenty times its weight of cold water.

This latter salt is readily purified by re-crystallisation and is useful for standardising volumetric solutions of alkalis and of potassium permanganate.

Both the acid salts are sold as 'salts of sorrel' or 'salts of lemon.' They are used for cleaning purposes, removing stains, etc., but are objectionable as being highly poisonous.

Ammonium Oxalate $(NH_4)_2C_2O_4 \cdot H_2O$, is used as a reagent in quantitative analysis for the precipitation of calcium. When distilled it yields oxamide, the amide of oxalic acid.

$$\begin{matrix} CO \cdot O \cdot NH_4 \\ | \\ CO \cdot O \cdot NH_4 \end{matrix} = \begin{matrix} CO \cdot NH_2 \\ | \\ CO \cdot NH_2 \end{matrix} + 2H_2O.$$

Ammonium hydrogen oxalate may be prepared by crystallising the normal oxalate with oxalic acid. When heated it yields oxamic acid, which is at once an *amide* and an *acid*:

$$\begin{matrix} CO \cdot O \cdot NH_4 \\ | \\ CO \cdot OH \end{matrix} = \begin{matrix} CO \cdot NH_2 \\ | \\ CO \cdot OH \end{matrix} + H_2O.$$

Calcium Oxalate, CaC_2O_4, is found in many plants as small aggregates of crystals. When oxalic acid or an oxalate is added to a calcium salt it is precipitated. When heated it decomposes as mentioned above (p. 210). Calcium is determined quantitatively by precipitating it as oxalate, washing the precipitate and

(1) Drying it and igniting it, either gently so as to form the carbonate, or strongly so as to form the oxide[1]; or

(2) Dissolving the precipitate in dilute sulphuric acid and titrating the resulting solution with permanganate.

Iron Oxalates.—Ferrous oxalate forms a bright yellow powder. It forms a soluble double salt with potassium oxalate which was formerly much used as a photographic developer.

Ferric oxalate forms double salts with ammonium and other

[1] It is easier to convert the precipitate in the crucible into calcium sulphate by addition of a few drops of sulphuric acid and igniting at a low red heat.

oxalates. These are reduced by light to ferrous salts, a reaction which is the basis of the platinotype process of photographic printing, in which the ferrous salts so produced reduce platinum salts to metallic platinum, and of the blue-print process in which the ferrous salts react with a ferricyanide giving an image of Prussian blue.

209. Esters of Oxalic Acid.—Oxalic acid, being stronger than most organic acids, reacts very readily with alcohols.

Methyl oxalate, $\begin{matrix}CO\cdot OCH_3\\ |\\ CO\cdot OCH_3\end{matrix}$, crystallises out from the liquid obtained by dissolving anhydrous oxalic acid in methyl alcohol. The crystals are washed with cold water. It is very easily hydrolysed, boiling with water being enough to break it up into oxalic acid and methyl alcohol.

The addition of ammonia to methyl oxalate converts it at once into oxamide:

$$\begin{matrix}CO\cdot OCH_3\\ |\\ CO\cdot OCH_3\end{matrix} + 2NH_3 = \begin{matrix}CO\cdot NH_2\\ |\\ CO\cdot NH_2\end{matrix} + 2CH_3OH.$$

Ethyl oxalate is readily prepared by heating ethyl alcohol and oxalic acid. It is similar in behaviour to methyl oxalate, but is a liquid.

Methyl hydrogen oxalate, $\begin{matrix}CO\cdot OH\\ |\\ CO\cdot O\cdot CH_3\end{matrix}$, and the corresponding ethyl compound are known.

210. Amides of Oxalic Acid.—*Oxamide*, $\begin{matrix}CO\cdot NH_2\\ |\\ CO\cdot NH_2\end{matrix}$, is made by the action of ammonia on methyl oxalate or by the distillation of ammonium oxalate (*q.v.*).

It is a white powder and has the general properties of amides (§ 115). When heated with phosphorus pentoxide it yields cyanogen (§ 135).

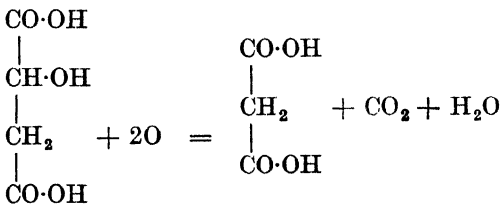
Oxamic acid, $\begin{matrix}CO\cdot NH_2\\ |\\ CO\cdot OH\end{matrix}$, is prepared by heating ammonium hydrogen oxalate. It is a white powder. It reacts both as an amide and an acid, forming salts, esters, etc.

Oximide, $\begin{matrix}CO\\ |\\ CO\end{matrix}\!\!>\!NH$, is made by removing the elements of water from oxamic acid with phosphorus pentachloride. It is much less stable than the

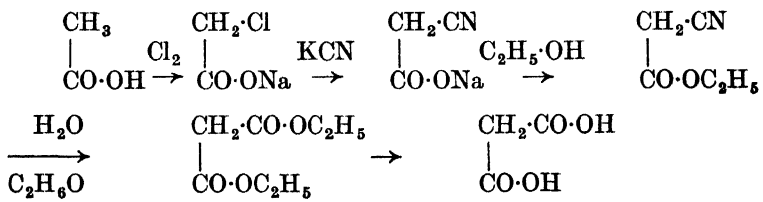
higher imides, such as succinimide. Three-membered rings are always less stable than four or five-membered rings, a fact which is explained in Chapter XXI.

It should be noted that no oxalic anhydride,  , is known.

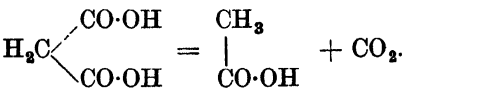
211. Malonic Acid,  .—Malonic acid can be made by oxidising malic acid (hydroxy-succinic acid) with chromic acid:



Synthetically it can be made from acetic acid. Acetic acid is treated with chlorine (§ 220), forming monochloroacetic acid, which is converted into sodium monochloroacetate. This is treated with concentrated potassium cyanide solution giving sodium cyano-acetate, which with alcohol and sulphuric acid gives ethyl cyano-acetate, which is hydrolysed by the acid present to give malonic ester. This is saponified and yields malonic acid:



Malonic acid forms crystals melting at 133°–134° C. and is readily soluble in water. When heated it breaks up into acetic acid and carbon dioxide:



The acid is of much less importance than its ethyl ester.

212. Ethyl Malonate.—*Malonic ester*, $C_2H_5 \cdot O \cdot CO \cdot CH_2 \cdot CO \cdot OC_2H_5$, is a most useful synthetic reagent. It is prepared as described under malonic acid above, and from it numerous compounds (chiefly higher fatty acids) can be synthesised. The method is discussed

under the heading of acetoacetic ester (§ 259), which reacts in a similar way.

213. Malonic Anhydride, Carbon Suboxide, $\begin{matrix} C=O \\ \| \\ C \\ \| \\ C=O \end{matrix}$.—'Malonic anhydride' is of interest as being an oxide of carbon. It is not the true anhydride of malonic acid, which would be $H_2C\begin{matrix} CO \\ \diagup\diagdown\diagup \\ CO \end{matrix}O$, and which does not in fact exist. It is obtained by the action of heat on malonic acid under certain conditions or by the action of phosphorus pentoxide on malonic ester. It is a gas (b.p. 7° C.) and reacts with water, giving malonic acid.

214. Succinic Acid, $\begin{matrix} CH_2—CO\cdot OH \\ | \\ CH_2—CO\cdot OH \end{matrix}$.—Succinic acid is usually made by the distillation of amber—a fossil resin—or by the fermentation of calcium malate. It can be synthesised from ethylene dibromide by the reactions given in § 205.

Succinic acid is a crystalline solid which melts at 185° C. and boils at 235° C. It is soluble in water. When heated it forms some succinic anhydride, which is better made by treating it with acetic anhydride,

$$\begin{matrix} CH_2—CO\cdot OH \\ | \\ CH_2—CO\cdot OH \end{matrix} = \begin{matrix} CH_2—CO \\ | \quad\diagdown\diagup O \\ CH_2—CO \end{matrix} + H_2O.$$

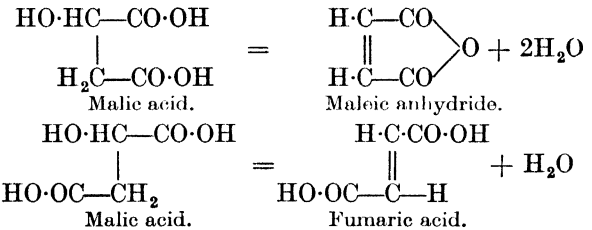
It behaves in general like oxalic acid, though it is a far weaker acid.

An isomeride of succinic acid (methylmalonic acid) of the formula $\begin{matrix} CH_3 \\ | \\ CH\begin{matrix} \diagup CO\cdot OH \\ \diagdown CO\cdot OH \end{matrix} \end{matrix}$ also exists. It differs from succinic acid in giving carbon dioxide and propionic acid when heated and in not forming an anhydride.

215. Adipic acid, $\begin{matrix} CO\cdot OH \\ | \\ (CH_2)_4 \\ | \\ CO\cdot OH \end{matrix}$, is sometimes used as the acid constituent of baking powder. It is made commercially from castor-oil or from *cyclo*hexane (§ 333).

UNSATURATED DIBASIC ACIDS

216. Maleic Acid and Fumaric Acid.—The simplest acids of this type are maleic and fumaric acids, which are isomeric, both having the formula $C_2H_2(CO_2H)_2$. Both acids are obtained by heating malic acid. This breaks up, giving the anhydride of maleic acid, which distils over while fumaric acid remains behind. The equations may be written (assuming the formulæ which are established in § 217):



Maleic acid and fumaric acid are solids which differ in solubility, taste, etc. They show a remarkable similarity in chemical properties, which are discussed below in connection with their formulæ.

217. Isomerism of Maleic and Fumaric Acids.—The two acids, maleic and fumaric, remained for a long time a problem, as both of them, while differing in properties, appeared to have the same formula:

$$\begin{matrix}\mathrm{CH(CO\cdot OH)}\\ \|\\ \mathrm{CH(CO\cdot OH)}.\end{matrix}$$

The evidence for the above formula is as follows:

(1) Both acids are reduced by sodium amalgam and water to succinic acid, $\begin{matrix}\mathrm{CH_2—CO\cdot OH}\\ |\\ \mathrm{CH_2—CO\cdot OH}\end{matrix}$.

(2) With hydrogen bromide both give bromosuccinic acid,

$$\begin{matrix}\mathrm{CHBr—CO\cdot OH}\\ |\\ \mathrm{CH_2—CO\cdot OH}.\end{matrix}$$

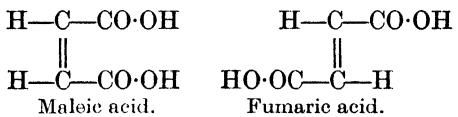
These two reactions clearly point to the formula:

$$\begin{matrix}\mathrm{CH(CO\cdot OH)}\\ \|\\ \mathrm{CH(CO\cdot OH)}\end{matrix}$$

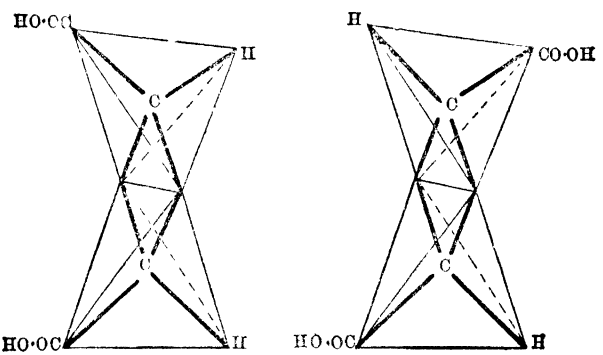
The differences between the acids are (1) that maleic acid reactive and tends to be changed into fumaric acid, *e.g.*

with dilute hydrochloric acid, and (2) maleic acid readily forms an anhydride while fumaric acid does not.

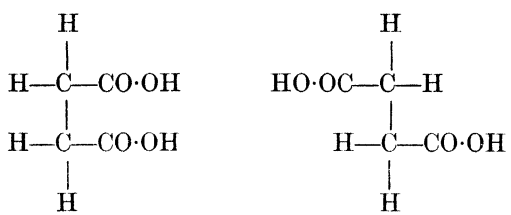
It was not at first found possible to write formulæ for the two acids which should account for these likenesses and differences. The view now accepted is that the acids have the formulæ:



or spatially represented:



We suppose that two succinic acids of formulæ



annot exist because the single bond connecting the carbon atoms llows free rotation of the carbon atoms and groups attached to hem. It seems reasonable to suppose, however, that the double nd shown in the formulæ for maleic and fumaric acid would not mit rotation of the radicals. If this is granted the behaviour of o acids is explained.

acid and fumaric acid when reduced give succinic acids of æ given above, which are identical. For the same reason entical bromosuccinic acid when treated with HBr. The

difference as to their anhydride formation also stands explained.

The acid $\begin{matrix} H—C—CO\cdot OH \\ \| \\ H—C—CO\cdot OH \end{matrix}$ readily gives $\begin{matrix} H—C—CO \\ \| \quad\quad O \\ H—C—CO \end{matrix}$

while the acid $\begin{matrix} HO\cdot OC—C—H \\ \| \\ H—C—CO\cdot OH \end{matrix}$ cannot do so, owing to the distance between the carboxyl groups.

The first formula is therefore given to maleic acid and the second to fumaric acid.

This kind of isomerism is known as *cis-trans-isomerism*. The compound with like groups on the same side is called the *cis*-compound while the other is called the *trans*-compound. Thus maleic acid is *cis*-ethylenedicarboxylic acid and fumaric acid is *trans*-ethylenedicarboxylic acid.

Cis-trans isomerides are, as a rule, more alike than ordinary isomerides but less alike than true stereoisomerides (§ 232 ff.).

QUESTIONS

(1) How is oxalic acid made; (*a*) commercially, (*b*) in the laboratory? How could it be synthesised from ethyl alcohol?

(2) Compare the reactions of oxalic acid with those of acetic acid. Which is (*a*) the more stable substance, (*b*) the stronger acid?

(3) What is the effect of heat upon the oxalates of silver, lead, calcium, sodium, ammonium?

(4) How would you prepare methyl oxalate and convert your product into oxamide? Compare the latter compound with acetamide.

(5) How are malonic and succinic acids prepared? What compounds are formed from these acids corresponding to acetic anhydride and acetamide, formed from acetic acid?

(6) An acid of the oxalic series was exactly neutralised by potassium hydroxide. The salt thus obtained was gently heated to drive off water of crystallisation. 1·000 G. of the salt was heated with sulphuric acid, and after gentle ignition at a low red heat, left 0·8970 g. potassium sulphate. Which acid was used?

CHAPTER XVI

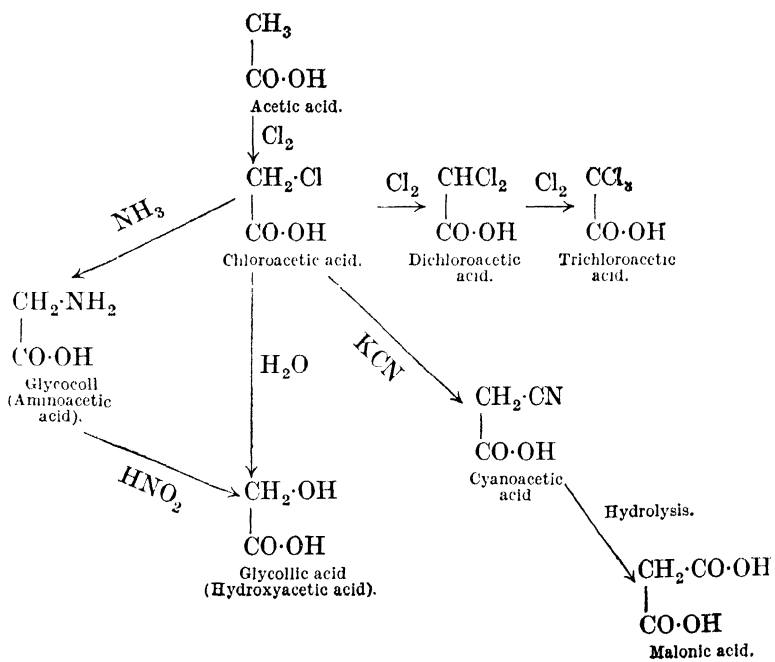
ACIDS CONTAINING A SUBSTITUENT GROUP

218. General Properties of Substituted Acids.—Numerous organic acids are known which contain other groups beside carboxyl. Thus among the acids containing two carbon atoms we have

CH_3	$CH_2 \cdot Cl$	$CH_2 \cdot CN$	$CH_2 \cdot NH_2$	$CH_2 \cdot OH$
$CO \cdot OH$	$CO \cdot OH$	$CO \cdot OH$	$CO \cdot OH$	$CO \cdot OH$
Acetic acid.	Monochloro-acetic acid.	Cyanoacetic acid.	Aminoacetic acid (Glycocoll).	Hydroxyacetic acid (Glycollic acid).

It would seem reasonable to suppose that these would have the properties of the acid and also the properties of the substituent group and this is approximately true. Thus aminoacetic acid has

SUBSTITUTED ACETIC ACIDS



the properties of a primary amine (§§ 119–120) and also of an acid. The groups however modify each other's properties. Thus chloroacetic acid is a very much stronger acid than aminoacetic acid, and the hydroxyl group in hydroxyacetic acid is much less ready to form esters, etc., than the corresponding group in ethyl alcohol.

As a general rule we may remember that substituted acids show the properties of the substituent group and also of an acid, and that electronegative substituents (CN, halogens) increase the strength of the acid while electropositive substituents (NH_2) decrease it.

The hydroxy-acids are numerous and important and will be considered in Chapter XVII, while the other substituted acids will be considered here.

219. Halogen-substituted Fatty Acids.—Chloroformic acid, $\begin{matrix}\text{Cl}\\|\\\text{CO·OH}\end{matrix}$, has not been prepared though its ester is known. This and its derivatives are discussed in § 306. Three chloroacetic, three bromoacetic and three iodoacetic acids are known.

$\begin{matrix}\text{CH}_2\text{·Cl}\\|\\\text{CO·OH}\end{matrix}$	$\begin{matrix}\text{CH}_2\text{·Br}\\|\\\text{CO·OH}\end{matrix}$	$\begin{matrix}\text{CH}_2\text{·I}\\|\\\text{CO·OH}\end{matrix}$
Monochloroacetic acid.	Monobromoacetic acid.	Mono-iodoacetic acid.
$\begin{matrix}\text{CHCl}_2\\|\\\text{CO·OH}\end{matrix}$	$\begin{matrix}\text{CHBr}_2\\|\\\text{CO·OH}\end{matrix}$	$\begin{matrix}\text{CHI}_2\\|\\\text{CO·OH}\end{matrix}$
Dichloroacetic acid.	Dibromoacetic acid.	Di-iodoacetic acid.
$\begin{matrix}\text{CCl}_3\\|\\\text{CO·OH}\end{matrix}$	$\begin{matrix}\text{CBr}_3\\|\\\text{CO·OH}\end{matrix}$	$\begin{matrix}\text{CI}_3\\|\\\text{CO·OH}\end{matrix}$
Trichloroacetic acid.	Tribromoacetic acid.	Tri-iodoacetic acid.

Preparation.—The chloroacetic and bromoacetic acids are made by the action of the halogen on acetic acid. The method is ordinarily employed only for the mono-substituted acids. The di- and trichloroacetic acids are best made from chloral (§ 72).

220. Monochloroacetic Acid, $\begin{matrix}\text{CH}_2\text{·Cl}\\|\\\text{CO·OH}\end{matrix}$.—The acid is best prepared by passing chlorine through heated acetic acid in presence of a little iodine, sulphur, phosphorus or other catalyst:

$$\text{CH}_3\text{·CO·OH} + \text{Cl}_2 = \text{CH}_2\text{Cl·CO·OH} + \text{HCl}.$$

Expt. 55.—*Preparation of Monochloroacetic Acid.*—The experiment is best performed on a sunny day as the reaction is

much affected by light. Arrange in the fume cupboard, or near a window, an apparatus for generating chlorine (best from conc. hydrochloric acid and potassium permanganate) and connect through a wash-bottle containing conc. sulphuric acid to a small wide-necked round-bottomed flask supported in a water-bath—rubber corks should not be used—and fitted with a reflux condenser and exit tube to window or flue of cupboard. The apparatus is the same as that of Fig. 56, except in that a water-bath is employed. In the flask are placed 50 c.c. of glacial acetic acid and 1 g. of iodine. The water-bath is heated to boiling and chlorine slowly passed through till the flask has gained in weight by 27 g. The reaction will require about 12 hours to complete itself, even in bright light. The liquid is then distilled, using a Liebig condenser. When the thermometer shows 170° C. the water is run out of the condenser and the fraction boiling between 170° C. and 200° C. is collected. This solidifies on cooling. Any liquid is drained from the crystals, which are then redistilled with an air-condenser. The fraction boiling between 180° C. and 190° C. is nearly pure monochloroacetic acid.

Properties.—Monochloroacetic acid forms colourless crystals which are odourless. It is corrosive to the skin. It melts at 62° C. and boils at 186° C. It is freely soluble in water.

Monochloroacetic acid is a stronger acid than acetic acid, while the di- and tri-chloroacetic acids are stronger still.

Formula of Acid.	Dissociation Constant × 10^3.
$CH_3 \cdot CO \cdot OH$	·0185
$CH_2Cl \cdot CO \cdot OH$	1·5
$CHCl_2 \cdot CO \cdot OH$	50
$CCl_3 \cdot CO \cdot OH$	1210

It forms salts and esters, and an acid chloride, anhydride and amide in the usual manner. Thus ethyl chloroacetate $CH_2Cl \cdot CO \cdot O \cdot C_2H_5$ is readily made by the reaction of the acid and alcohol in presence of sulphuric acid. It has an odour recalling the pear-drop smell of ethyl acetate and is irritating to the eyes.

The halogen group in the acid reacts in many of the same ways as the halogen in a paraffin halide (cf. § 58). Thus when chloroacetic acid is heated with water, or better, moist silver oxide, the halogen is replaced by hydroxyl and glycollic (hydroxyacetic) acid is formed:

$$CH_2Cl \cdot CO \cdot OH + H_2O = CH_2(OH)CO \cdot OH + HCl.$$

This is the usual method employed for making glycollic acid (§ 229). Potassium cyanide converts it into cyanoacetic acid:

$$CH_2Cl{\cdot}CO{\cdot}OH + KCN = CH_2(CN)CO{\cdot}OH + KCl.$$

This reaction is utilised in making malonic acid (*q.v.* § 211).

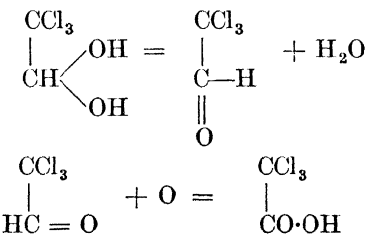
Monochloroacetic acid is of great commercial importance for the synthesis of indigo (§ 563).

221. Dichloroacetic Acid.—$CHCl_2{\cdot}CO_2H$ can be made by the tedious process of continuing the chlorination of acetic acid until enough chlorine has been absorbed. It is, however, best produced by the action of potassium cyanide on chloral hydrate:

$$CCl_3{\cdot}CHO + H_2O + KCN = CHCl_2{\cdot}CO{\cdot}OH + KCl + HCN.$$

It forms crystals readily soluble in water and is a fairly strong acid.

222. Trichloroacetic Acid.—$CCl_3{\cdot}CO_2H$ has been prepared by chlorinating acetic acid but is usually made by oxidising chloral hydrate with fuming nitric acid:



Trichloroacetic acid is a crystalline solid melting at 57° C. It is freely soluble in water.

It is a comparatively strong acid. It is decomposed when heated to 300° C. When boiled with water or alkalis it is hydrolysed, giving chloroform and carbon dioxide, $CCl_3{\cdot}CO{\cdot}OH = CHCl_3 + CO_2$. It is notably less stable than the other chloroacetic acids, perhaps on account of the concentration of electronegative groupings on a single carbon atom.

223. Bromoacetic and Iodoacetic Acids.—The three bromoacetic acids are very similar to the chloroacetic acids and are made by similar methods.

The iodoacetic acids cannot be made by the direct action of iodine on acetic acid. The ethyl ester of monoiodoacetic acid has been made by treating ethyl chloroacetate with potassium iodide and alcohol:

$$C_2H_5{\cdot}O{\cdot}CO{\cdot}CH_2{\cdot}Cl + KI = C_2H_5O{\cdot}CO{\cdot}CH_2{\cdot}I + KCl.$$

The acid can be obtained from the ester. Ethyl iodoacetate has been employed as a 'tear-gas' in warfare, under the name SK.

224. Halogen Derivatives of other Fatty Acids.—All fatty acids form halogen derivatives. Many can be made by treating hydroxy

acids with phosphorus halides, or by treating unsaturated acids with halogens or halogen hydrides (cf. §§ 168, 178).

225. Cyanoacetic Acid.— $\begin{matrix}CH_2\cdot CN\\ |\\ CO\cdot OH\end{matrix}$ is made as described in § 211 by the action of potassium cyanide on a chloroacetate.

It is a crystalline solid melting at 65° C. and is a stronger acid than acetic acid.

Its ester $C_2H_5\cdot O\cdot CO\cdot CH_2\cdot CN$ can be used for certain syntheses in the same way as malonic and acetoacetic esters (*v.* § 259).

Cyanoacetic acid is readily hydrolysed to malonic acid when heated with dilute acids:

$$HO\cdot OC\cdot CH_2\cdot CN + 2H_2O = HO\cdot OC\cdot CH_2\cdot CO\cdot OH + NH_3.$$

AMINO-ACIDS

226. Amino-acids and Proteins.—The acids containing an amino-group, $-NH_2$, are of much interest as being the chief component parts from which the complicated molecules of proteins are built up. The proteins (Ch. XXXIII) are highly complex nitrogen-containing organic substances and exist in great variety in living animals and plants. Albumin from the white of egg, gelatin from bones, etc., casein from milk are typical proteins. Since the proteins are the substances essential to the composition of all living matter, the understanding of their composition would be of the utmost interest. No very great progress has been made towards the synthesis of the proteins, but it seems clear that they are largely composed of amino-acid molecules linked together in the fashion of an amide. The simplest amino-acid is glycine or aminoacetic acid, the formula of which is

$$H_2N\cdot CH_2\cdot CO\cdot OH.$$

Two molecules of these may be linked by appropriate means to form glycylglycine,

$$H_2N\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot CO_2H.$$

Two molecules of this may again be linked to form triglycylglycine,

$$H_2N\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot CO_2H.$$

The proteins when partially hydrolysed produce *polypeptides*, complex chain compounds such as the above, built up from many and different amino-acids, and it is thought that the enormous protein molecules, of molecular weight more than 30,000, contain chains of linked amino-acids in some cases joined to molecules of other substances, purine bases, glucosamine, etc.

If proteins are split up as completely as possible by hydrolysis—

usually accomplished by boiling with solutions of acids or alkalis—a great number of products are obtained, mostly amino-acids. All natural amino-acids have the amino-group in the α-position except pantothenic acid, one of the growth-factors, which is a β amino-acid These include the following:—

(1) *Mono-amino fatty acids, e.g.,*

Aminoacetic acid, glycocoll, $NH_2 \cdot CH_2 \cdot CO \cdot OH$

α-Aminopropionic acid, alanine, $CH_3 \cdot CH(NH_2) \cdot CO \cdot OH$

α-Amino*iso*butylacetic acid, leucine, $\begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>\!CH \cdot CH_2 \cdot CH(NH_2) \cdot CO \cdot OH$

α-Amino*iso*valeric acid, valine, $(CH_3)_2 \cdot CH \cdot CH(NH_2) \cdot CO \cdot OH$

(2) *Mono-amino dibasic acids, e.g.,*

α-Aminosuccinic acid, aspartic acid,

$HO \cdot OC \cdot CH(NH_2) \cdot CH_2 \cdot CO \cdot OH.$

α-Aminoglutaric acid, glutamic acid,

$HO \cdot OC \cdot CH(NH_2) \cdot CH_2 \cdot CH_2 \cdot CO \cdot OH.$

(3) *Diamino-acids, e.g.,*

α-ε-Diaminocaproic acid, lysine,

$NH_2 \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot CO \cdot OH.$

(4) *Hydroxy-amino-acids, e.g.,*

α-Amino-β-hydroxypropionic acid, serine,

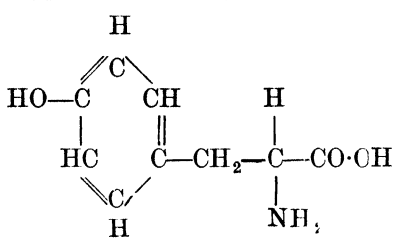
$HO \cdot CH_2 \cdot CH(NH_2) \cdot CO \cdot OH.$

(5) *Amino-acids containing sulphur, e.g.,*

α-Amino-β-thiol-propionic acid, cysteine, $HS—CH_2—\underset{\displaystyle H}{\overset{\displaystyle NH_2}{C}}—CO \cdot OH$

(6) *Amino-acids containing cyclic groups, e.g.,*

β-*p*-Hydroxyphenyl-α-aminopropionic acid, tyrosine,



sulphide and evaporate the solution of glycocoll to a small bulk, when crystals will separate on cooling.

(2) Aminoacetic acid can also be obtained by the hydrolysis of a protein. Most proteins yield some, but gelatin is the most suitable. Glue is boiled with dilute sulphuric acid till completely hydrolysed, and the glycocoll separated by means of the copper derivative.

Structure.—The method of formation and its properties suggest the formula $NH_2 \cdot CH_2 \cdot CO \cdot OH$, but its high solubility in water, insolubility in most organic solvents and high melting point suggest a salt-like constitution. It is now accepted that amino-acids both in the

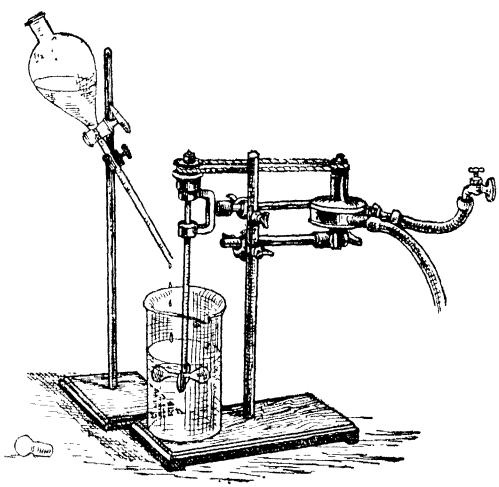


FIG. 36.—Preparation of glycocoll

solid state and in solution consist of ions of an exceptional type, known as "zwitter ions." It is supposed that the whole ion is neutral, the amino-group becoming a charged cation while the acidic group becomes a charged anion $^{+}H_3N \cdot CH_2 \cdot CO \cdot O^{-}$.

Properties.—Aminoacetic acid forms large colourless prismatic crystals with a sweet taste. It melts at 236° C. and decomposes above this temperature. It is readily soluble in water, but is insoluble in alcohol and ether.

Glycocoll is both an acid and a base. It reacts with bases as an *acid* and forms salts with metals of which copper glycocoll

$$Cu(O \cdot CO \cdot CH_2 \cdot NH_2)_2 \cdot H_2O$$

is the best known. This salt has a fine blue colour and readily

crystallises. It is used for separating glycocoll from other compounds. Like other acids glycocoll forms esters, amides, etc.

With acids it reacts as a *base* and also forms salts. Thus with hydrochloric acid the salt glycocoll hydrochloride

$$HO{\cdot}OC{\cdot}CH_2{\cdot}\overset{+}{N}H_3\}Cl^-$$

is formed.

Glycocoll has the characteristic properties of a primary amine. Thus nitrous acid substitutes hydroxyl for the amino-group and so converts it into hydroxyacetic acid:

$$HO{\cdot}OC{\cdot}CH_2{\cdot}NH_2 + HO{\cdot}NO = HO{\cdot}OC{\cdot}CH_2{\cdot}OH + N_2 + H_2O.$$

Its ester ethyl aminoacetate behaves in an interesting manner with nitrous acid, recalling the behaviour of the aromatic compounds (§§ 382, 395) though not identical with it. Instead of ethyl hydroxyacetate, as would be expected, *ethyl diazoacetate* is formed:

$$C_2H_5{\cdot}O{\cdot}CO{\cdot}CH_2{\cdot}NH_2 + HNO_2 = C_2H_5{\cdot}O{\cdot}CO{\cdot}CH = N_2 + 2H_2O.$$

This compound is considered to be a 'resonance-hybrid' of the two forms

$$C_2H_5{\cdot}O{\cdot}CO{\cdot}CH = N \rightleftharpoons N \text{ and } C_2H_5{\cdot}O{\cdot}CO{\cdot}CH \rightleftharpoons N \equiv N$$

and it is of interest because it was the original source of hydrazine $\begin{matrix}NH_2\\|\\NH_2\end{matrix}$ and hydrazoic acid $N \rightleftharpoons N = N - H \rightleftharpoons N \equiv N \rightarrow N - H$.

QUESTIONS

(1) How is monochloroacetic acid prepared? How does it react with water, ammonia, phosphorus halides?

(2) How does the strength of a derivative of acetic acid vary with the substituent groups contained in it? Illustrate your answer by reference to chloroacetic acid and to glycocoll.

(3) Indicate the steps you would take to prepare from acetic acid, 20 g. of chloroacetyl chloride, and to isolate the product (b.p. 143·5° C.) of its reaction with ethyl alcohol.

(4) How is glycocoll prepared? Describe its chemical properties. In what respect does it resemble and differ from (*a*) methylamine, (*b*) acetic acid?

(5) How are the amino-acids related to the proteins? How would you try to prepare glycocoll from glue?

(6) The hydrochloride of a mono-amino-acid of formula

$$NH_2{\cdot}C_nH_{2n}{\cdot}CO{\cdot}OH$$

contained 28·3 per cent. of chlorine. What is its formula? How would you try to find out whether the carboxyl and amino-groups were attached to the same carbon atom?

CHAPTER XVII

THE HYDROXY-ACIDS

Common Hydroxy-acids

Monobasic.		Dibasic.			Tribasic.
Corresponding Fatty acid.	Hydroxy-acid.	Corresponding acid of Oxalic Series.	Monohydroxy-acid	Dihydroxy-acid.	Monohydroxy-acid.
CH_3 | $CO\,OH$ Acetic acid	$CH_2\,OH$ | $CO\,OH$ Glycollic acid.	$CO\,OH$ | $CO\,OH$ Oxalic acid.			
CH_3 | CH_2 | $CO{\cdot}OH$ Propionic acid.	$CH_2\,OH$ CH_3 | | CH_2 $CH\,OH$ | | $CO\,OH$ $CO\,OH$ Hydracrylic acid. Lactic acid.	$CO\,OH$ | CH_2 | $CO\,OH$ Malonic acid.	$CO{\cdot}OH$ | $CH\,OH$ | $CO\,OH$ Tartronic acid		
		$CO\,OH$ | CH_2 | CH_2 | $CO\,OH$ Succinic acid	$CO\,OH$ | $CH{\cdot}OH$ | CH_2 | $CO\,OH$ Malic acid	$CO\,OH$ | $CH{\cdot}OH$ | $CH{\cdot}OH$ | $CO{\cdot}OH$ Tartaric acid.	
					$CH_2{\cdot}CO{\cdot}OH$ | $HO{\cdot}C{\cdot}CO{\cdot}OH$ | $CH_2{\cdot}CO{\cdot}OH$ Citric acid.

228. Naturally Occurring Hydroxy-acids.—The compounds containing both carboxyl and hydroxyl are known as hydroxy-acids and some of them are of great importance as occurring naturally in animals and plants.

The most important of these are:

Lactic acid	α-hydroxypropionic acid.
Malic acid	α-hydroxysuccinic acid.
Tartaric acid	αβ-dihydroxysuccinic acid.
Citric acid	β-hydroxypropane-αβγ-carboxylic acid.

The relationship between these acids and the fatty acids and oxalic series is shown in the table on p. 227.

The chemistry of all these except the last is complicated by the occurrence of *stereo-isomerides*, the nature of which is explained in § 232 *ff*.

The simplest hydroxy-acid is *hydroxyacetic acid* (glycollic acid).

229. Hydroxyacetic Acid, Glycollic Acid, $HO{\cdot}CH_2{\cdot}CO{\cdot}OH$.—Gly-

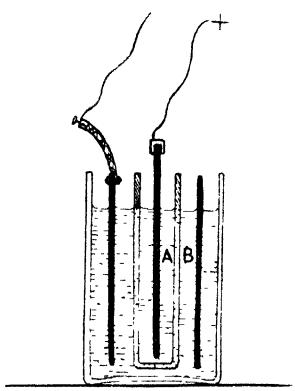


FIG. 37.—Preparation of glycollic acid by electrolytic reduction

collic acid occurs in sugar-cane juice, but is always prepared synthetically.

Preparation.—(1) Glycollic acid is usually made by the hydrolysis of chloroacetic acid, which may be boiled with water. Marble is added to the mixture to neutralise the acid formed and make the reaction more complete:

$$CH_2Cl{\cdot}CO{\cdot}OH + H_2O \rightleftharpoons HO{\cdot}CH_2{\cdot}CO_2H + HCl.$$

(2) Oxalic acid may be reduced electrolytically (Fig. 37). An electrolytic cell contains a sheet lead cathode surrounded by a solution of oxalic acid in dilute sulphuric acid. The anode is immersed in a porous pot containing dilute sulphuric acid. The solution is kept at 35° C. and a current is passed for several hours. The hydrogen liberated at the cathode reduces the oxalic acid:

$$\begin{matrix}CO\cdot OH\\|\\CO\cdot OH\end{matrix} + 4H = \begin{matrix}CH_2\cdot OH\\|\\CO\cdot OH\end{matrix} + H_2O.$$

Any excess of oxalic acid is separated by treating the liquid with calcium carbonate. Calcium glycollate is soluble, while calcium sulphate and oxalate are not.

(3) The oxidation of glycol (§ 188) with dilute nitric acid yields glycollic acid:

$$\begin{matrix}CH_2\cdot OH\\|\\CH_2\cdot OH\end{matrix} + 2O = \begin{matrix}CH_2\cdot OH\\|\\CO\cdot OH\end{matrix} + H_2O.$$

Properties.—Glycollic acid forms colourless crystals, freely soluble in water, alcohol and ether. It melts at 80° C.

Glycollic acid behaves both as a primary alcohol and as an acid.

GLYCOLLIC ACID

$$\begin{matrix}CH_2\cdot OH\\|\\CO\cdot OH\end{matrix}$$

(Hydroxyacetic acid)

Reacts as an alcohol to form	*Reacts as an alcohol and an acid to form*	*Reacts as an acid to form*
$\begin{matrix}CH_2\cdot O\cdot C_2H_5\\|\\CO\cdot OH\end{matrix}$ Ethyl glycollic acid (ether and acid).	$\begin{matrix}CH_2\cdot O\cdot C_2H_5\\|\\CO\cdot O\cdot C_2H_5\end{matrix}$ Ethylic ethyl glycollate (ether and ester).	$\begin{matrix}CH_2\cdot OH\\|\\CO\cdot OC_2H_5\end{matrix}$ Ethyl glycollate (ester and alcohol).
$\begin{matrix}CH_2\cdot Cl\\|\\CO\cdot OH\end{matrix}$ Monochloroacetic acid (halide and acid).	$\begin{matrix}CH_2\cdot Cl\\|\\COCl\end{matrix}$ Chloroacetyl chloride (halide and acid halide).	
	$\begin{matrix}CH_2\cdot ONa\\|\\CO\cdot ONa\end{matrix}$ Disodium glycollate (alcoholate and salt).	$\begin{matrix}CH_2\cdot OH\\|\\CO\cdot ONa\end{matrix}$ Sodium glycollate (salt and alcohol).
		$\begin{matrix}CH_2\cdot OH\\|\\CO\cdot NH_2\end{matrix}$ Glycollamide (amide and alcohol).

Reactions as an Acid.—Glycollic acid forms salts and esters, known as glycollates, and an amide. It does not form an acid chloride.

Reactions as an Alcohol.—Glycollic acid is oxidised by nitric acid to oxalic acid:

$$\begin{array}{l}CH_2\cdot OH\\ |\\ CO\cdot OH\end{array} + 2O = \begin{array}{l}CO\cdot OH\\ |\\ CO\cdot OH\end{array} + H_2O.$$

It forms the usual derivatives of an alcohol, *e.g.*, ethers, halides, and esters in which it reacts with *acids*, which must be distinguished from the esters formed when it reacts as an acid with another alcohol.

Reactions as both Alcohol and Acid.—Finally the alcohol and acid groups may both react, forming the compounds shown in the centre column of the scheme given above.

When glycollic acid is heated to 100° C., one molecule of it, acting as an acid, forms an ester with another molecule acting as an alcohol. The compound is called glycollic anhydride.

$$HO\cdot CH_2\cdot CO\cdot OH + HO\cdot CH_2\cdot CO\cdot OH = HO\cdot CH_2\cdot CO\cdot O\cdot CH_2\cdot CO\cdot OH + H_2O.$$

230. The Lactic Acids or Hydroxypropionic Acids, $C_3H_6O_3$.—At first sight only two hydroxypropionic acids would be expected:

$$\begin{array}{l}CH_3\\ |\\ CH\cdot OH\\ |\\ CO\cdot OH\end{array}$$

α-Hydroxypropionic acid (Ethylidenelactic acid).

$$\begin{array}{l}CH_2\cdot OH\\ |\\ CH_2\\ |\\ CO\cdot OH\end{array}$$

β-Hydroxypropionic acid (Ethylenelactic acid).

Both of these are known, but the first of them exists in three forms which differ in their behaviour towards polarised light.

231. Preparation and Constitution of Ethylidenelactic Acid (α-Hydroxypropionic Acid) —α-Hydroxypropionic acid is prepared by—

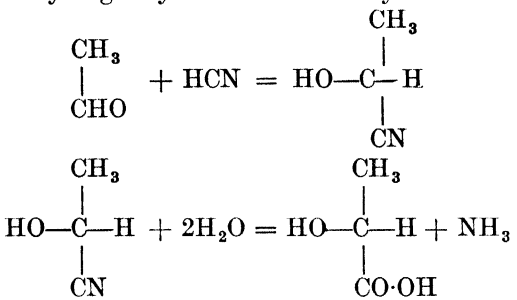
(1) Oxidation of propylene glycol, which may itself be prepared by gently oxidising propylene:

$$\begin{array}{l}CH_3\\ |\\ CH\\ \|\\ CH_2\end{array} \xrightarrow{H_2O + O} \begin{array}{l}CH_3\\ |\\ CH\cdot OH\\ |\\ CH_2\cdot OH\end{array} \longrightarrow \begin{array}{l}CH_3\\ |\\ CH\cdot OH\\ |\\ CO\cdot OH\end{array}$$

(2) By the action of water and alkalis on α-chloropropionic acid, itself prepared by the action of chlorine on propionic acid:

$$\begin{array}{l}CH_3\\ |\\ CH_2\\ |\\ CO\cdot OH\end{array} \xrightarrow{Cl_2} \begin{array}{l}CH_3\\ |\\ CH\cdot Cl\\ |\\ CO\cdot OH\end{array} \xrightarrow{Ba(OH)_2} \begin{array}{l}CH_3\\ |\\ CH\cdot OH\\ |\\ CO\cdot OH\end{array}$$

(3) By hydrolysis of acetaldehyde-cyanohydrin (§ 70), prepared by the action of hydrogen cyanide on acetaldehyde:



These three methods of synthesis make it quite clear that lactic acid is α-hydroxypropionic acid.

(4) Lactic acid is commonly made by fermentation of sugars. When milk becomes sour certain species of bacteria—the lactic bacilli—convert the sugars contained in it into lactic acid. In the laboratory we make a solution of glucose and add sour milk or a culture of the lactic acid bacillus together with chalk or zinc carbonate. The mixture is kept at about blood heat for about ten days. The acid is formed in quantity, and since it is deleterious to the bacilli it is removed as fast as it is formed by reaction with the chalk or zinc carbonate added to the mixture.

The lactic acid prepared in this way is ordinarily identical with synthetic lactic acid, but if a particular type of bacillus is employed, the so-called *l*-lactic acid is obtained which rotates the plane of polarised light to the left (§ 232).

Lactic acid is found in the muscles of animals and is formed by the breaking down of the glycogen (§ 298) they contain. This reaction furnishes the energy required for muscular work. The lactic acid produced in the muscles is reconverted into glycogen during rest, the necessary energy being supplied by the oxidation of glycogen by the oxygen of the blood. The lactic acid obtained from muscle is called sarcolactic acid or *d*-lactic acid. It rotates the plane of vibration of polarised light to the right.

232. Stereoisomerism of Lactic Acid.—The lactic acids made by syntheses 1–3, by fermentation with the *l*-lactic bacillus and by extraction from animal tissues, *are identical in their chemical properties and in most of their physical properties.*

The solubilities of the salts of the synthetic acid differ, however, slightly from those of the acids obtained by fermentation and from animal tissues. A marked difference between the three forms of lactic acid is at once noticeable when their effect on polarised light is examined.

233. Polarised Light.[1]—Light is a transverse vibration, which, in an ordinary ray of light, is being executed in all planes simultaneously or in very rapid succession. By passage through certain crystals, notably Iceland spar, a ray of light is broken up into two rays, each of which consists of *vibrations in one plane only*, and is said to be polarised. The two rays have, for certain directions through the crystal, different speeds and therefore can be made to leave the crystal in paths slightly inclined to each other; by cutting a crystal of Iceland spar at an appropriate angle and cementing it with



Ordinary light: vibration in all planes.



Polarised light: vibration in (say) a vertical plane.



Same polarised light after passage through a solution of a dextro-rotatory substance: plane of vibration rotated clockwise.

Canada balsam, one ray may be totally reflected while the other passes on. This arrangement is known as a Nicol prism (Fig. 38). If the emergent polarised ray is now incident on a second Nicol prism it will pass through at full intensity only if the latter is oriented in the same direction as the polarising prism; and if it is set at right angles to the position of the polarising prism, no light will pass through it. In intermediate positions light of varying intensity is transmitted. It is thus possible to find the plane in which polarised light is vibrating by discovering the positions in which a Nicol prism must be set to give the maximum light or darkness. Now it is found that if a polarised ray passes through solutions of certain substances, the direction of the plane in which the polarised light is vibrating is rotated through an angle which depends on the length of solution traversed, the strength of the solution and finally on the substance used.

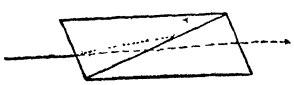


FIG. 38.—Nicol prism.

The instrument used for the study of this phenomenon is called a polarimeter. The modern instrument has many refinements leading to increased accuracy, but the principle is most easily understood from a description of the original type of instrument. A source of monochromatic light, *e.g.*, a sodium flame at A, gives a beam of light which passes through the polarising Nicol prism N_1 and is polarised. The light is then vibrating wholly in one plane. The plane of vibration

[1] The student unfamiliar with the phenomena associated with polarised light should consult a text book of Physics.

is ascertained by rotating the analysing Nicol prism N_2 mounted on a graduated circle until the maximum degree of darkness is reached. A tube T filled with the liquid to be examined is then placed between the polarising and analysing prisms. In traversing this tube the direction of the plane of vibration of the light is rotated through some angle. In order to discover this angle the analysing prism N_2 is rotated until the maximum degree of darkness is again obtained and the angle through which it has been rotated is measured. Clearly this

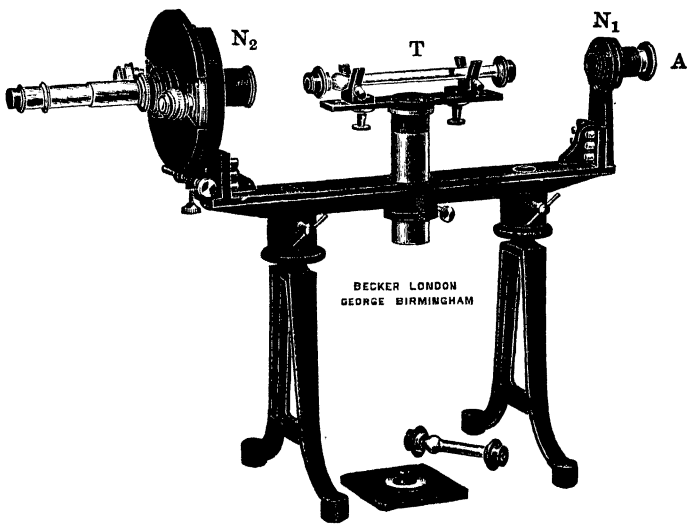


FIG. 39.—Polarimeter.

is equal to the angle through which the plane of polarisation has been rotated by the liquid.

The refinements on this early type of instrument have been mainly directed to (*a*) a more exact means of measuring the point of maximum darkness; (*b*) the use of accurately monochromatic light; (*c*) arrangements for keeping the liquid to be examined at a fixed and constant temperature. It is impossible to adjust the analysing Nicol in the simplest form of polarimeter so that it absolutely extinguishes the light, and there is a range of several degrees over which darkness is nearly complete. There are several more accurate forms of the instrument, of which the *biquartz polarimeter* is perhaps the easiest to understand. In this, the plane-polarised light, before reaching the solution, passes through the *biquartz*; this consists of two semicircles, each occupying half the field of view (Fig. 40); P is of

left-handed quartz, Q of right-handed quartz, and both are of such a thickness (about 3·75 mm.) as to produce a rotation of nearly 90°. Thus if the light were originally polarised along OA the two halves of the field of view would transmit light polarised respectively along OB and OB^1; each of these is rotated by the solution; thus the field of view through the analyser has two halves, each illuminated by plane polarised light, the planes being, say, OC and OC^1, such that $\angle COC^1 = \angle BOB^1$.

Clearly, when the analysing Nicol has its plane along the bisector OD the field consists of two equally dim halves, and a slight movement either way makes a marked contrast in brightness. This is for sodium yellow light; the amount of rotation by quartz depends on the wavelength of the light, so that if white light be used, the two halves of the field assume, at the critical position, the same tint—

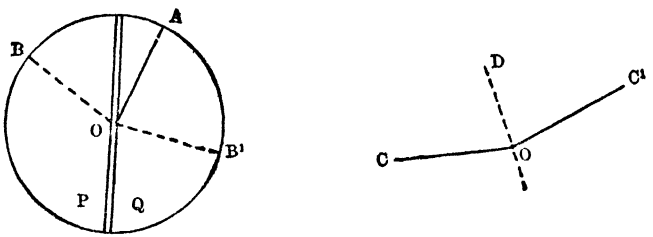


FIG. 40.—Biquartz.

a greyish-violet, known as the *sensitive tint*; slight rotation makes one blue and the other red, so that very accurate setting is possible. There are many commercial adaptations of this method, since the sensitive tint is easily recognised and used, even by the inexpert.

Many substances will rotate the plane of polarised light and a study of these reveals the remarkable fact that the only substances of which the solutions[1] have this effect are those which have *asymmetric molecules*.

234. Effect of the Lactic Acids on Polarised Light.—It is found on examination by the polarimeter that the synthetic lactic acid does not alter the plane of vibration of polarised light.

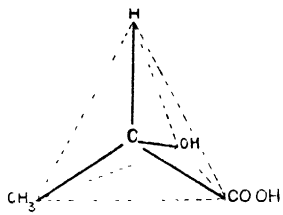
The lactic acid made by fermentation with certain pure strains of bacteria is found to rotate the plane of polarised light to the left (anti-clockwise as we face the source of light) and is called lævo-lactic acid or *l*-lactic acid. The lactic acid obtained from muscle turns the plane of polarised light to the right by a precisely equal amount and

[1] *Crystals* of many substances, *e.g.*, quartz, rotate the plane of polarised light. The phenomenon is due to an asymmetric arrangement of molecules, not to asymmetry of the individual molecule.

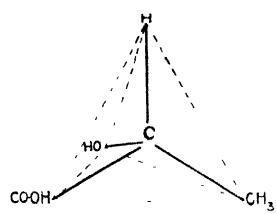
is called dextro-lactic acid or *d*-lactic acid. By methods which will be discussed later it can be shown that synthetic lactic acid is a mixture of these two in equal proportions. It is therefore called *dl*-lactic acid.

235. Asymmetry of the Lactic Acid Molecule.—An object is said to be asymmetric when it cannot be divided by a plane into two precisely identical halves. A symmetrical object can be so divided. A hand[1] is an asymmetric object; a pear, on the other hand, is (ideally) symmetrical, for a plane drawn lengthways through the centre of the fruit separates it into identical halves.

A test for asymmetry which is readily applied is based on the fact that an asymmetrical object cannot be made to coincide with its reflection in a mirror. The image of a right hand in a mirror is a left hand and the two cannot be made to coincide [1] The image of a pear in a mirror could be made to coincide, in imagination at least, with the pear itself.



I.



II.

If, as we decided was a reasonable hypothesis (§§ 19, 20), the valencies of a carbon atom are exerted in the direction of the points of an imaginary tetrahedron circumscribing the atom, it will at once be obvious that the molecule of lactic acid is asymmetrical and can therefore exist in two possible forms, which are the mirror images of each other and which cannot be made to coincide. Formulæ I and II both represent α-hydroxypropionic acid, $CH_3{\cdot}CH(OH){\cdot}CO{\cdot}OH$, but they are not identical. The molecules represented by Formulæ I and II are in fact mirror-images of each other and are said to be *enantiomorphous*. If any three of the groups are laid one on the other, the carbon atoms and the remaining groups will lie on *opposite sides* of the plane of the other three. We cannot say which of the above formulæ represents dextrolactic acid and which lævolactic, for the mechanism by which the plane of polarised light is rotated has not yet been elucidated.

[1] Remember the hand is a solid figure and the front is different from the back. Plane two-dimensional figures of the shapes of the outline of a right and left hand could be made to coincide.

This principle may obviously be extended and we may say that *any compound in which a carbon atom is attached to four different groups will be asymmetric and will exist in two forms which will rotate the plane of polarised light in opposite directions.* These forms are said to be stereoisomeric.

The three α-hydroxypropionic acids are then:

(1) *d*-lactic acid (from muscle)
(2) *l*-lactic acid (by fermentation) } Formulæ I and II
(3) *dl*-lactic acid (synthetic). Equal proportions of *d*- and *l*-lactic acids.

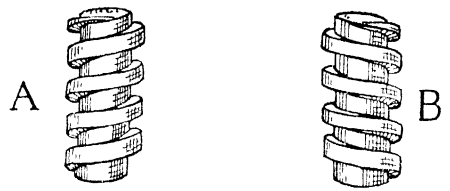
236. Separation of the Two Isomerides from *dl*-Lactic Acid.—Since dextro- and lævo-lactic acids are identical in their ordinary properties it might seem hopeless to try and separate them from the synthetic lactic acid containing both. None the less, the genius of Pasteur, who elucidated the first case of stereoisomerism by his study of tartaric acid (*q.v.* §§ 242–247), succeeded in devising three ways of separating these stereoisomerides.

(1) The first method depends on the fact that the asymmetry of the molecules of the isomerides manifests itself in an asymmetry of the crystals of some of their compounds. Just as the molecules of the two active lactic acids differ in the same way as an object and its reflection in a mirror, so do the crystals of zinc ammonium *d*-lactate and zinc ammonium *l*-lactate $Zn(C_3H_5O_3)_2$, $2NH_4C_3H_5O_3$, $2H_2O$ differ in their internal structure. If the above salt is prepared from ordinary lactic acid (*d*-lactic acid and *l*-lactic acid) both lactates will be present in the product. If a supersaturated solution of these lactates is made and a crystal of, say, the *d*-lactate is added, the *d*-lactate in the solution will crystallise out on it as a nucleus, while the *l*-lactate, having a crystal of different molecular arrangement, will not. The crops of the *d*- and *l*-lactate crystals so obtained can be decomposed by the usual methods and *d*- and *l*-lactic acids prepared from them. In the case of the tartaric acids (§ 247), the crystals of sodium ammonium *d*-tartrate are *visibly* mirror images of the crystals of sodium ammonium *l*-tartrate. The crystals can in this instance be separated by hand-picking. The crystals of zinc ammonium lactate are not well enough formed for this process to be possible.

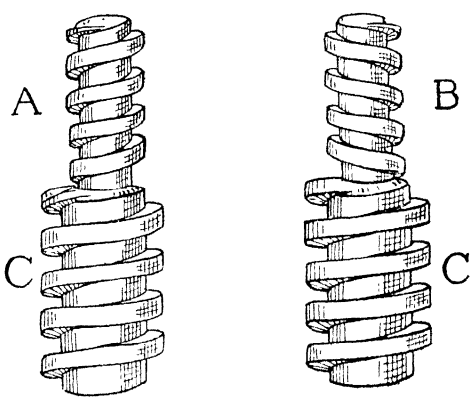
(2) A second method of separation depends on the fact that while the molecules of the two isomerides differ only as an object and its mirror-image, the compounds of these with another *asymmetric* substance no longer differ only in this way, but are entirely different. This is difficult to illustrate by molecular diagrams, but may be illustrated by combinations of simple asymmetric objects. A right-

handed and left-handed screw (A, B) are asymmetric objects which are mirror-images of each other.

If we combine each of these with another screw (say right-handed) we obtain two objects (AC, BC) wholly different and not merely mirror images.



Right-handed screw & left-handed screw
are mirror-images.



Combinations of

Two right-handed screws & a left-handed and a right-handed screw

are not mirror-images.

FIG. 41.

The method used to separate the two optically active lactic acids from the *dl*-lactic acid is to form a salt of the latter with an optically active base, say *l*-strychnine. It is found that *l*-strychnine *d*-lactate has a different solubility from *l*-strychnine *l*-lactate. The two salts can be separated by fractional crystallisation and then decomposed, yielding the *d*- and *l*-lactic acids.

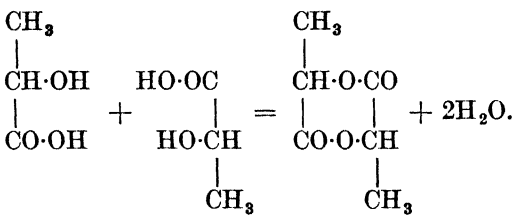
(3) Living creatures are composed mainly of asymmetric compounds, and for this reason they usually assimilate one stereoisomeride more easily than the other. The moulds and bacteria have a

catholic taste in foods and can be made to assimilate a great variety of substances. If green mould, *Penicillium glaucum*, is grown in a solution of ammonium *dl*-lactate it assimilates the *l*-lactate more rapidly than the *d*-lactate. Accordingly, the latter accumulates and the solution becomes dextrorotatory. A complete separation is difficult.

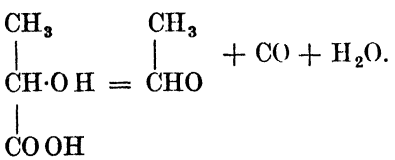
Modifications of these methods avail to separate most stereoisomerides. The first method is difficult to apply, for it is not possible to prepare large crystals of the derivatives of many substances, nor is it always possible to obtain a crystal of one stereoisomeride with which to seed the supersaturated solution of the inactive mixture. The second is the most valuable method. Acids are usually combined with the bases strychnine and brucine; bases with *d*-camphorsulphonic acid. The third method does not usually afford a complete separation, and moreover it is not always possible to persuade a mould or bacterium to feed upon the substance to be split up.

237. Properties of Lactic Acid.—Lactic acid, as commonly met with, is a thick syrupy liquid from which ordinary evaporation will not remove all the water without decomposing the acid. By evaporation *in vacuo* the pure acid is obtained as crystals melting at 18° C. Ordinary 'syrupy' lactic acid contains about 25 per cent. of lactide (*v.* below). Lactic acid is soluble in water, alcohol and ether. It is a stronger acid than acetic acid.

Lactic acid when heated forms lactide, which is really an ester formed from two molecules of the acid, the carboxyl of one forming an ester with the hydroxyl of the other:



Lactic acid when heated also breaks up to some extent into acetaldehyde, carbon monoxide and water:



Lactic acid forms salts with the metals and, like glycollic acid, reacts both as an alcohol and an acid. It forms the analogues to all the

derivatives of glycollic acid given in § 229. The student may with advantage try to write their formulæ.

When oxidised, lactic acid forms acetic acid and carbon dioxide:

$$\begin{array}{l} CH_3 \\ | \\ CH{\cdot}OH \\ | \\ CO{\cdot}OH \end{array} + O_2 = \begin{array}{l} CH_3 \\ | \\ CO{\cdot}OH \end{array} + CO_2 + H_2O.$$

238. Ethylene-lactic acid, β-Hydroxypropionic acid, Hydracrylic acid, $CH_2(OH)—CH_2—CO{\cdot}OH$.—β-Hydroxypropionic acid exists only in one form, for its molecule is not asymmetric. It differs in several respects from lactic acid, giving different products on oxidation (oxalic acid and carbon dioxide), and also on heating, when acrylic acid (§ 178) is formed instead of an anhydride:

$$\begin{array}{l} CH_2{\cdot}OH \\ | \\ CH_2 \\ | \\ CO{\cdot}OH \end{array} = \begin{array}{l} CH_2 \\ \| \\ CH \\ | \\ CO{\cdot}OH \end{array} + H_2O$$

239. Higher Hydroxy-acids: Lactones.—Numerous higher hydroxy-acids exist, and in general resemble lactic acid. Those hydroxy-acids which have the carboxyl and hydroxyl groups somewhat separated readily lose water and form *lactones*. Thus γ-hydroxybutyric acid readily forms γ-butyrolactone when heated:

$$\begin{array}{l} CH_2—CH_2—OH \\ | \\ CH_2—CO—OH \end{array} = \begin{array}{l} CH_2—CH_2—O \\ | \qquad\quad | \\ CH_2—CO—\quad | \end{array} + H_2O$$

They are comparatively stable liquids which distil without decomposition. They are not formed from α-hydroxy-acids, with difficulty from β-acids, but most easily from γ- and δ-hydroxy-acids. This is thought to be due to the tetrahedral arrangement of the valencies of the carbon atom bringing the hydroxyl and carboxyl groups nearest to each other in the γ- and δ-acids (cf. § 267 on the same phenomenon in the sugars).

MONOHYDROXY-DIBASIC ACIDS

240. Tartronic Acid.—The simplest acid of this type is tartronic acid (hydroxymalonic acid)—

$$\begin{array}{l} CO{\cdot}OH \\ | \\ H{\cdot}C{\cdot}OH \\ | \\ CO{\cdot}OH \end{array}$$

It is obtained by careful oxidation of glycerol with potassium permanganate.

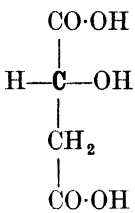
The only important member of the series is malic acid.

241. Malic Acid, Hydroxysuccinic Acid,

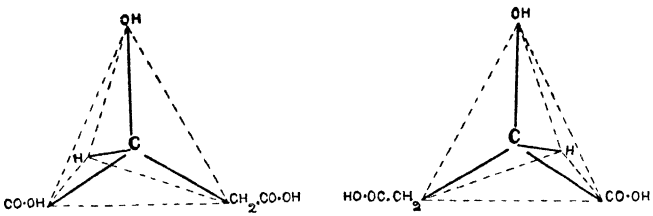
$$HO{\cdot}OC{\cdot}CH(OH){\cdot}CH_2{\cdot}CO{\cdot}OH$$

Occurrence and Stereoisomerism.—Malic acid is found in a great variety of fruits—unripe apples and grapes, mountain-ash berries, etc. The acid obtained from these sources is lævo-rotatory. The acid made by the synthetic methods mentioned below is inactive, and a dextrorotatory malic acid has been prepared from it by methods similar to those used to split up *dl*-lactic acid.

As the syntheses (1 and 2 below) show, its formula is



The C atom shown in Clarendon type is attached to four different groups and the molecule is asymmetric, existing in the two forms, *d*-malic and *l*-malic acid, represented by the formulæ:



d- and *l*-Malic acids.

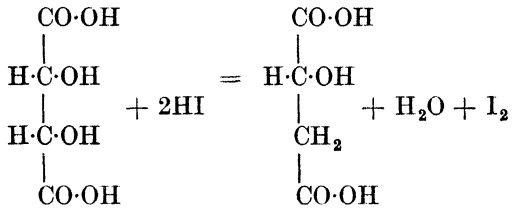
The inactive malic acid is an equimolecular mixture of these.

Preparation.—(1) Malic acid may be synthesised by the action of moist silver oxide on bromosuccinic acid.

$$\begin{array}{l} CO{\cdot}OH \\ | \\ CH_2 \\ | \\ CH_2 \\ | \\ CO{\cdot}OH \end{array} + Br_2 = \begin{array}{l} CO{\cdot}OH \\ | \\ CHBr \\ | \\ CH_2 \\ | \\ CO{\cdot}OH \end{array} + HBr: \quad \begin{array}{l} CO{\cdot}OH \\ | \\ CHBr \\ | \\ CH_2 \\ | \\ CO{\cdot}OH \end{array} + AgOH = \begin{array}{l} CO{\cdot}OH \\ | \\ CH{\cdot}OH \\ | \\ CH_2 \\ | \\ CO{\cdot}OH \end{array} + AgBr$$

Succinic acid. Bromosuccinic acid. Malic acid.

(2) The reduction of tartaric acid by means of hydrogen iodide also gives malic acid:



(3) *l*-Malic acid may be made from unripe mountain-ash berries, and these, when obtainable, are the most convenient source of the acid. The berries are crushed and the juice is evaporated somewhat and neutralised with milk of lime. Calcium malate is precipitated, filtered off and washed, and dissolved in warm dilute nitric acid. Calcium hydrogen malate is thus formed which can be recrystallised. This reacts with lead acetate, giving insoluble lead malate, which may be suspended in water and decomposed by hydrogen sulphide. The lead sulphide is filtered off and the solution of malic acid concentrated to a syrup and left to crystallise.

Properties.—Malic acid crystallises in needles which are soluble in water and alcohol. It melts at 100° C.

When heated more strongly, malic acid decomposes, forming maleic anhydride, which vaporises, and fumaric acid, which remains (*v.* §§ 216, 217).

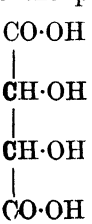
Malic acid, like other hydroxy-acids, forms the usual derivatives of an acid. It forms normal and acid salts with metals, and esters with alcohols. It also forms an amide.

As an alcohol it is less reactive than, say, glycollic acid, but the hydroxyl group will form an ester (acetyl derivative) when treated with acetic anhydride.

DIHYDROXY-DIBASIC ACIDS

The only important dihydroxy-dibasic acids are tartaric acid and its isomerides.

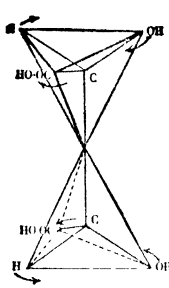
242. Tartaric Acid, Dihydroxysuccinic Acid, $C_4H_6O_6$.—The molecule of tartaric acid contains two asymmetric carbon atoms and it is well to consider at once the possible stereoisomerides we might obtain in this way.



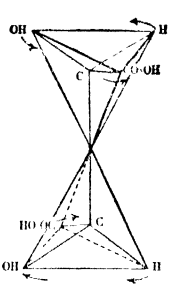
The two asymmetric carbon atoms each have the groups H, OH, CO·OH and –CH(OH)—CO·OH attached to them, and each of these two sets of groups may be so arranged as to rotate the plane of polarised light to the right or to the left. We may then have the molecules arranged in four ways.

	Rotates plane of polarised light to			
	1	2	3	4
Top carbon atom .	Left	Left	Right	Right
Lower carbon atom .	Left	Right	Left	Right
Whole molecule .	Left	No effect	No effect	Right

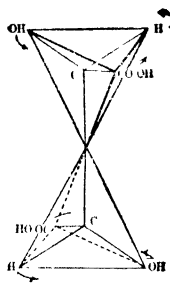
There should then be a lævotartaric acid (1), a dextrotartaric acid (4), and a truly inactive tartaric acid (2) and (3). But in the case of



Lævotartaric acid.



Dextrotartaric acid.



Mesotartaric acid.

(*See* footnote, p. 243.)

lactic and malic acids we found that the synthetic acid was *apparently* inactive, being a *mixture* or loose compound of *d*- and *l*-acids. Accordingly we might expect another tartaric acid of this type.

In actual fact four tartaric acids are known.

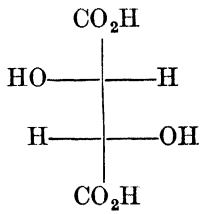
(i) Lævotartaric acid.

(ii) Dextrotartaric acid.

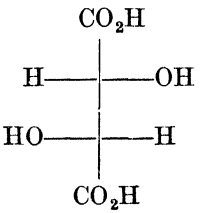
(iii) Inactive tartaric acid or mesotartaric acid, in which the two asymmetric carbon atoms *in the same molecule* neutralise each other's effect.

(iv) 'Racemic acid,' *dl*-tartaric acid, a compound of *separate molecules* of (i) and (ii).

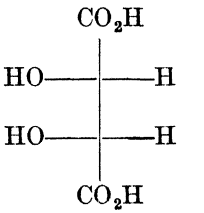
Since these three-dimensional representations are somewhat cumbrous, the positions of the groups are often expressed as a projection. Thus the above formulæ are written:



I.
Lævotartaric acid.



II.
Dextrotartaric acid.



III.
Inactive mesotartaric acid.

The asymmetric carbon atoms are only represented by the junctions of the lines. Note that in the first, the order of the groups H, OH, CO_2H is clockwise in both the upper and lower halves, and it is lævorotatory.[1] In the second the order is anti-clockwise in both, hence it is dextrorotatory. In the third the order is clockwise in the upper half, anti-clockwise below; hence no rotation.

243. Dextrotartaric acid is the ordinary acid found in nature. It occurs chiefly as the sparingly soluble acid potassium tartrate HO·OC·CH(OH)·CH(OH)·CO·OK. When wine is made, this acid potassium tartrate crystallises out as *argol* or lees of wine, and when recrystallised is known as cream of tartar. This is boiled with chalk and calcium chloride and forms neutral calcium tartrate:

$$2KHC_4H_4O_6 + CaCl_2 + CaCO_3 = 2CaC_4H_4O_6 + 2KCl + CO_2 + H_2O$$

The insoluble calcium tartrate is filtered off and decomposed by dilute sulphuric acid, liberating tartaric acid. The solution of the acid is filtered from calcium sulphate and crystallised.

The synthetic methods of preparing tartaric acid yield racemic acid (§ 247) or mesotartaric acid (§ 248) or both.

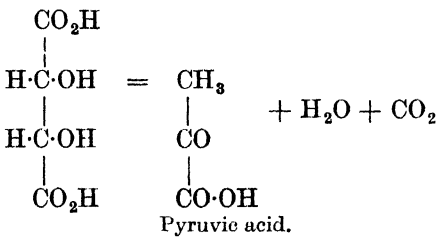
Dextrotartaric acid can also be made by splitting up racemic acid (*q.v.*).

Its chemical properties are identical with those of lævotartaric acid and differ only in minor points (*e.g.*, solubilities of certain salts) from those of racemic and mesotartaric acid.

Dextrotartaric acid forms large prismatic crystals with an acid taste. It is soluble in water and alcohol, but not in ether. It melts at 170° C.

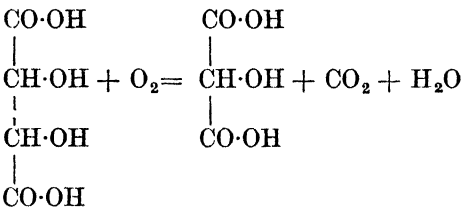
When heated it gives an anhydride and then breaks up into pyruvic acid together with other products.

[1] There is evidence in favour of choosing this formula for the dextro-acid and not the lævo- (Fischer, *Ber.*, 1896, **29** 1377). The solid models illustrated on p. 242 appear at first to be inconsistent with the description and projection formulæ. The lower tetrahedron must be viewed from the same position, *relative to its orientation*, as the top one. It must therefore be viewed *from below* when the apparent direction of rotation will appear reversed.



Pyruvic acid.

It is readily oxidised to tartronic acid. The equation is:



As a consequence of this reaction both tartaric acid and its salts will reduce a warm ammoniacal solution of silver nitrate, forming a silver mirror on the glass vessel containing it. This reduction is used in making silver mirrors.

Expt. 57.—*To Silver a Test-tube.*—Dissolve 0·7 g. of silver nitrate in 5 c.c. of distilled water, and add three or four drops of ammonia (sp. gr. 0·880) (only enough just to cause any precipitate to redissolve). Dissolve 0·25 g. of Rochelle salt (sodium potassium *d*-tartrate) in 2 c.c. of water ; cool, and mix the solutions. Clean a test-tube well, rinse it with stannous chloride solution and then with distilled water. Mix the solutions in it and immerse in a beaker of hot water. A brilliant mirror will form on the test-tube. The above proportions give good results but are not essential.

Tartaric acid forms salts with metals; the tartrates commonly met with, being prepared from the vegetable acid, are dextro-tartrates.

244. Salts and Esters of Tartaric Acid.—*Potassium hydrogen tartrate* (*Cream of Tartar*), $KH{\cdot}C_4H_4O_6$, is sparingly soluble in water. It is much used as a weak acid for making effervescing drinks, fruit salts, baking powders, etc. It can also be used as a standard for acidimetry and alkalimetry.

A qualitative test to detect potassium salts in presence of sodium salts is based on the slight solubility of potassium hydrogen tartrate. If a solution of a potassium salt is mixed with a solution of tartaric acid and an equal volume of alcohol, a white crystalline precipitate of potassium hydrogen tartrate is produced.

Potassium sodium tartrate, $KNaC_4H_4O_6 \cdot 4H_2O$, is known as Rochelle salt. It forms large well-defined crystals. It is used in silvering mirrors and in making Fehling's solution.

Potassium antimonyl tartrate, $K(SbO)C_4H_4O_6 \cdot \frac{1}{2}H_2O$, *tartar emetic*. —This salt is made by heating cream of tartar with antimony oxide and water. It is very poisonous and finds uses in medicine for the treatment of certain tropical parasitic diseases, *e.g.*, *kala-azar*. It is also used as a mordant in dyeing. In chemical work it affords a convenient soluble salt of antimony.

Esters.—Tartaric acid forms two series of esters which are made by the usual methods. Monoethyl tartrate,

$$C_2H_5O \cdot CO \cdot CH(OH) \cdot CH(OH) \cdot CO \cdot OH,$$

is a crystalline solid, while diethyl tartrate,

$$C_2H_5O \cdot CO \cdot CH(OH) \cdot CH(OH) \cdot CO \cdot OC_2H_5,$$

is an oily liquid.

The hydroxyl groups in tartaric acid are not very reactive but it forms acetyl derivatives in the nature of esters when it is treated with acetic anhydride.

245. Tests for Tartaric Acid.—Tartaric acid is distinguished from other common organic acids by the tests described in § 252. The following is a useful special test. To the solution add a freshly-made solution of ferrous sulphate and two drops of hydrogen peroxide. A yellow coloration which becomes violet on addition of alkalis, indicates a tartrate or free tartaric acid.

Expt. 58.—*Reactions of Tartaric Acid.*—(1) Heat, note acid vapours containing aldehyde, acetone, formic acid, etc.

(2) Heat with conc. H_2SO_4: note charring and evolution of SO_2.

(3) Heat with acid $K_2Cr_2O_7$ solution: evolution of CO_2.

(4) Add silver nitrate solution to a solution of tartaric acid, and then ammonia drop by drop till white ppt. of silver tartrate, at first formed, redissolves. Add a crystal of solid $AgNO_3$ and heat in a beaker of boiling water. Silver mirror formed near crystal.

(5) Add concentrated solution of tartaric acid to potassium chloride solution. Crystalline ppt. of potassium hydrogen tartrate.

(6) Neutralise a portion of the acid and add calcium chloride. White crystalline ppt. of calcium tartrate.

(7) To a solution of tartaric acid add a few drops of ferrous sulphate and then a little hydrogen peroxide. Yellow colour, becoming violet with alkalis.

246. Lævotartaric Acid.—Lævotartaric acid is made by separating the two isomerides from racemic acid (*q.v.*). It is precisely like dextrotartaric acid in all respects except in its action on polarised light and in the form of the crystals of some of its salts (Fig. 42).

247. Racemic Acid.—Racemic acid $(C_4H_6O_6)_2 \cdot 2H_2O$, is obtained from the racemates contained in the mother-liquor from which dextrotartaric acid has been made (§ 243).

It differs from the dextro- and lævo-acids in being inactive towards polarised light. It forms salts which are not identical with the *d*- and *l*-tartrates, differing in solubility, etc.

Racemic acid is a loose compound of *d*- and *l*-tartaric acid. It is formed when solutions of these two isomerides are mixed, heat being evolved—a fact which shows it to be a compound.

The separation of racemic acid into *d*- and *l*-tartaric acid was the first separation of an optically inactive substance into two active isomerides, and the name *racemic* compounds has been given to all such inactive loose compounds of active isomerides.

The methods employed were all discovered by Pasteur and they

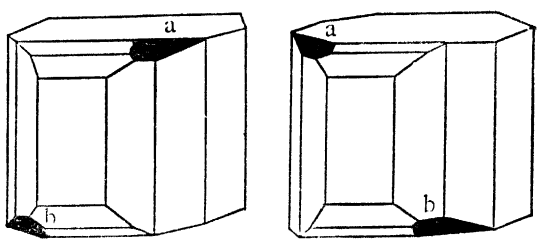


FIG. 42.—Enantiomorphic crystals of sodium ammonium *d*-tartrate and *l*-tartrate.

are similar to those already mentioned under the heading of lactic acid (§ 236).

Racemic acid has been separated into *d*- and *l*-tartaric acid by the following methods:

(1) If sodium ammonium racemate is crystallised below 27° C. it splits up into sodium ammonium *d*-tartrate and *l*-tartrate. These form fine crystals, having the forms illustrated in Fig. 42. These have small *hemihedral* faces (a, b), shown black in the diagram, situated in a manner which makes some of the crystals appear like mirror images of the others. By separating the two types of crystal by hand and preparing the free acid from each, pure *d*-tartaric acid and *l*-tartaric acid are obtained.

(2) Pasteur prepared the racemate of the alkaloidal base *d*-cinchonine. As explained in § 236 *d*-cinchonine *d*-tartrate and *d*-cinchonine *l*-tartrate differ not only stereochemically but also in other respects, such as solubility, and so are separable by fractional crystallisation.

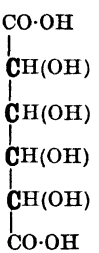
(3) Pasteur grew the mould *Penicillium glaucum* in solutions of

ammonium racemate. This mould was found to feed on the *d*-tartrate in preference to the *l*-tartrate and so the former was destroyed, leaving the latter.

248. Mesotartaric Acid.—Mesotartaric acid, which, as we have seen, has the opposite type of asymmetry in its two asymmetric carbon atoms (§ 242), is different from all the other acids in that it has a much lower melting point (143° C.). It differs also in solubility. It cannot be resolved into *d*- and *l*-tartaric acids.

POLYHYDROXY-DIBASIC ACIDS

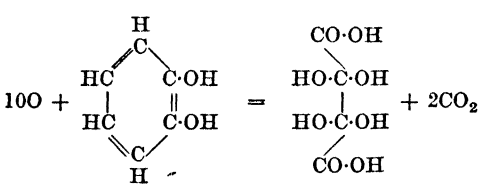
249. Saccharic Acid and Mucic Acid.—Saccharic acid and mucic acid, obtained by oxidising various sugars, gums, etc., are isomeric, and have the formulæ:



The formula contains four asymmetric carbon atoms and accordingly $2^4 = 16$ stereoisomerides are possible. Most of them are known. The acids are of some interest on account of their relation to the sugars.

250. Dihydroxytartaric Acid.—Dihydroxytartaric acid has the formula $HO{\cdot}OC{\cdot}C(OH)_2{\cdot}C(OH)_2{\cdot}CO{\cdot}OH$. In view of the rarity of two hydroxyl groups being attached to a single carbon atom, its formula has been written $(HOOC{\cdot}CO{\cdot}CO{\cdot}CO{\cdot}OH){\cdot}2H_2O$, but the first formula is the more probable.

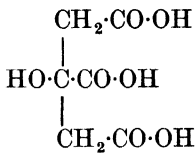
It is made by the action of nitrous acid on pyrocatechol:—



Its chief interest lies in the sparing solubility of its sodium salt. Sodium can be detected by adding a solution of dihydroxytartaric acid to a solution of the suspected salt. A colourless crystalline precipitate of disodium dihydroxytartrate is formed.

MONOHYDROXY-TRIBASIC ACID

251. Citric Acid, β-Hydroxypropane-αβγ-tricarboxylic Acid.



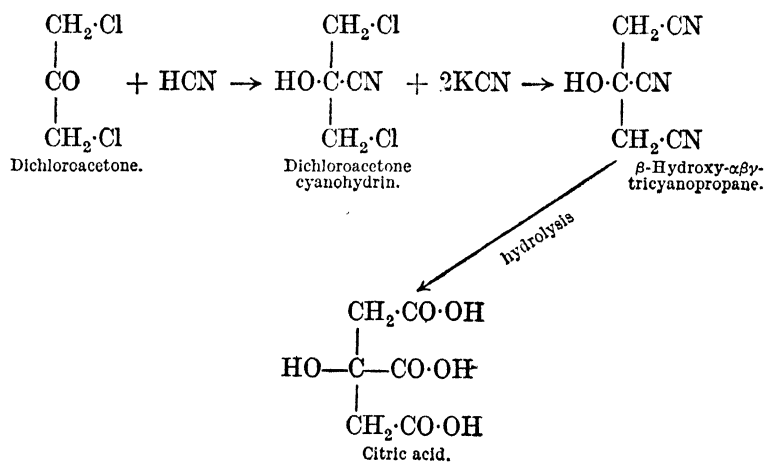
Preparation and Synthesis.—Citric acid occurs in various fruits, notably lemons and limes.

Concentrated lemon juice, prepared in Sicily from inferior and unsaleable fruit, is boiled with calcium carbonate (whiting) and water, whiting being added as long as any effervescence is produced. Calcium citrate is precipitated and is decomposed by addition of a slight excess of sulphuric acid. The solution of citric acid is filtered off and evaporated in leaden pans till it crystallises. Citric acid so made may contain lead, which is objectionable in foodstuffs. The concentrated liquid may be treated with hydrogen sulphide to precipitate the lead and then crystallised in vessels containing no lead.

Citric acid is now made by the fermentation of glucose with various species of mould, *Aspergillus* and *Citromyces*; the doubtless very complex reactions may be summarised by the equation:

$$3C_6H_{12}O_6 + 9O_2 = 2C_6H_8O_7 + 6CO_2 + 10H_2O$$

It has been synthesised from dichloroacetone, and this synthesis shows its composition:

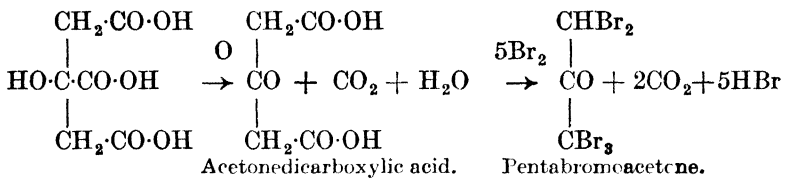


Properties.—Citric acid forms large rhombic crystals of the formula $C_6H_8O_7 \cdot H_2O$. It is soluble in water and alcohol, but not readily in

ether. Citric acid loses water at 130° C., and the anhydrous acid melts at 153° C.

The action of heat and also that of oxidising agents produces a variety of products. Citric acid forms stable salts with the metals. Being tribasic, it forms three series of salts and three series of esters. Citric acid is recognised by the tests given in § 252 below. It is also to be distinguished from other organic acids by Stahre's test.

To a solution of the free acid or a solution of a citrate in very dilute H_2SO_4, add 2–5 drops of $N/10$-potassium permanganate solution and warm to 30–40° C. (*do not boil*). When the solution becomes brown by precipitation of hydrated manganese dioxide, add 1 or 2 drops of ammonium oxalate and 1 c.c. of 10 per cent H_2SO_4, which will cause the solution to become clear. On adding a few drops of bromine water a crystalline precipitate of pentabromoacetone is obtained.



Acetonedicarboxylic acid. Pentabromoacetone.

252. Analytical Tests for the Common Solid Organic Acids.—The commonest solid organic acids, oxalic acid, tartaric acid and citric acid, are similar in appearance and simple tests for distinguishing between them are desirable.

Action of	Oxalic Acid and Oxalates.	Tartaric Acid and Tartrates.	Citric Acid and Citrates.
Concentrated H_2SO_4 on solid.	CO + CO_2 evolved on heating. *No charring* and no evolution of SO_2.	CO, CO_2, SO_2, etc., evolved. Empyreumatic odour: and liquid coloured brown.	Similar to tartrates.
Silver nitrate and ammonia on solutions.	White ppt. (which redissolves in excess of ammonia). No reduction on warming.	White ppt. (in neutral or alkaline solution only). Ppt. dissolves in ammonia and solution deposits a silver mirror *at 60°–70°* C. (Expt. 57).	As for tartaric but the silver mirror is only produced slowly and *on boiling.*
Calcium chloride on solutions.	White ppt. of calcium oxalate *insoluble in acetic acid* but soluble in hydrochloric acid.	White ppt. often only slowly formed, *soluble in acetic acid,* and less soluble in hot water than in cold.	No ppt. in cold neutral or acid solution. White ppt. in alkaline solution.

The special tests mentioned in §§ 207, 245, 251 may also be used.

QUESTIONS

(1) How is glycollic acid prepared? In what respects does it resemble (*a*) ethyl alcohol, (*b*) acetic acid?

(2) How does glycollic acid react with (*a*) sodium hydroxide, (*b*) phosphorus pentachloride, (*c*) nitric acid? What is formed when it is heated alone?

(3) What formulæ have lactic acid, malic acid, tartaric acid, citric acid? How many isomerides of these acids are known, and what are their names?

(4) How many acids of the formula $C_3H_6O_3$ are known? How could a specimen of each be prepared? What steps would you take to identify a specimen of one of these acids?

(5) What connection is there between the structure of a compound and its effect upon polarised light? Explain the term *stereoisomeride*, and indicate the method by which you would ascertain the effect of a given specimen of tartaric acid upon polarised light.

(6) Explain the existence of four isomeric tartaric acids. In what respects do their properties differ?

(7) How would you, starting from dibromosuccinic acid, prepare three of the stereoisomerides of tartaric acid?

(8) What is the formula of malic acid? How can it be synthesised, and how can it be converted into malonic acid?

(9) Compare the isomerism of maleic and fumaric acid with that of *d*- and *l*-tartaric acid.

(10) What are the chief uses of tartaric acid and its salts? How would you distinguish tartaric acid from oxalic acid and citric acid respectively?

(11) How many stereoisomerides (if any) of the following formulæ would you expect to exist:—

(1) $(CH_3)_2C(CO\cdot OH)\cdot CH_2\cdot C_2H_5$.

(2) $HO\cdot OC\cdot CH(OH)\cdot CH(OH)\cdot CH(OH)\cdot CO\cdot OH$.

CHAPTER XVIII

ALDEHYDIC AND KETONIC ACIDS: THE ACETOACETIC ESTER SYNTHESES

ALDEHYDIC ACIDS

ONLY one acid containing an aldehydic group is of sufficient importance to be mentioned, viz., glyoxylic acid, $\begin{matrix}\mathrm{CHO}\\|\\\mathrm{CO{\cdot}OH}\end{matrix}$.

253. Glyoxylic acid occurs in some unripe fruits. It is formed when glycol is oxidised (§ 188), but it is best made by heating dichloroacetic acid with water under pressure. Since two hydroxyl groups will not as a rule remain on a single carbon atom, dihydroxyacetic acid is presumably first formed and then breaks up, giving glyoxylic acid:

$$\begin{matrix}\mathrm{CHCl_2}\\|\\\mathrm{CO{\cdot}OH}\end{matrix} + 2\mathrm{H_2O} = \begin{matrix}\mathrm{CH(OH)_2}\\|\\\mathrm{CO{\cdot}OH}\end{matrix} + 2\mathrm{HCl}$$

$$\begin{matrix}\mathrm{CH(OH)_2}\\|\\\mathrm{CO{\cdot}OH}\end{matrix} = \begin{matrix}\mathrm{CHO}\\|\\\mathrm{CO{\cdot}OH}\end{matrix} + \mathrm{H_2O}$$

It is a crystalline solid which is easily soluble in water. It is readily oxidised to oxalic acid and reduced to glycollic acid:

$$\begin{matrix}\mathrm{CH_2{\cdot}OH}\\|\\\mathrm{CO{\cdot}OH}\end{matrix} \overset{2\mathrm{H}}{\leftarrow} \begin{matrix}\mathrm{CHO}\\|\\\mathrm{CO{\cdot}OH}\end{matrix} \overset{+\,\mathrm{O}}{\rightarrow} \begin{matrix}\mathrm{CO{\cdot}OH}\\|\\\mathrm{CO{\cdot}OH}\end{matrix}$$

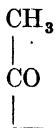
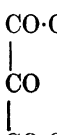
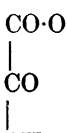
Glyoxylic acid is employed as Hopkins and Cole's reagent in testing for the amino-acid tryptophan, formed by the hydrolysis of many proteins. It gives a violet colouration with this acid. A solution of glyoxylic acid suitable for this test can be made by reducing oxalic acid with magnesium powder.

KETONIC ACIDS

Ketonic acids contain a carbonyl group as well as one or more carboxyl groups. The table on p. 252 gives a list of the more important; many others exist.

They are classified as α-, β-, or γ-ketonic acids, according to the position of the carbonyl group, the carbon atoms in the acid being

lettered α, β, γ, etc., counting the carbon atom attached to the carboxyl group as the α-atom.

α-Ketonic.	β-Ketonic.	γ-Ketonic.
	MONOBASIC.	
 Pyruvic acid.	 Acetoacetic acid.	 Lævulic acid.
	DIBASIC.	
 Mesoxalic acid.	 Oxalacetic acid.	

MONOBASIC α-KETONIC ACIDS

254. Pyruvic acid, $CH_3 \cdot CO \cdot CO \cdot OH$, obtained by distilling tartaric acid (§ 243), is the simplest of these. Its constitution is made clear by the fact that it can be made by hydrolysing acetyl cyanide:

$$CH_3 \cdot CO \cdot CN + 2H_2O = CH_3 \cdot CO \cdot CO \cdot OH + NH_3.$$

It is a liquid boiling at 165—170° C., and is a fairly strong acid. It has the reactions of a ketone, forming additional products with hydrogen cyanide, etc., as well as the reactions of an acid. Its rôle in processes of fermentation is discussed in § 301b.

MONOBASIC β-KETONIC ACIDS

255. Acetoacetic Acid, $CH_3 \cdot CO \cdot CH_2 \cdot CO \cdot OH$—This acid is of considerable importance in view of the use made of its ethyl ester in synthetic reactions (§ 258).

Acetoacetic acid is prepared by carefully hydrolysing the ester, which is made as described in § 256.

It is a liquid miscible with water, and is a fairly strong acid. It gives a red-violet colour with ferric chloride. It has the usual reactions of a ketone and an acid.

256. Ethyl acetoacetate, $CH_3 \cdot CO \cdot CH_2 \cdot CO \cdot OC_2H_5$, is made by the action of sodium on ethyl acetate containing a little alcohol.

The reaction, known as the *Claisen condensation*, appears to be:

(1) Formation of sodium ethoxide and its reaction with a molecule of ethyl acetate.

$$2C_2H_5OH + 2Na = 2C_2H_5ONa + H_2$$

$$CH_3{-}C(=O)(O{\cdot}C_2H_5) + Na{\cdot}OC_2H_5 = CH_3{\cdot}C(O{\cdot}C_2H_5)_2(ONa)$$

(2) Reaction of the product with another molecule of ethyl acetate:

$$CH_3{\cdot}C(O{\cdot}C_2H_5)_2(ONa) + H_2CH{\cdot}CO{\cdot}OC_2H_5 =$$

$$CH_3{-}C(ONa)=CH{-}CO{\cdot}OC_2H_5 + 2C_2H_5OH$$

The product thus obtained is the sodium derivative of acetoacetic ester. When treated with acetic acid it gives the 'enolic' form of the ester.

$$CH_3{-}C(ONa)=CH{-}CO{\cdot}OC_2H_5 = CH_3{\cdot}C(OH)=CH{\cdot}CO{\cdot}OC_2H_5$$
$$+ CH_3{\cdot}CO_2H \qquad\qquad + CH_3{\cdot}CO{\cdot}ONa$$

The ester, as we shall see, exists in two forms in equilibrium, known as 'enolic' and 'ketonic,' and may be represented as:

$$\underset{\text{Enolic form.}}{CH_3{\cdot}C(OH)=CH{\cdot}CO{\cdot}OC_2H_5} \rightleftharpoons \underset{\text{Ketonic form.}}{CH_3{\cdot}CO{\cdot}CH_2{\cdot}CO{\cdot}OC_2H_5}$$

Expt. 59.—*Preparation of Ethyl Acetoacetate.*—100 G. of dry ethyl acetate containing a trace of alcohol are placed in a round flask fitted with a reflux condenser, and 10 g. of clean sodium in very thin slices are quickly added. The reaction may become too vigorous, in which case the flask may be cooled by surrounding it with cold water. When the reaction abates, the flask is heated on the water-bath until no sodium remains. The liquid is removed and allowed to cool. The acetoacetic ester is now present as the sodium derivative, which is decomposed by adding 50 c.c. of 50 per cent acetic acid. An equal volume of saturated salt solution is then added, when an upper layer separates, containing ethyl acetate and acetoacetate. This is distilled until the temperature reaches 100° C., thus removing the ethyl acetate.

The residue of ethyl acetoacetate is best purified by distillation under reduced pressure, b.p. 79°/18 mm., 94°/45 mm.,

100°/80 mm. A somewhat inferior yield is obtained by distilling under atmospheric pressure and collecting the fraction boiling between 175° C. and 185° C.

257. Tautomerism.—When two isomerides are in chemical equilibrium with each other, they are said to be *tautomerides* or *tautomeric forms*, and the phenomenon is known as tautomerism.

Acetoacetic ester presents the most thoroughly investigated case of tautomerism, the chief facts bearing on the case being the following:

(1) Acetoacetic ester reacts additively with hydrogen cyanide and also with sodium bisulphite in the same manner as a ketone, and when hydrolysed with dilute sulphuric acid gives acetone, ethyl alcohol and carbon dioxide.

These reactions can only be accounted for by assigning it the formula $CH_3{\cdot}CO{\cdot}CH_2{\cdot}CO_2Et$. (Et = abbreviation for C_2H_5, ethyl.)

$$\begin{array}{lcl} CH_3 & & CH_3 \\ | & & | \\ CO & = & CO \\ | & & | \\ CH_2 + H{\cdot}OH & & CH_3 \\ | & & \\ CO{\cdot}OEt & & + CO_2 + EtOH. \end{array}$$

(2) Acetoacetic ester reacts with ammonia and gives an unsaturated compound, β-aminocrotonic acid. Moreover, it reacts with bromine like an unsaturated compound.

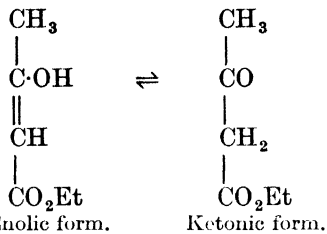
These reactions are only explainable by giving it the formula

$$\begin{array}{l} CH_3{-}C = CH{-}CO_2Et. \\ \quad\ | \\ \quad OH \end{array}$$

$$\begin{array}{lcl} CH_3 & & CH_3 \\ | & & | \\ C{\cdot}OH & \xrightarrow{NH_3} & C{\cdot}NH_2 \\ \| & & \| \\ CH & & CH \\ | & & | \\ CO_2Et & & CO_2Et \end{array}$$

(3) From the pure ester at very low temperatures it has been found possible to separate two compounds which have respectively the properties to be expected of the pure enol and keto-forms. At low temperatures these attain equilibrium very slowly, but on allowing them to become warm, they both become identical with ordinary acetoacetic ester.

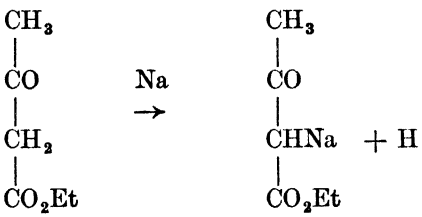
This and other evidence, not detailed here, makes it clear that acetoacetic ester is an equilibrium mixture, and may be represented as:



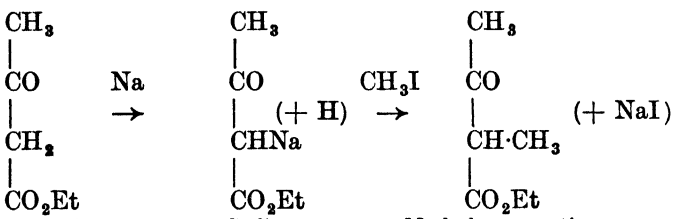
Enolic form. Ketonic form.

At the ordinary temperature it contains some 7·5 per cent. of the enolic form.

258. Synthetic Use of Acetoacetic Ester.—Acetoacetic ester readily forms a sodium derivative when it is acted on by sodium or treated with sodium ethoxide. The exact mechanism of the reaction is not very certain, but it appears that one of the hydrogen atoms of the methylene group is replaced by sodium. The whole of the ester is thus converted into the sodium derivative:

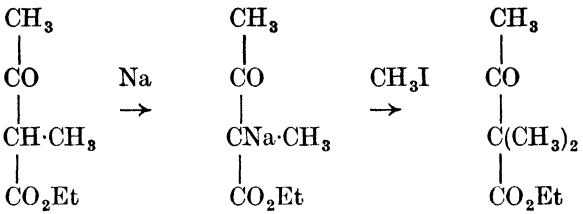


This sodium derivative is a reactive solid, and the sodium in it readily reacts with halogen when it is heated with alkyl halides, the alkyl group attaching itself to the α-carbon atom. Thus, when it is heated with methyl iodide, ethyl methylacetoacetate is produced.



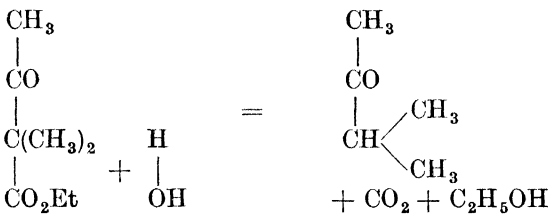
Acetoacetic ester. Sodium derivative. Methylacetoacetic ester.

Methylacetoacetic ester can form a second sodium derivative from which, say, ethyl *di*methylacetoacetate can be made.

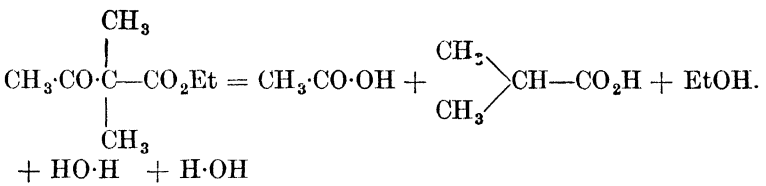


These methylacetoacetates may be hydrolysed either to *ketones* by means of dilute sulphuric acid or to *acids* by means of alcoholic potash.

Thus from ethyl dimethylacetoacetate, by hydrolysis with dilute sulphuric acid, we can make methyl *iso*propyl ketone:



while by hydrolysis with alcoholic potash we make *iso*butyric acid:

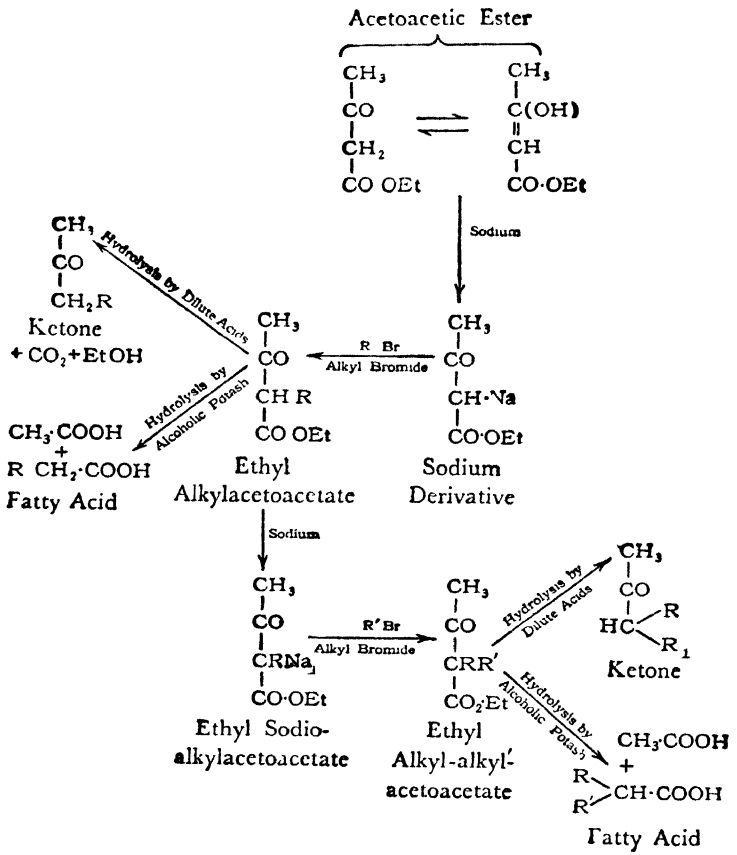


Since any alkyl groups can be introduced instead of the methyl groups in the above description, it is possible to make a great number of fatty acids and ketones in this way.

These are the most important synthetic reactions of acetoacetic ester, but numerous other compounds, mostly cyclic, can be made from it.

Expt. 60.—*Preparation of Methyl Propyl Ketone.*—2·5 G. of sodium are cut into small portions and dissolved a little at a time in 35 g. of alcohol, previously well dried over lime (§ 36). To this solution are added, first 16 g. of ethyl acetoacetate, then 20 g. of ethyl iodide. The mixture is then heated on the water-bath till it no longer colours litmus blue (2¼ hr.). The

REACTIONS OF ACETOACETIC ESTER



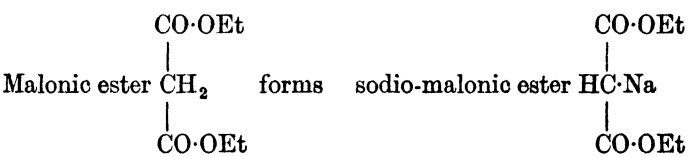
alcohol is distilled off on the water-bath and the residue is mixed with a little water, and then extracted with ether. The upper layer is dried over calcium chloride. The ether is distilled off on the water-bath and the remaining oil fractionated, the portion boiling at 190°–196° being collected. This is ethyl ethylacetoacetate. 10 G. of this liquid are placed in a 250 c.c. round-bottomed flask with 100 c.c. of dilute sulphuric acid (1 : 2) and boiled under a reflux condenser for three hours. The liquid is *well cooled* and extracted with several successive portions of ether (25 c.c. each). The ether is distilled off on the water-bath and the oily residue fractionated, the portion

boiling between 95° C. and 102° C. being collected. This is methyl propyl ketone.

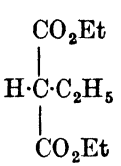
259. Similar Tautomeric Compounds.—Any ester of the type R—CH_2—CO·OEt where R is an acidic grouping, *e.g.*, carbonyl or cyanide, is tautomeric and can exist also in an enolic form R—CH =C(OH)·OEt.

Thus malonic ester, C_2H_5·O·CO·CH_2·CO·O·C_2H_5 and oxalacetic ester[1] EtO·OC·CO·CH_2·CO·OEt are both tautomeric and are valuable synthetic reagents. They form sodium derivatives like those of acetoacetic ester and from these alkyl derivatives may be made.

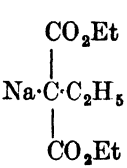
Thus:



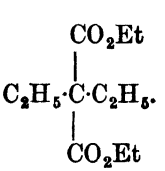
from which by the action of an alkyl halide (say) ethylmalonic ester



can be made. This again gives a sodium derivative

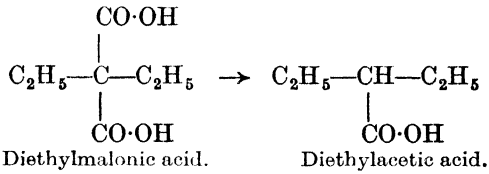


from which we can make, say, diethylmalonic ester



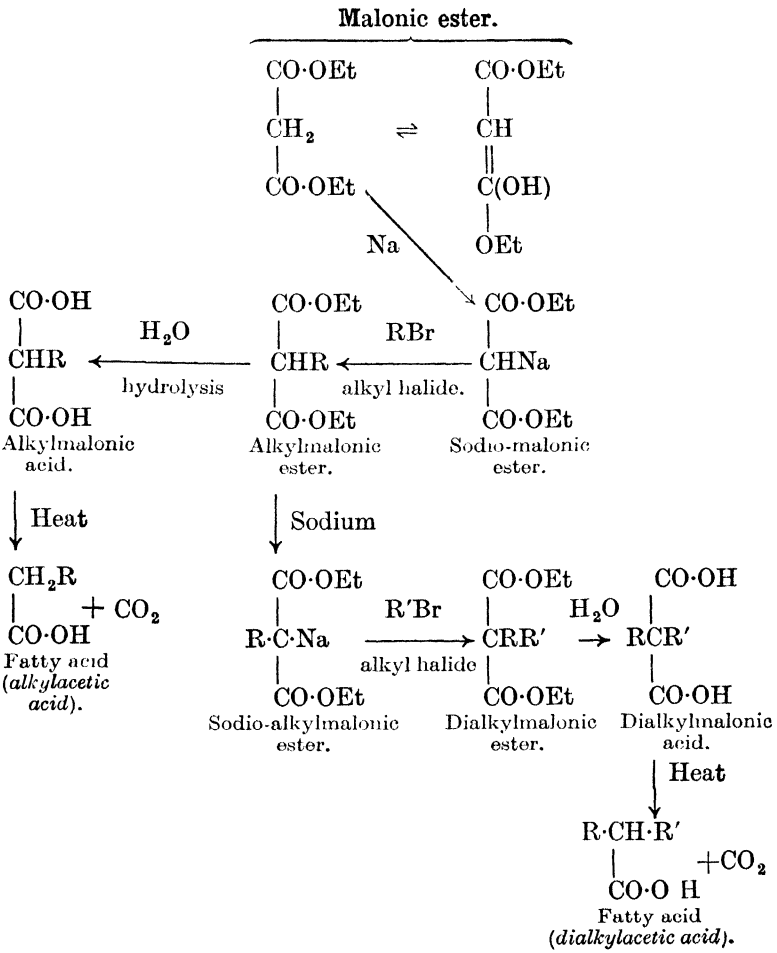
These esters when hydrolysed give monoethyl- and diethyl-malonic acids, which it would be difficult to prepare otherwise. Moreover, these acids, when heated, break up and give fatty acids.

[1] Also cyanoacetic ester, benzoylacetic ester, etc.



This reaction thus affords a valuable means of making any fatty acid of the type $R{\cdot}CH_2{\cdot}CO{\cdot}OH$ or $\begin{matrix} R \\ R \end{matrix}\!\!>\!CH{\cdot}CO_2H$.

SYNTHESIS OF FATTY ACIDS FROM MALONIC ESTER.



γ-KETONIC ACIDS

260. Lævulic acid, $CH_3{\cdot}CO{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$, and its esters have none of the tautomeric properties of acetoacetic ester. It has ketonic properties, giving an oxime and phenylhydrazone (§§ 112, 409).

DIBASIC KETONIC ACID

261. Mesoxalic acid, HO·OC—CO—CO·OH, can be made by oxidising glycerol (§ 201). It is best made by the action of barium hydroxide solution on dibromomalonic acid. Instead of dihydroxymalonic acid (which would have two hydroxyl groups on one carbon atom) mesoxalic acid is formed:

$$\begin{array}{l} CO{\cdot}OH \\ | \\ CBr_2 \\ | \\ CO{\cdot}OH \end{array} + Ba(OH)_2 = \begin{array}{l} CO{\cdot}OH \\ | \\ CO \\ | \\ CO{\cdot}OH \end{array} + H_2O + BaBr_2$$

It behaves like a ketone in forming addition products, but since it and its compounds somewhat firmly retain a molecule of water, it is possible that it can exist both as dihydroxymalonic acid, $HO—C(CO{\cdot}OH)_2—OH$, and as a ketonic acid,

$$\begin{array}{l} CO_2H \\ | \\ CO. \\ | \\ CO_2H \end{array}$$

The hydrate of mesoxalic ester has recently been prepared by oxidising malonic ester with selenium dioxide at 120°—130° C.

262. Oxalacetic acid, HO·OC·CO·CH_2·CO·OH, much resembles acetoacetic acid. It is made from ethyl oxalacetate, which is made by the action of sodium ethoxide on a mixture of ethyl oxalate and acetate. *Ethyl oxalacetate,* $EtO_2C{\cdot}CO{\cdot}CH_2{\cdot}CO_2Et$, is tautomeric like ethyl acetoacetate, and forms sodium and alkyl derivatives in the same way. It is a useful synthetic reagent for preparing ketonic acids, etc.

QUESTIONS

(1) What is meant by tautomerism? Give an account of the evidence for the tautomeric formulæ of acetoacetic ester.

(2) How are acetoacetic ester and malonic ester prepared? What is the effect of hydrolysing the former with (*a*) acids, (*b*) alkalis?

(3) How would you use acetoacetic ester to synthesise (*a*) methyl ethyl ketone, (*b*) propionic acid, (*c*) valeric acid? Give practical details in one case.

(4) Using malonic ester, how would you synthesise (*a*) diethylmalonic acid, (*b*) normal butyric acid, (*c*) *iso*butyric acid?

(5) Write the formulæ of an α-, a β-, and a γ-ketonic acid. Which, if any, of these are tautomeric, and why?

CHAPTER XIX

THE CARBOHYDRATES

263. Carbohydrates.—The term carbohydrate is applied to a class of compounds which are either sugars (§ 264) or may be readily converted into them by hydrolysis. The name is taken from the fact that they contain only carbon, together with hydrogen and oxygen in the correct proportion to form water. Their formula may therefore be expressed as $C_x(H_2O)_y$. The carbohydrates are, however, in no way comparable to the molecular compounds of various substances with water of crystallisation, commonly known as hydrates. Among many less important members, the group contains the sugars, glucose, fructose, maltose, lactose and sucrose, and starch, which form a substantial part of the human diet, and also the industrially and biologically important cellulose, the essential part of wood, paper, linen, cotton and vegetable fibre in general.

264. The Sugars.—The carbohydrates are of four chief types:—

Sugars

(1) Monosaccharides mostly of formula $C_6H_{12}O_6$[1] (*e.g.*, glucose, fructose). These are not affected by hydrolysis.

(2) Disaccharides of formula $C_{12}H_{22}O_{11}$ (*e.g.*, cane-sugar, maltose, lactose). These are easily hydrolysed to 2 molecules of monosaccharides.

(3) Trisaccharides of formula $C_{18}H_{32}O_{16}$ (*e.g.*, raffinose). These are easily hydrolysed to three monosaccharide molecules.

(4) Polysaccharides of formula $(C_6H_{10}O_5)_n$, where n may be from 6 to 200 (*e.g.*, cellulose and starch). These also may be hydrolysed to many disaccharide or monosaccharide molecules.

Since di-, tri- and poly-saccharides can all be hydrolysed to monosaccharides it is most important to understand the structure of the latter. The elucidation of the structure of the carbohydrates has been a task which has engaged some of the greatest masters of organic chemistry and the problem is not completely solved to-day. The structures of most of the more important carbohydrates are well understood, but it is significant that the structural formula of so important and abundant a compound as cane-sugar is still uncertain in some details.

[1] But also of formula $C_xH_{2x}O_x$ where x is any number from 3 to 9.

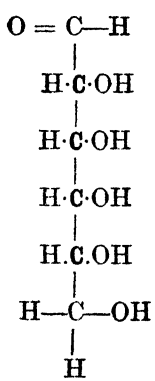
The foundation for our study of the sugars will be a study of the formulæ of *d*-glucose (the commonest of sugars and the most important from the physiological point of view) and *d*-fructose, the next most important.

265. Structure of *d*-Glucose.—Glucose is found in nature in most fruits and in the blood of animals in small quantities. It is moreover produced when starch or cellulose is hydrolysed by boiling with dilute acids.

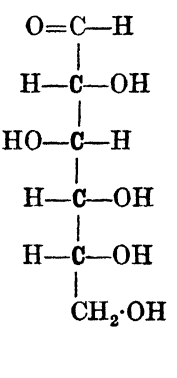
These methods of production, however, throw no light on its structure.

Its formula is $C_6H_{12}O_6$. It reacts with the reagents which react with $-OH$ groups. Thus with acetic anhydride and sodium acetate it gives a penta-acetyl derivative, $C_6H_7O(O{\cdot}CO{\cdot}CH_3)_5$, and with methyl sulphate and alkali it gives a penta-methyl ether $C_6H_7O(O{\cdot}CH_3)_5$. Thus glucose evidently contains five hydroxyl groups.

In its reactions with hydrocyanic acid, phenylhydrazine and hydroxylamine, it behaves like an aldehyde forming addition and condensation products (§ 70). It is also, like aldehydes a strong reducing agent. These and other facts led to the formula I being given for glucose, which would be pentahydroxyhexyl aldehyde. This formula explains its reactions fairly well, but fails to explain why it does not form an aldehyde-ammonia or a bisulphite compound (§ 70), and most notably it does not explain the existence of two different stereoisomeric forms of *d*- or *l*-glucose.



I.



II.

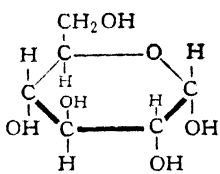
Older formula for glucose.

In the formula I there are four asymmetric carbon atoms (bold type) and since each can give two stereoisomeric forms there should be $2^4 = 16$ different substances of that formula, each of which should be a different sugar. Most of these are known and *d*-glucose was

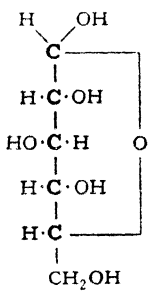
shown by a remarkable piece of work which cannot be detailed here to have the five hydroxyl groups in the positions indicated in formula II (the method of projection described on p. 243 being used).

Now it was found that not one, but *two* *d*-glucoses apparently of this formula existed, readily interconvertible and differing only in their optical properties. This is not accounted for by the above formula and requires one with five asymmetric carbon atoms. This and other facts led to the formulation by Emil Fischer, of a ring structure for glucose. Fischer believed a five-membered ring to be formed, but Haworth by arguments which cannot be detailed here, showed that glucose contained a six-membered ring.

The formula finally adopted for *α*-*d*-glucose is III, which may be

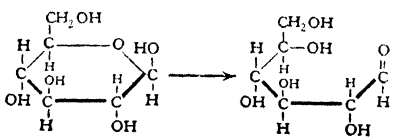


III.



IV.

written as in IV. It is readily seen that this formula has five asymmetric carbon atoms (those in the ring) and so accounts for the existence of *α*-*d*- and *β*-*d*-glucose, which formula II does not. Since there is no free aldehyde group the slight divergence of glucose from the normal aldehyde properties is explained, but it will be easily seen that the breaking of the ring would *produce* the aldehyde group and that, to chemical agents energetic enough to break the ring, it would react as an aldehyde. It is the conversion of this –CHO group into = CH(OH) in the ring which enables *α*- and *β*-isomerides to exist (pp. 267, 271).



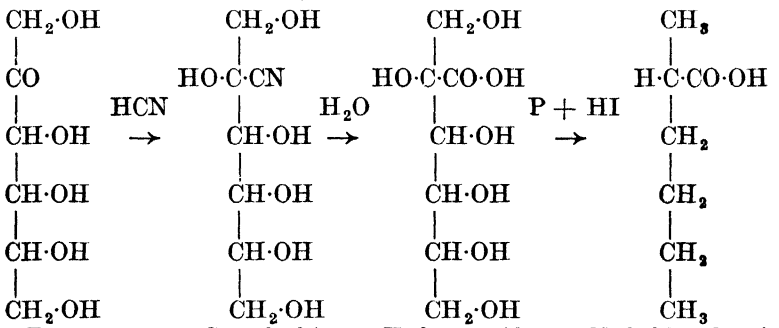
"Pyranose" formula for *β*-glucose.

Transformed to hydroxy-aldehyde if ring is broken and one hydrogen atom transferred. (Identical with Formula II.)

266. Structure of *d*-Fructose.—Very similar arguments led to the establishment of a ring-formula for fructose.

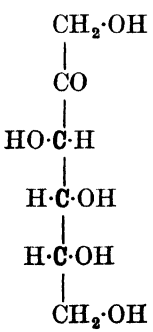
Fructose has the formula $C_6H_{12}O_6$ and forms a penta-acetyl derivative and a pentamethyl ether, as does glucose. We are therefore led to suppose that it has five hydroxyl groups in its molecule. It has powerful reducing properties, but unlike glucose does not reduce bromine to hydrogen bromide. It shows the reactions of an *aldehyde* or *ketone*, forming a phenylhydrazone, an oxime, a cyanohydrin, etc.

These reactions of fructose are consistent with aldehydic or with ketonic properties. However, its cyanohydrin can be hydrolysed to a hydroxy-acid which, when vigorously reduced with phosphorus and hydrogen iodide yields methyl-butylacetic acid. Consequently the =CO group must be the second group in the chain, and fructose must be ketonic, not aldehydic:



Fructose (old formula). Cyanohydrin. Hydroxy-acid. Methyl-butylacetic acid.

for if fructose had a *terminal* $-CHO$ group, normal heptoic acid would have been produced. The position of the $-CO\cdot OH$ group in the acid actually formed settles the position of the ketonic group as on the second carbon atom. The position of the hydroxyl groups was fixed by the researches of Fischer as that shown in Formula V.



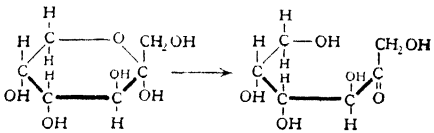
V.

This formula has three asymmetric carbon atoms. There should therefore be (p. 247) $2^3 = 8$ different sugars of this formula, but in

fact only two or three of these are known. The formula V here given for fructose proved itself unsatisfactory for reasons similar to those given under glucose. Thus, though an α- and β-fructose have not both been isolated, α- and β-methylfructosides exist which could not be accounted for on formula V and require formula VI with four asymmetric carbon atoms.

As a result of the work, first of Emil Fischer and recently of Haworth, a cyclic formula for fructose has been established (VI).

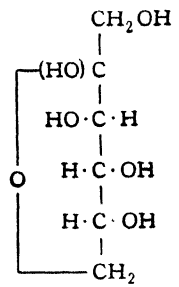
The ring is, as in the case of glucose, readily broken, when fructose reacts as a ketone.



α-d-Fructose often reacts as a hydroxy-ketone. (Identical with V.)

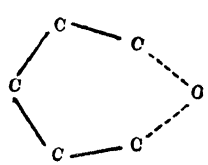
VI.

The formula VI is often distorted and written as VII for reasons of convenience in printing.



VII.

267. Shape of Sugar Molecules.—The use of atomic models at once shows how likely is the formation of a ring system in a 5- or 6-membered chain of carbon atoms. If we remember that the valencies of a carbon atom are distributed as if to the corners of a tetrahedron surrounding it (see § 20), it can be shown that they will be inclined at an angle of 109° 28′ to each other. Accordingly a system of five carbon atoms will form a horseshoe-shaped figure which is very



readily bridged by the oxygen 'lactone' atom as in formulæ III, VI above. If we construct a model of the glucose molecule from spheres (of sizes proportional to the spaces shown by X-ray measurements to be taken up by the C, H and O atoms in molecules) joined by connections set at the correct angles we obtain the arrangement shown in Fig. 43. It is at once clear that a ring formula is one which would be expected to be formed easily, and to involve no strain such as might be involved in the alteration of the natural direction of the valency bonds.

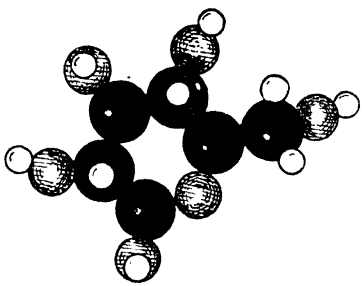
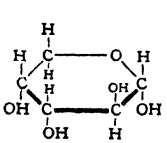


FIG. 43.—Model of Molecule of α-*d*-Glucose. The black spheres represent carbon atoms, the grey spheres oxygen atoms, and the white spheres hydrogen atoms.

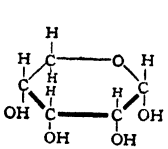
268. The Monosaccharides.—Monosaccharides may be defined as sugars which cannot be further hydrolysed to simpler sugars. They may contain from three to nine carbon atoms and are classed as trioses, tetroses, pentoses, hexoses, heptoses, octoses and nonoses according to the number of carbon atoms contained in them.

Most of these classes are represented by only a few individuals and are of small importance. A few pentoses are found in nature, notably arabinose $C_5H_{10}O_5$. The pentoses are of some theoretical interest as having been used in the difficult problem of discovering the exact structural formula to be assigned to each of the hexoses.

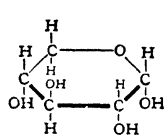
269. The Pentoses, $C_5H_{10}O_5$.—There are four pentoses—arabinose, ribose, xylose, and lyxose. Each of these can exist in a *d*- and *l*- form, the formulæ of which are mirror-images. The formulæ of the four *d*-forms are shown below.



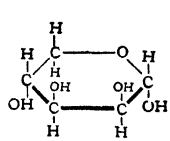
α-*d*-Arabinose.



α-*d*-Ribose.



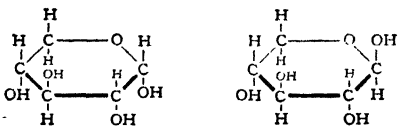
α-*d*-Xylose.



α-*d*-Lyxose.

Each of the four *d*- and *l*- pentoses can exist in an α- and β-form very readily interconvertible. The existence of these is explained by the asymmetry of the

carbon atom of the reducing group. The formulæ of α-*d*-xylose and β *d*-xylose are shown below.



α-Form. β-Form.

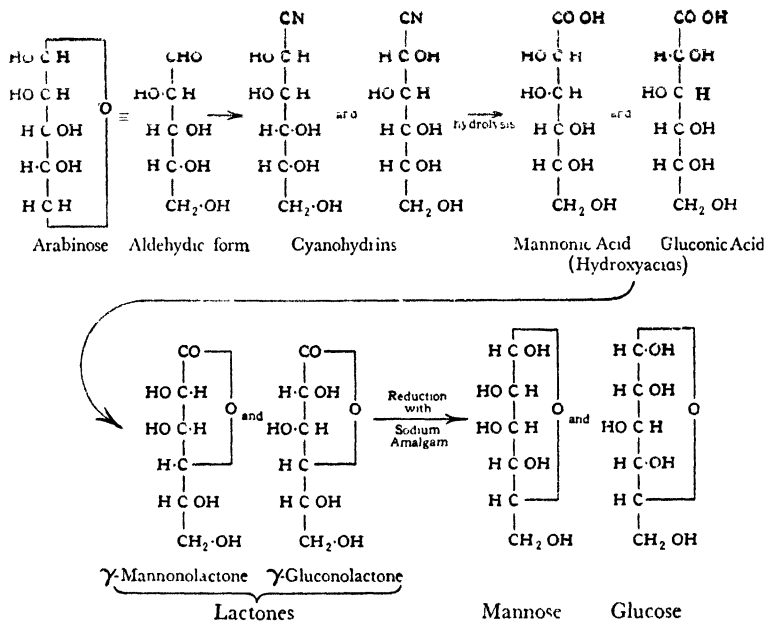
The existence of such forms is further discussed on p. 271.

The student is advised to try to write the formulæ for the sixteen possible forms, α-, β-, *d*, and *l*, derivable from the four pentoses. This will make the principles of the isomerism really clear.

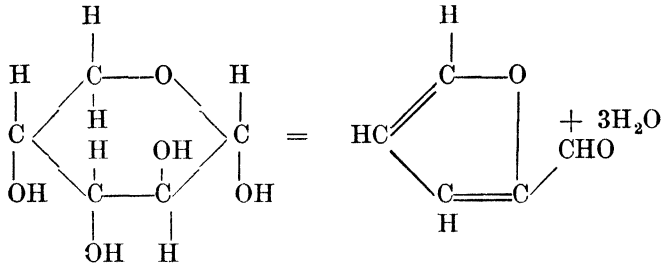
The best-known pentose is *d*-arabinose. Ribose is of interest as forming a part of the molecule of nucleoproteins (§ 619).

270. Arabinose, $C_5H_{10}O_5$, is obtained by boiling gum arabic with dilute acid. It is occasionally found in urine.

It forms white crystals, which melt at 160° C. In most respects it resembles glucose. It is a reducing agent, and is readily oxidised, first to arabonic acid, $CH_2(OH)\cdot(CH\cdot OH)_3\cdot CO\cdot OH$, and then to trihydroxyglutaric acid, $HO\cdot OC\cdot(CH\cdot OH)_3\cdot CO\cdot OH$. It is reduced to an alcohol arabitol, $CH_2(OH)\cdot(CH\cdot OH)_3\cdot CH_2\cdot OH$. It may be converted into the hexoses by the cyanohydrin synthesis outlined below



Arabinose and other pentoses, when boiled with dilute hydrochloric acid, give the volatile furfuraldehyde:



This reaction is of great use for detecting pentoses, for furfuraldehyde (§ 549) is easily detected by giving a strong red colour with aniline acetate.

Xylose is formed by hydrolysing straw, wood, etc. It resembles arabinose closely. *Ribose* and *lyxose* also have very similar properties.

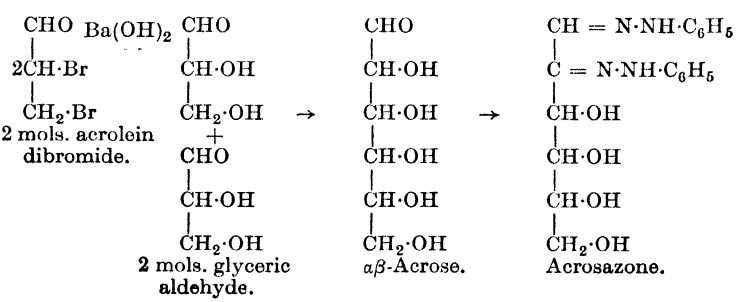
271. The Hexoses, $C_6H_{12}O_6$.—The hexoses include all the important natural monosaccharoses. Glucose, galactose, mannose and fructose are of sufficient importance to be discussed here.

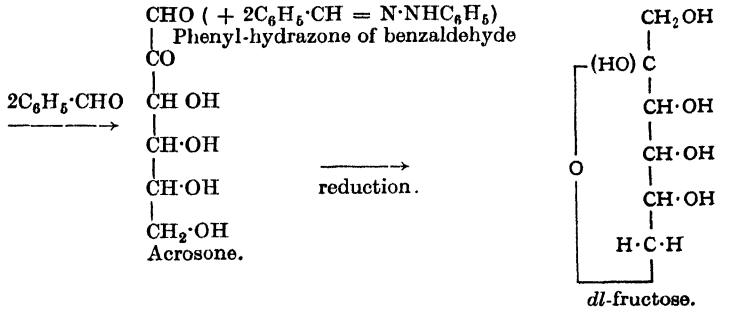
272. Glucose, *d*-Glucose, Dextrose, $C_6H_{12}O_6.H_2O$.—

Occurrence in Animals and Plants.—This very important sugar occurs together with fructose in various fruits and in honey. It is a normal constituent of the blood in small proportion.

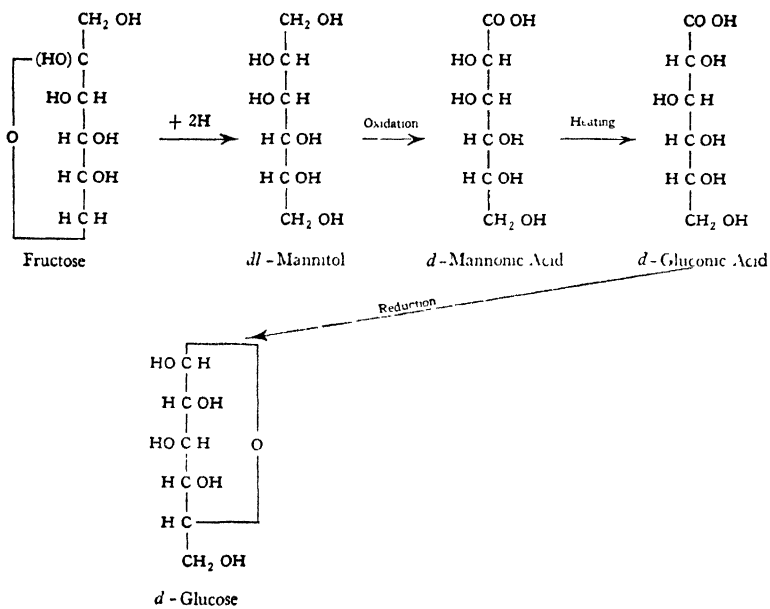
The production and utilisation of glucose in animals and plants is discussed in §§ 300, 301.

Synthesis.—*d*-Glucose has been prepared synthetically by several methods, one of which, due to Fischer, may be given here. Two molecules of acrolein dibromide react when treated with barium hydroxide solution, giving glyceric aldehyde which later condenses to give $\alpha\beta$-acrose. This, with phenylhydrazine, gives $\alpha\beta$-acrosazone (cf. p. 273), which, when heated with benzaldehyde, gives acrosone. This latter can be reduced to *dl*-fructose.





The *dl*-fructose is reduced to *dl*-mannitol, which is oxidised (in two stages) to *dl*-mannonic acid. From this *d*-mannonic acid is separated (by crystallisation of the brucine salt, § 236), and converted into *d*-gluconic acid by heating with quinoline. *d*-Gluconic acid is then converted into *d*-glucose by reduction.



Manufacture.—Glucose is manufactured on the large scale for use in numerous industries, notably in brewing as an addition to malt, and in jam and confectionery as a substitute for cane sugar.

The source of glucose is some form of *starch* $(C_6H_{10}O_5)_n$, which, when boiled with a dilute acid, is converted into glucose, $C_6H_{12}O_6$. Cellulose can also be converted into glucose, but only by such prolonged treatment that the process has not been found of commercial value.

In America, green maize is used as the source of starch, in Europe chiefly rice, maize and potato starch.

The starch is heated under pressure with about 2½ times its weight of water and about 1 per cent. of sulphuric acid in closed boilers. In about an hour and a half the contents are run off and mixed with rather more chalk than is needed to neutralise the acids. The calcium sulphate so formed is filtered off and the solution of glucose is decolourised by charcoal (*v.* under cane sugar, § 279) and concentrated in vacuum pans. The very concentrated solution is left to solidify in moulds. The glucose is sometimes recrystallised, but is often used in the form of the moist crystalline mass so obtained.

To obtain pure glucose it may be recrystallised from methyl alcohol.

Glucose may be prepared in the laboratory by the hydrolysis of cane sugar.

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6.$$

d-Glucose and *d*-fructose are produced: the former can be separated by crystallisation.

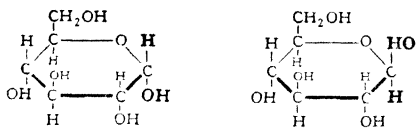
Expt. 61.—*Preparation of Glucose.*—In a 250-c.c. flask mix 6 c.c. concentrated hydrochloric acid with 150 c.c. of 90 per cent alcohol. Maintain the liquid at 45°–50° C. on the water-bath and add 50 g. of very finely powdered cane sugar, 5 g. at a time. Shake from time to time until all the sugar has dissolved. Keep the solution at 50° C. for two hours to allow hydrolysis to become complete, filter (if required), and allow to cool. To the cold liquid add 0·1 g. of anhydrous glucose in order to afford nuclei for crystallisation and leave the liquid to stand in a corked flask for some days, shaking it vigorously from time to time. The glucose slowly crystallises, and may be filtered off at the pump and washed with absolute alcohol. If required pure it may be crystallised from 80 per cent. ethyl alcohol.

If anhydrous glucose is not available, crystallisation will ultimately take place, though less certainly and less quickly. Anhydrous glucose may be made by adding to a hot 10 per cent. solution of glucose in water enough boiling methyl alcohol to cause it to become cloudy. Anhydrous glucose separates on cooling.

Physical Properties of Glucose.—*d*-Glucose crystallises in masses of small six-sided crystals which contain one molecule of water. The hydrate melts at 86° C., while anhydrous glucose melts at 146° C. It is freely soluble in water and in alcohol. Like most of the sugars, glucose has a sweet taste; it is, however, less sweet than cane sugar. Solutions of *d*-glucose turn the plane of polarised light to the right

and this phenomenon is used for measuring the strength of solutions of glucose.

Glucose and many other sugars display the phenomenon of *muta-rotation.* When glucose is crystallised from acetic acid or alcohol the α-form crystallises and a freshly prepared solution of this rotates polarised light strongly to the right: specific rotation ($[\alpha]_D$ + 113°).[1] In solution this changes to an equilibrium mixture of the α- and β- forms with less rotation of polarised light ($[\alpha]_D$ + 52·5°). From solution in pyridine β-glucose can be crystallised and

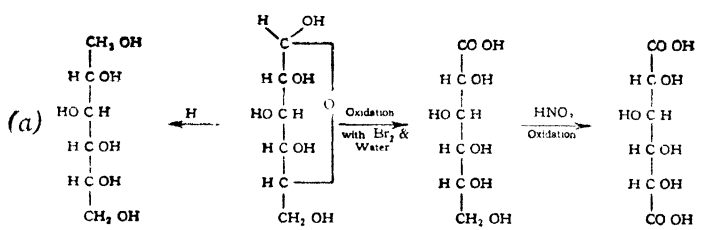


α-Glucose $[\alpha]_D$ + 113°. β-Glucose $[\alpha]_D$ + 17°.

a fresh solution of this at first shows a rotation of $[\alpha]_D$ + 17°. This solution also becomes gradually converted into the equilibrium mixture of specific rotation $[\alpha]_D$ + 52·5°.

Fructose (§ 276) also shows mutarotation, and we infer the existence of an α- and β-fructose, though they have not been isolated.

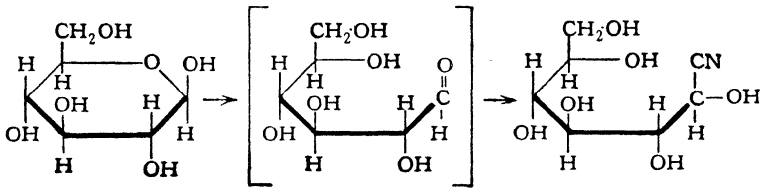
Chemical Properties.—Glucose can function as an aldehyde, and shows many of the properties associated with the simple aldehydes (§70). It can be converted into an alcohol, *d*-sorbitol (§ 203), by reduction with sodium amalgam and can be oxidised, first to gluconic acid, then to saccharic acid.



[1] The specific rotation is the angle α through which the plane of polarised light derived from the D line of the sodium spectrum would be rotated by a column of solution, 1 sq. cm. in cross section and of such length as to contain 10 g. of the solute. Alternatively, it may be regarded as the rotation of 1 dcm. of solution multiplied by $\frac{100}{c}$, where c is the weight of solute in 100 g. of solution.

The oxidation of glucose to gluconic acid is very easily brought about, and accordingly glucose is a strong reducing agent. Thus it reduces Fehling's solution to cuprous oxide, and ammoniacal solutions of silver salts to silver.

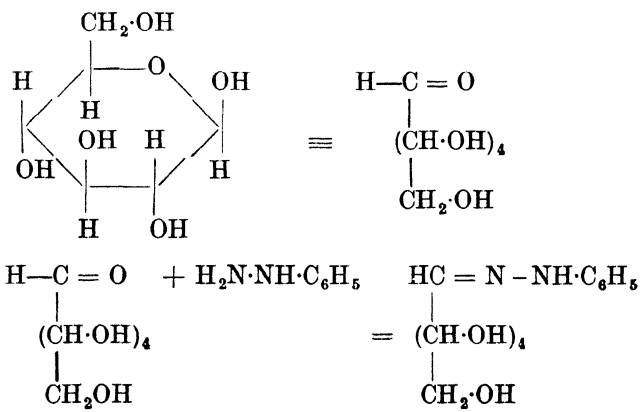
Unlike aldehydes it does not form addition products with ammonia or with sodium bisulphite. It does, however, form a cyanohydrin with hydrogen cyanide, the ring breaking and giving the hydroxy-aldehyde form which reacts with the hydrocyanic acid. With hydroxylamine it gives an oxime.



Pyranose form of Glucose. Hydroxyaldehyde form. Cyanohydrin.

The formation of *phenylhydrazones* and *osazones* with phenylhydrazine is characteristic of the monosaccharides. The reaction is valuable as the products are easily isolated and have definite melting points which serve to identify the various sugars. Since there is little difference in the melting point of some osazones, many are identified, not by their melting points but by their crystalline forms. These are very distinctive when examined under the microscope.

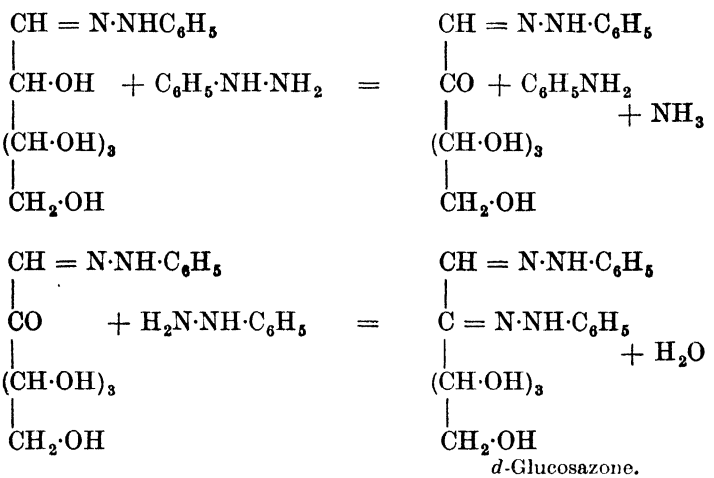
Glucose and phenylhydrazine give *d*-glucose phenylhydrazone.



Glucose phenylhydrazone.

The phenylhydrazine and water then oxidise the CH(OH) group

next to the phenylhydrazone group to carbonyl CO, the phenylhydrazine being reduced to aniline and ammonia. The CO group then reacts with another phenylhydrazine molecule giving a compound called an *osazone*.



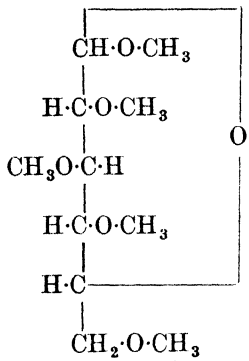
d-Glucosazone.

Expt. 62.—*To Prepare Phenylglucosazone and Determine its Melting Point.*—Dissolve 2 g. of phenylhydrazine in a solution of 2 g. glacial acetic acid in 20 c.c. of water contained in a large test-tube. Add 1 g. of finely-powdered glucose, shake till dissolved and heat on the water-bath at 100° for ¼–½ hr. Fine yellow needles separate. When a fair quantity of crystals has accumulated, filter them off through a small Buchner funnel and wash well with water and dry, first by pressing with filter papers (or on a porous plate) and then in a water-oven. Prepare a melting-point apparatus such as is shown in Fig. 11, using sulphuric acid or glycerol as the heating liquid. The phenylglucosazone should melt at 204°–205° C.

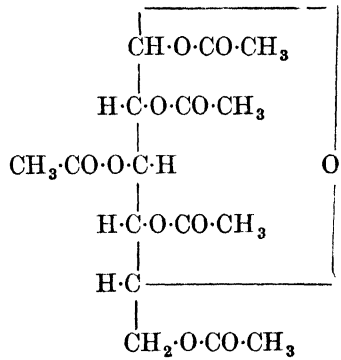
The hydroxyl groups in glucose, as we have already seen (§ 265). display some of the reactions associated with alcohols.

Thus when treated with methyl sulphate and alkali, methyl-ethers, or methyl-derivatives of glucose are formed.

With acetic anhydride and anhydrous sodium acetate glucose gives a penta-acetyl derivative (really an ester, glucose penta-acetate). Glucose also forms metallic derivatives when treated

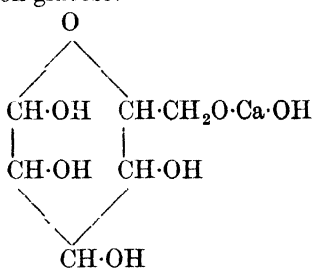


Tetramethyl-methylglucoside.



Glucose penta-acetate.

with alkalis. Thus a basic salt, calcium glucosate, is formed by the action of lime on glucose.



The detection and determination of glucose is of great importance in diagnosing the disease *diabetes*, in which glucose is excreted in the urine (§ 301).

Detection and Estimation of Glucose.—Fehling's solution and Benedict's solution are the reagents ordinarily employed. 10 c.c. of Fehling's solution, prepared as in Expt. 18, are heated to boiling in a test-tube, fragments of porous pot being added to prevent undue bumping. To the boiling liquid 1 c.c. of urine is added. If glucose is abundant a yellowish or red deposit of cuprous oxide will be produced; where the glucose is present in only small proportion, more urine may be used.

Benedict's solution, which is used in the same manner, is preferred to Fehling's solution by many. It is made by dissolving 86·50 g. of sodium citrate and 50·00 g. of sodium carbonate in 300 c.c. of water and making up to 425 c.c. To this solution is added 8·65 g. of crystallised copper sulphate dissolved in 75 c.c. of water. The mixed solution keeps well. The use of Benedict's solution obviates the use of two stock bottles as required for Fehling's solution.

Fehling's or Benedict's solution can be used volumetrically. 10 c.c. of the reagent are mixed with 10 c.c. distilled water and

boiled in a large test-tube The solution to be analysed is added from a burette a little at a time, boiling between each addition. When the blue colour has almost disappeared the end-point is determined by filtering small portions, acidifying and testing for copper with potassium ferrocyanide. When no chocolate colour is given, the reaction is complete. The copper solution is standardised against a standard solution of pure dextrose.

Expt. 63.—*Reactions of Glucose.*—(1) Heat a portion in a small test-tube: note charring and evolution of a complex mixture of steam and various volatile substances.

(2) Warm with acidified potassium permanganate. Note reducing action.

(3) Show reduction of Fehling's solution (*v.* Expt. 18 and § 272).

(4) Add ammonia to silver nitrate solution (not too dilute) till brown ppt. re-dissolves. Warm with glucose solution. Silver mirror readily formed.

(5) Warm a little indigo with glucose solution and sodium hydroxide solution till the blue colour disappears (formation of indigo-white). Filter. Wet a piece of filter paper with the liquid. The indigo-white is reoxidised by the air to the blue indigo (*v.* § 565).

273. Glucosides.—Compounds of glucose with an extraordinary variety of organic substances are found in plant tissues. The *glucosides*, as these compounds are called, consist of glucose connected by an ether linkage —O— to almost any substance capable of forming such a linkage. They easily break up into their constituents on hydrolysis, and the plant tissues which contain the glucosides usually afford an enzyme capable of bringing about the hydrolysis.

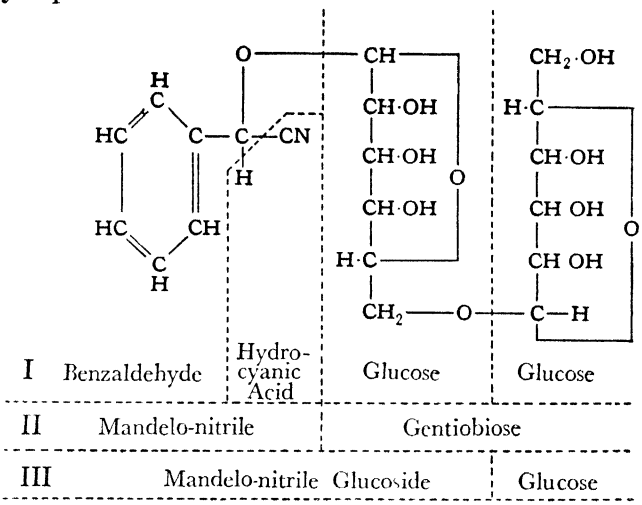
The glucosides appear to afford the plant a means of storing reactive or volatile chemical substances in an inert form, from which they may be liberated at any time.

Thus mustard seed (§ 176) contains the volatile allyl *iso*thiocyanate combined with glucose and potassium hydrogen sulphate as the glucoside *sinigrin*. On crushing and moistening the dry seed the enzyme *myrosin* hydrolyses this and liberates the allyl *iso*thiocyanate which gives mustard its flavour and odour.

The glucosides are very numerous. They include most of the pigments which give the colour to flower petals; the large group of tannins; many drugs of importance, *e.g.*, jalap, digitalis, strophanthin.

As an example of their structure and behaviour we may take amygdalin, found in bitter almonds. This, when vigorously hydrolysed is split into four molecules, benzaldehyde, hydrocyanic acid and two molecules of glucose. Less vigorous hydrolysis may only split it into two or three constituents. The enzyme *emulsin* found in bitter almonds brings about the complete hydrolysis. Its structure is that shown below; the result of hydrolysis is to split it

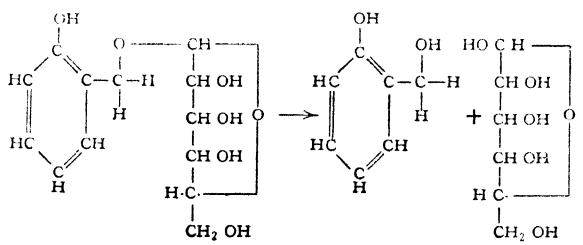
up along any one, two or three of the dotted lines, so forming a variety of products.



I. Complete hydrolysis; II, III, partial hydrolysis.

The glucoside *salicin*, used in medicine, may be taken as a second example. It is contained in willow bark and was formerly used as a remedy for fever.

It is a compound of glucose and *saligenin* (*o*-hydroxybenzyl alcohol). The enzymes *emulsin* (mentioned above) and *salicase*, found in willow twigs, hydrolyse it to its constituents.

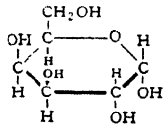


Salicin. *o*-Hydroxy-benzyl alcohol. Glucose.

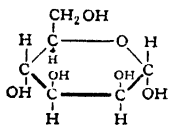
The tendency of glucose to form condensation products with itself and other sugars (§ 277) is only a special case of the formation of glucosides, the linkage being through an oxygen atom as shown above.

274. *d*-Galactose is formed by the hydrolysis of lactose or milk-sugar. It is a stereoisomeride of glucose, and resembles it in all respects except in some of its physical properties.

275. *d*-Mannose, $C_6H_{12}O_6$, is prepared from the peculiar polysaccharides known as mannosans. Mannosan is the chief constituent of the vegetable ivory nut used in making collar studs, trouser buttons, etc. When this is hydrolysed by means of hydrochloric acid, mannose is obtained. It is, of course, a stereoisomeride of glucose, and resembles it closely in its properties. The formulæ of galactose and mannose are:—



d-Galactose



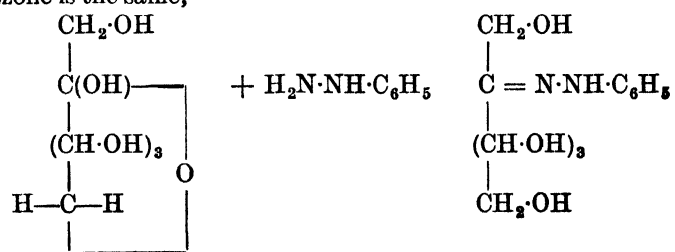
d-Mannose.

276. Fructose, *d*-Fructose, Lævulose, Fruit-sugar.—Fructose is found (with *d*-glucose) in fruit juices and honey. It is formed with *d*-glucose by the hydrolysis of cane-sugar, but is best made by hydrolysing *inulin*, a starch-like substance contained in dahlia-tubers, by means of dilute acids. It is now manufactured from Jerusalem artichokes, which contain inulin, by a method similar to that employed in the manufacture of glucose.

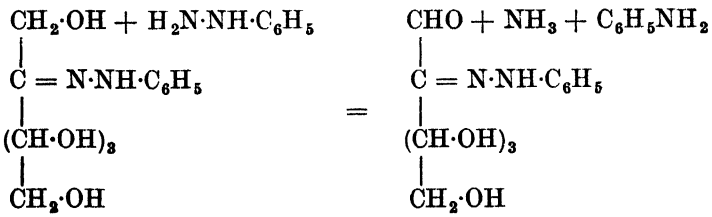
It forms anhydrous crystals melting at 95° C. and readily soluble in water. Fructose is lævorotatory: $[\alpha]_D = -92°$. It is called *d*-fructose on account of its analogy of structure to other dextrorotatory sugars.

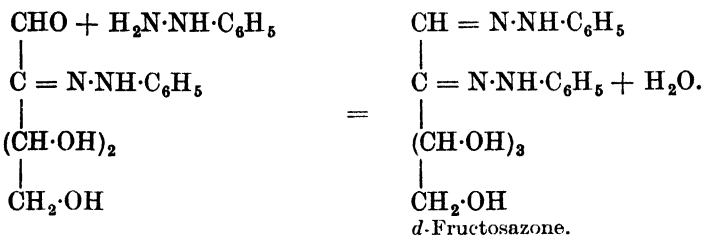
d-Fructose is a ketohexose, *i.e.*, a sugar with six carbon atoms, which behaves in some respects as if it contained a carbonyl group and had the formula V (p. 264) though its formula is actually VI (p. 265).

It therefore behaves like a ketone and an alcohol. It differs from glucose in its properties in much the same way as a ketone differs from an aldehyde (§ 111). Thus, like glucose, it forms an oxime, a cyanohydrin, a phenylhydrazone and an osazone. The formation of the last proceeds (1) by the formation of the phenylhydrazone: (2) by the oxidation of the alcoholic group next to the phenylhydrazone group to an aldehyde group and the reaction of the aldehyde group with phenylhydrazine. The phenylhydrazone of fructose is different from the phenylhydrazone of glucose but the osazone is the same,



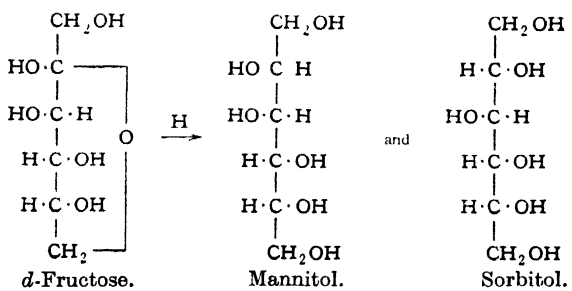
d-Fructose phenylhydrazone.





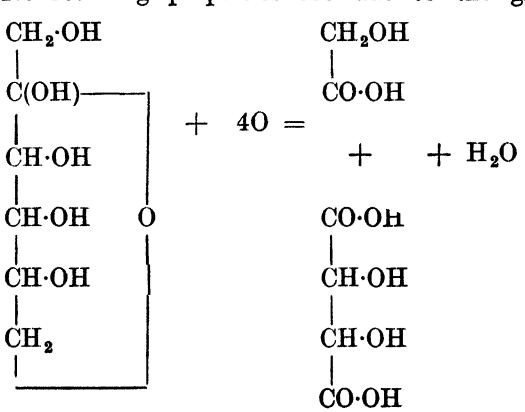
d-Fructosazone.

When reduced *d*-fructose forms the stereoisomeric alcohols, mannitol and sorbitol. Fructose is a strong reducing agent and



d-Fructose. Mannitol. Sorbitol.

quickly reduces Fehling's solution. It resists, however, the action of bromine. Its reducing properties are due to the grouping

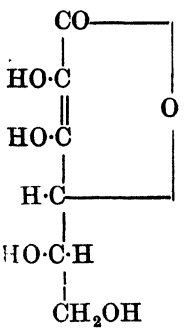


R—CO—CH_2·OH, produced when the ring opens. Unlike other ketonic groupings this is very readily oxidised, forming

R—CO—CO·OH.

When oxidised by nitric acid it forms tartaric and glycollic acids.

276a. Ascorbic Acid.—(Vitamin C.). This important substance may be considered with the hexoses. It normally exists as a lactone (§ 239). It is widely distributed in animal and plant tissues, the best sources being orange juice. A regular supply of this substance a few mg. per diem) is necessary to maintain health; vitamin-C deficiency brings about the serious and sometimes fatal disease of scurvy.



DISACCHARIDES

277. Disaccharides.—These compounds are anhydrides, or rather ethers, derived from two molecules of a monosaccharide by the loss of a molecule of water. They are all easily broken up into monosaccharides when hydrolysed by boiling with dilute acids. Certain enzymes such as invertase and maltase (§ 36) readily bring about this hydrolysis.

Some of the disaccharides have only recently been synthesised from the mono-

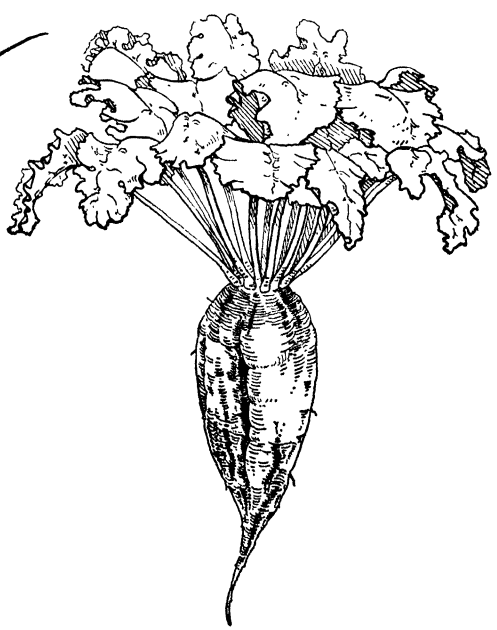


FIG. 44.—Sugar-beet.

saccharides, but there is reason to suppose that this synthesis takes place in plant tissues with great facility (§ 300).

278. Sucrose, Cane Sugar, $C_{12}H_{22}O_{11}$.—Cane sugar occurs in certain plants notably the sugar-beet, the sugar cane and the sugar-maple.

It occurs in many plants as a storage material and its manufacture from sugar-beet and sugar cane is one of the most important industries, the world's consumption being estimated at about 26,000,000 tons yearly.

279. Manufacture of Cane Sugar.—*Sugar from Beet.*—The sugar-beet is cultivated in all parts of Europe and in most other temperate climates. It forms a root weighing between 1 and 2 lbs. Careful breeding has evolved a race of beetroot with an average sugar content of some 15 per cent.

The roots are first well washed and then sliced mechanically into fine shreds, resembling vermicelli. The sugar solution is confined in the cells; to extract it the shreds are soaked in hot water. The sugar diffuses out of the cell into the water while the colloidal constituents (proteins, pectins, etc.) which diffuse very slowly remain behind. The diffusion is performed as a rule in a 'battery' of eight diffusers—large cylindrical iron tanks—and the extraction is performed on the counter-current system. Fresh water is admitted to the diffuser (say No. 8), which contains beetroot almost completely extracted after treatment with seven lots of solution. The solution is transferred from one diffuser to the next, till when fairly concentrated it meets the fresh beet slices in No. 1 diffuser. Thus fresh water with the maximum extracting power is used on the beetroot containing little sugar. The exhausted beet is discharged from No. 8 and the strong solution run off from No. 1. No. 8 is refilled with fresh beetroot, No. 7 receiving the liquid it contained, and the liquid from each diffuser is passed on to the next. In this way each portion of beetroot is seven times extracted with successively weaker solutions, while each lot of water meets seven portions of beet successively richer in sugar and is thus converted into a solution of adequate concentration.

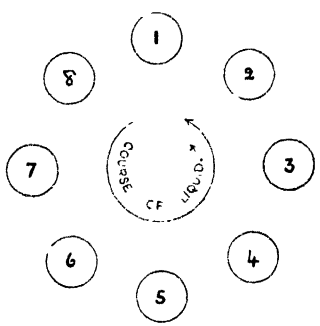


FIG. 45.—Plan of Diffusers.

The 'juice' so obtained contains 12–15 per cent. of sugar together with dissolved mineral salts, some colloidal matter, etc.; 2–3 per cent.

of lime is added to it and it is heated to 80–85° C. and filtered. The lime precipitates much of the impurity, which is filtered off. The juice is then concentrated by boiling *in vacuo*. Elaborate evaporators are employed in which the steam evolved by boiling one solution is made to heat and so boil another kept at a lower pressure, the steam from this being made to boil a third solution maintained at a lower pressure still. The evaporation is carefully regulated, and the liquid is finally allowed to cool and crystallise.

The result is a thick mixture of sugar crystals and mother liquor, known as '*massecuite*.' The massecuite is whirled in centrifuges by means of which the crystals are separated from the mother liquor. The crystals are now 'raw sugar,' and are further refined as described at the close of this section. The mother liquor still contains much sugar and is usually boiled down further, so obtaining a fresh crop of sugar crystals. The mother liquor from this second operation contains much impurity and is known as molasses. No more sugar can be crystallised from it. The molasses is often used for making alcohol or for manufacturing a nutritious cattle food; but the lime or strontia process may also be used to extract more sugar.



FIG. 46.—Sugar Cane.

The molasses in this process is diluted and mixed with quicklime, and insoluble *calcium saccharate* is precipitated. This is filtered off, suspended in water, and decomposed by carbon dioxide, giving calcium carbonate and a solution of sugar, which is added to the raw juice. Strontia has been used in place of quicklime.

Manufacture of Sugar from Sugar Cane.—The sugar cane is an enormous grass with a solid stem consisting of cellular tissue, in which the sugary juice is stored. It grows only in tropical or semi-tropical climates.

A few factories slice the cane and remove the sugar by diffusion,

as described above, but the usual practice is to pass the canes between iron rollers, so squeezing out the juice. The crushed cane is sprayed with water and again squeezed, this process being repeated several times. The raw juice contains 12–18 per cent of sucrose, and much impurity, which includes glucose and fructose, mineral matters, chlorophyll and various colloidal substances. As in the case of beet sugar, lime is added and the juice heated. The precipitated impurities are filtered off and the juice is evaporated in vacuum pans, as described above. The concentrated juice is allowed to crystallise, and the massecuite so obtained is centrifuged. The mother liquor is then further concentrated. The sugar crystals so obtained are then refined, as described below.

Sugar Refining.—The raw sugar, obtained from cane or beet, consists of sugar crystals and molasses adhering to them. They are placed in centrifugal machines and rotated at about 15 revolutions a second. They are then sprinkled with water in such quantity that most of the molasses is carried off with the water without dissolving an appreciable quantity of the crystals.

The sugar is now of 97·5—99·5 per cent. purity. It is next dissolved in a small quantity of hot water, and the brown syrup so obtained is filtered slowly through 'char,' a form of charcoal which has a remarkable power of absorbing and retaining the impurities of high molecular weight which colour the sugar. Char is usually a form of animal charcoal made by heating bones to redness; the carbon so obtained is much more effective than wood charcoal, possibly owing to its fine subdivision. Certain 'activated' forms of wood charcoal are now much used, and are greatly superior to bone-char. They appear to be made by treating wood with mineral salts (calcium acetate, etc.) and then carbonising it. The char does not retain its power of removing colouring matters indefinitely. When it ceases to remove the colouring matters, it is washed, dried and heated to *ca.* 1,050° C. in absence of air. The impurities, colouring matters, etc., are carbonised and the char may be used again for an indefinite number of times.

The colourless syrup obtained by treatment with 'char,' has now merely to be evaporated in vacuum pans, allowed to crystallise, separated from the mother liquor in centrifugals and dried by hot air. This gives *granulated* or *caster* sugar.

Cube sugar is usually made by mechanically moulding the moist sugar from the centrifugals and drying the soft cubes so obtained.

Demerara sugar is obtained by bleaching the raw cane juice[1] to a yellow tint by means of sulphur dioxide, adding a little stannous chloride, and concentrating it till it crystallises. Much 'Demerara'

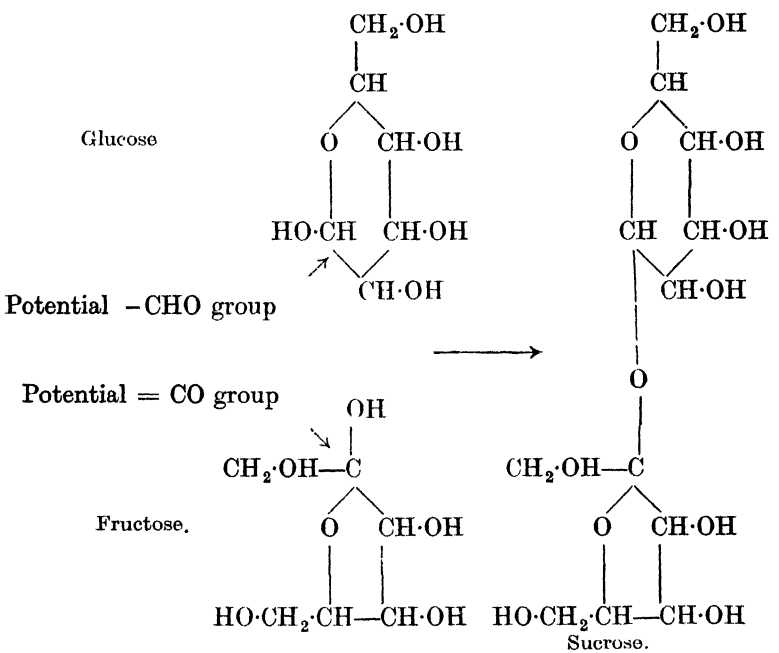
[1] Beet juice cannot be used, as the flavour of the product is objectionable.

sugar is, however, merely the white crystals tinted by means of a yellow dye.

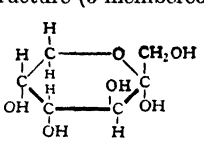
280. Structure of Sucrose.—Cane sugar is very readily broken up into *d*-glucose and *d*-fructose by boiling it with dilute acids (Expt.61):

$$C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6$$

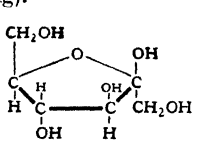
It has no reducing power, so presumably does not contain any structure which can form an aldehydic group $-CHO$. It does not form a hydrazone and so cannot contain any grouping which could easily yield a $-CO-$ group. It forms an octa-acetyl derivative, and so has eight hydroxyl groups. The formula adopted is that of a glucose and a fructose molecule[1] connected by an oxygen linkage *through their reactive carbon atoms.*



[1] While free fructose has a *pyranose* formula with a 6-membered ring combined fructose in disaccharides (sucrose) and in polysaccharides (inulin) has a *furanose* structure (5-membered ring).



Pyranose form of fructose.



Furanose form of fructose.

The stereoisomerism of sucrose, *i.e.*, the relative positions of all the groups, has not been fully worked out.

281. Properties of Sucrose.—Cane sugar forms large monoclinic crystals, very soluble in water. It melts at 160° C. It is dextro-rotatory, and the strength of its solutions is ordinarily measured by ascertaining the angle through which the plane of polarised light is turned by a known length of solution at a known temperature.

Sucrose breaks up when heated above its melting point, forming brown amorphous substances known as *caramel*. This is sometimes used for colouring foodstuffs, beer, etc. When heated with sulphuric acid, a bulky charred mass containing free carbon, etc., is produced.

Sucrose resembles glucose in forming salts; these are usually known as saccharates [which should not be confused with the salts of saccharic acid, $HO{\cdot}OC{\cdot}(CH{\cdot}OH)_4{\cdot}CO{\cdot}OH$]. The saccharates of calcium, strontium, etc., being slightly soluble in water are used, as we have seen, in the separation of more cane sugar from the syrups from which as much sugar as possible has been crystallised.

Sucrose differs widely from glucose and fructose. It does not form addition products (hydrazones, etc.), nor is it a reducing agent.

When boiled with dilute acids, it breaks up into *d*-glucose and *d*-fructose. This process is known as the *inversion* of cane sugar. The mixture of *d*-glucose and *d*-fructose so obtained is called *invert sugar*. The term inversion refers to the effect of the solution on polarised light. Cane sugar is dextro-rotatory, *d*-glucose is also dextro-rotatory, but *d*-fructose is more strongly lævo-rotatory. Thus the hydrolysis of a solution of dextro-rotatory cane sugar forms a lævo-rotatory solution of invert sugar.

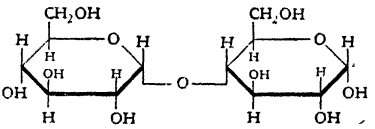
Expt. 64.—*Reactions of Sucrose.*—(1) Heat alone until liquid becomes dark brown. Dissolve product in water. Deep brown solution of caramel.
(2) To 1 g. sucrose add 2 drops water and 1 c.c. conc. sulphuric acid. Warm (if necessary). Porous bulky mass of carbon, etc., produced.
(3) Show that cane sugar does not reduce Fehling's solution.
(4) Boil a little sucrose with dilute hydrochloric acid. Neutralise with caustic soda and show that the product (containing glucose) reduces Fehling's solution (*v.* Expt. 63).

282. Maltose, $C_{12}H_{22}O_{11}{\cdot}H_2O$.—Maltose is obtained when starch is hydrolysed by the enzyme diastase, contained in germinating seeds. It is extracted from malt by boiling it with water and evaporating the solution. It forms white crystals. Maltose, when hydrolysed, yields *d*-glucose only.

It is less sweet than cane sugar. It differs from cane sugar in having reducing power and forming cyanohydrins, hydrazones, etc.

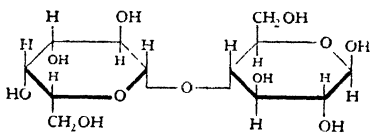
Maltose has reducing properties, etc., because the two groups are not *both* linked through the reactive carbon atom next to the oxygen linkage (the potential aldehyde group). Its formula may be written:—

The group conferring reducing power is marked with an asterisk (cf. formula, p. 263).



283. Lactose, Sugar of Milk, $C_{12}H_{22}O_{11}.H_2O$.—Lactose is contained in milk, and is obtained by evaporating the whey from which as much fat as possible has been separated. It forms white crystals which are less sweet than sugar.

When hydrolysed it forms *d*-glucose and *d*-galactose. Lactose has the formula



and is a stereoisomeride of maltose, which it therefore closely resembles in its chemical properties.

284. Tri- and Tetra-saccharides.—The tri- and tetra-saccharides are found in certain plants, but are not important.

POLYSACCHARIDES

General Characteristics of the Polysaccharides.—The polysaccharides include the very important substances starch and cellulose, and the less important dextrin, inulin, glycogen and others.

They all have the character of colloidal substances. They are non-crystalline and dissolve in water, if at all, to form thick colloidal sols, which may solidify to gels. All the polysaccharides have the formula $(C_6H_{10}O_5)_n$. Their molecular weights as approximately known are always very high (1,600—30,000, or more).

When hydrolysed by dilute acids or by water in presence of certain enzymes, monosaccharides are ultimately produced,

$$(C_6H_{10}O_5)_n + nH_2O = nC_6H_{12}O_6,$$

the nature of which varies with the particular polysaccharide. Disaccharides and other substances are often formed as intermediate products. Thus starch produces first maltose, then *d*-glucose, while inulin gives *d*-fructose and cellulose gives *d*-glucose.

285. Cellulose.—Cellulose forms the chief constituent of the cell walls of plants, and is more especially abundant in the harder and more fibrous strengthening tissues. It thus forms the greater part of wood, cotton, linen and other plant fibres, and is the chief constituent of paper, which is derived from these. It is always associated with other substances, but is found in its purest condition in cotton, the seed hairs of the cotton plant (*Gossypium*). If cotton wool is boiled with dilute caustic soda (1 per cent.) and then treated with dilute acetic acid and washed, a product containing some 99·8 per cent. of cellulose is obtained, while the best filter paper which has been extracted with hydrofluoric acid is almost pure cellulose.

The formation of cellulose in the plant is further discussed in § 300.

286. Structure of Cellulose.—Cellulose, $(C_6H_{10}O_5)_n$, when hydrolysed, first yields dextrins, then a disaccharide, *cellobiose*, which finally yields *d*-glucose when completely hydrolysed. The molecular weight of cellulose is very high, so that, if, as appears, it is built up of *d*-glucose units, there must be very many of them. Haworth (1932) has reached the conclusion that the cellulose molecule is a long thread-like assemblage of glucose units linked as in the glucosides and disaccharides (§§ 273, 280) through an oxygen atom. Cellulose is then probably

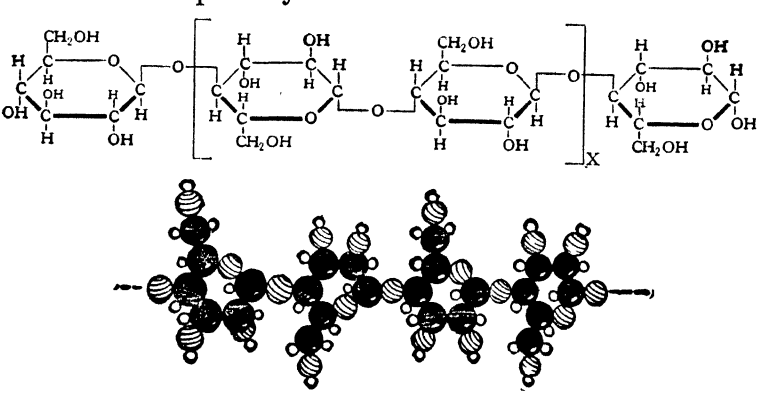


FIG 46A.—Four "units"—about a fiftieth—of a cellulose molecule, represents about 30,000,000 times natural size. The whole molecule represented on this scale would be ten feet long.

The value of X is uncertain and we are not sure that it has any fixed limit. Physical measurements indicate a value of 3,000 for the number of glucose residues: chemical methods give a value as low as 200, which lower figure is probably due to the decomposition of the native cellulose molecule.

Estimates of X have been made by forming methyl derivatives of cellulose. The left-hand end group gives a tetramethyl glucose on hydrolysis, while the others give a trimethyl glucose. The proportion of tetramethyl glucose has been determined, and since it is about 1/100—1/200 of the whole, X is between 100 and 200.

287. Physical Properties of Cellulose.—Pure cellulose forms colourless transparent fibres of a shape depending on the plant from which it is derived. It decomposes below its melting-point. It is insoluble in water but, being colloidal in character, readily absorbs some 6—8 per cent. of moisture, which can be removed by drying.

Cellulose is denser than water (sp. gr. 1·58); the apparent lightness of wood is due to air spaces contained in it.

288. Chemical Properties of Cellulose.—Cellulose, when heated, first becomes brown and then breaks up, giving a great variety of products—acetic acid, water, tarry matters, etc.

It is highly resistant to chemical reagents in general, as is witnessed by its use as filter paper.

Concentrated sodium hydroxide attacks cellulose, causing it to swell up to a gelatinous mass. When the cotton fibre is treated with sodium hydroxide of 15—20 per cent. strength it loses its ribbon-like form and swells into a smooth glassy cylinder. The treatment of cotton goods with caustic soda accordingly gives them a peculiar silky lustre and the process is known as *mercerisation.*

The action of nitric acid on cellulose produces *esters* with its hydroxyl groups. These esters, known as *cellulose nitrates* or, incorrectly, as *nitrocellulose*, are discussed under a separate heading.

Concentrated sulphuric acid breaks up cellulose, giving various carbonaceous products, but other acids have little or no effect upon cellulose. When cellulose is boiled with diluted sulphuric acid, it is first 'parchmentised,' or converted into a tougher and thicker material, which is probably a first stage in the degradation of the cellulose molecule. Further boiling produces first cello-dextrins somewhat resembling the dextrin from starch (§ 297). These are finally broken down into cellobiose, $C_{12}H_{22}O_{11}$, a disaccharose, and this is finally hydrolysed to *d*-glucose. The hydrolysis is not at all easily brought about; a simple method of performing it would give a valuable source of glucose. The difficulty of hydrolysing cellulose renders it indigestible by the higher animals. Bacteria can, however, utilise it. Herbivorous animals have in their digestive system enormous colonies of bacteria, which break down at least a part of the cellulose of the plants eaten to products which the animal can digest.

Cellulose resembles the other saccharides in forming ethers when methylated with methyl sulphate and alkali, and esters with acetic

anhydride (§ 265). These, the cellulose acetates, are of great importance in the artificial silk industry (§ 289).

Cellulose probably does not form a true solution in any solvent. It does, however, appear to dissolve in a solution of a copper salt in ammonia. The cuprammonium hydroxide, $Cu(NH_3)_4 \cdot (OH)_2$, combines with cellulose, forming a soluble complex. The treatment of cotton and linen goods with this reagent destroys their absorbent properties and affords a valuable way of water- and rot-proofing them. Materials so treated are called Willesden goods. The solution of cellulose in the cuprammonium reagent is employed in the manufacture of artificial silk.

A solution of sodium xanthogenate, Na_2CS_3, also dissolves cellulose, forming a soluble colloidal ester. The reaction is the foundation of the very important *viscose* process for artificial silk, and is discussed in § 289.

Expt. 65.—*Reactions of Cellulose.*—Filter paper or degreased cotton wool may be used.

(1) Warm gently with a little conc. sulphuric acid until just disintegrated. Dilute (care!): neutralise with NaOH, and test with Fehling's solution. Reducing sugars are present.

(2) Precipitate some cupric hydroxide from copper sulphate and alkali, avoiding excess of the latter. Warm, filter, wash and dissolve blue solid in minimum of ammonia (sp. gr. 0 880). Place a tuft of cotton wool in the liquid, cork, and leave for some hours. Filter through glass wool. Acidify the resulting solution. Cellulose is precipitated in gelatinous flakes.

(3) Moisten filter paper with 17 per cent. caustic soda solution and blot off excess. Place in a corked test-tube and after a few hours add two drops CS_2. Cork, and leave overnight. Dissolve the gelatinous yellow product in caustic soda. Acidify the 'viscose' solution so produced: cellulose is precipitated.

289. Artificial Silk.—Real silk consists of a very fine filament of a nitrogenous protein material secreted by the silkworm caterpillar. Artificial silk consists of filaments made from cellulose or from one of its esters. The artificial silk industry has made tremendous strides in the last ten years, and now produces over 125,000 tons yearly.

Four processes are adopted, the essential principle being the same in each case. Cellulose is converted into a compound which forms a viscous solution in some solvent. The solution is squirted through a minute orifice forming a fine fibre, which is solidified either by treatment with a solution or by air drying.

The *viscose* process produces by far the greatest quantity of artificial silk. The other processes, which between them do not provide a fifth of the world's artificial silk, produce more expensive products which are each of them, however, superior in some particular to the viscose silk.

Viscose Process.—An alkaline solution of sodium thiocarbonate

(xanthogenate), Na_2CS_3, reacts with cellulose, giving a colloidal solution of cellulose thiocarbonate in sodium hydroxide solution. This solution is coagulated by acids, cellulose being formed once more.

The starting material is bleached wood pulp. It is treated with 17 per cent. sodium hydroxide solution. The excess of this is squeezed out and after some hours carbon disulphide is added. This forms sodium thiocarbonate with the caustic soda, and this reacts with the cellulose forming an orange-coloured gelatinous mass. This is then mixed with caustic soda solution, when a viscous colloidal solution is obtained. This is 'ripened' for a couple of days and then spun by forcing it through fine jets into a solution of dilute acid, which converts the filament into cellulose containing a little free sulphur. The filament is then wound and simultaneously twisted and coiled into 'cakes.'

The spun filaments are washed, and soaked in a weak solution of sodium sulphide to remove the free sulphur, bleached and again washed.

The process has taken the first place owing to the extreme cheapness of the materials used.

Acetate silk is made by treating cotton with acetic anhydride containing 10 per cent. of sulphuric acid. The cotton gradually dissolves. The solution is thrown into water and the white fibrous mass of cellulose acetate which is precipitated is washed, dried, and dissolved in acetone. It is spun by forcing the viscous solution through a nozzle pierced with many fine holes. A current of air evaporates the acetone, and the filaments are wound on to a bobbin. The acetone is recovered from the air used for drying. The product is very beautiful, but the process is more expensive than the viscose one.

Nitrocellulose Process.—'Nitrocellulose' of the pyroxylin type (§ 290) is dissolved in an alcohol-ether mixture and spun as described above. The filament of nitrocellulose, which would be far too inflammable for wearing apparel, is denitrated, *i.e.*, reconverted into cellulose, by treating it with a solution of a soluble sulphide. The product resembles real silk very closely.

Cuprammonium Silk.—In this process cotton is dissolved in a cuprammonium solution produced by the action of ammonia solution on copper in presence of air.

The viscous solution is spun in much the same way as viscose, a setting bath of water being used. The filament of cuprammonium silk can be *stretched* while being spun, and very fine filaments can thus be obtained. The filament is treated with dilute acid to remove copper and then very thoroughly washed and dried. The product

is a silk fibre of great fineness which has advantages over the other products for certain types of goods.

290. Cellulose Nitrates. 'Nitro-cellulose.'—When cellulose is treated with concentrated nitric acid, with or without the addition of sulphuric acid, a series of nitric esters are obtained containing up to three nitrate groups per $C_6H_{10}O_5$ unit of the cellulose molecule. It is not possible to isolate pure nitrates of any definite formula, such as $[C_6H_7O_2{\cdot}(NO_3)_3]_n$. It is probably better to regard the enormous cellulose molecule as being attacked at any or all of its several hundred hydroxyl groups and to consider the formula as being $C_{6n}H_{10n-x}O_{5n-x}(NO_3)_x$ where x may be anything up to $3n$.

These nitric esters are of great technical importance, and comprise:—

(1) *Guncottons.*—Guncotton consists of cellulose nitrated as much as is possible. It is used only as an explosive.

(2) *Pyroxylins.*—Pyroxylins are slightly less nitrated. They are of considerable value for manufacturing the cellulose paints, lacquers used for motor-car bodies, etc.

(3) *Collodions.*—Collodions are less nitrated and are used in medicine and photography.

(4) *Celluloids.*—The nitrocellulose used for making celluloid (*v. infra*) is the least fully nitrated of these products.

Nitration of Cellulose.—To make nitrocellulose a pure cotton is thoroughly dried and then steeped in a warm mixture of nitric acid and sulphuric acid containing about 71 per cent. H_2SO_4, 21 per cent. HNO_3, 7·5 per cent. water, and a little nitrous acid. After six hours the cotton is removed, most thoroughly washed from acid and dried. The type of nitrocellulose obtained is determined by the strength of acid and the time of nitration.

Expt. 66.—*Preparation and Reactions of Nitrocellulose.*—In a beaker[1] mix 20 c.c. of fuming nitric acid with 20 c.c. conc. sulphuric acid. Add a filter paper cut into strips and leave for thirty minutes. Take out paper on glass rod, wash well with water and alcohol and dry.

(1) Note harsh texture.

(2) Note very rapid combustion.

(3) Dissolve in boiling amyl acetate; let a few drops of product evaporate on glass. A colourless tough skin of nitrocellulose is formed.

(4) Dissolve as above in a mixture of alcohol and ether. The ease of dissolving depends on the degree of nitration.

Properties of Nitrocellulose.—Nitrocellulose exactly resembles in appearance the cellulose from which it was prepared. It is, however, harsher to the touch. Nitrocellulose differs from cellulose in being readily soluble in a number of solvents to a transparent viscous solution. Among such solvents are acetone, amyl acetate and

[1] If larger quantities are used cooling is advisable. Handle the acids with care.

mixtures of ether and alcohol. Its solubility seems to vary considerably with its method of preparation as well as with the degree of nitration.

The solutions of pyroxylin (moderately nitrated cellulose) are greatly used as paints and lacquers. These consist of pyroxylin together with a 'plasticiser,' usually an ester of high boiling point (*e.g.*, triphenyl or tricresyl phosphate, § 416a) dissolved in acetone, butyl alcohol, amyl acetate, etc. The function of the plasticiser is to ensure that the film of lacquer or paint is not brittle, as is a film of pure nitrocellulose.

Nitrocellulose is soluble in camphor, and when lightly nitrated nitrocellulose is thoroughly incorporated with camphor (alcohol being employed as a solvent), *celluloid* is formed which, owing to its transparency and flexibility, has found a great number of uses. Its inflammability is its chief drawback. Celluloid softens when heated to about 70° C. and may then be moulded into any shape.

The use of nitrocellulose in the artificial silk industry has already been described (§ 289).

Nitrocellulose is intensely inflammable, this property being most accentuated in the most highly nitrated forms. Guncotton in fibres or thin sheets burns instantaneously with a bright flash, and when incorporated with nitroglycerin, as described below, it is a most valuable explosive. It is, as a rule, not employed in the fibrous form obtained by nitration. The usual procedure is to gelatinise it by incorporating it with nitroglycerin and some solvent which is subsequently evaporated. Thus *cordite*, used as a propulsive explosive, is made by incorporating 30 per cent. nitroglycerin, 65 per cent. guncotton and 5 per cent. of mineral jelly (vaseline). Acetone is used as solvent.

The explosives so obtained are at once very powerful and very safe. They burn vigorously but do not explode when ignited. Explosion is only brought about by causing them to burn in a confined space or by using a detonator of fulminate, etc. (*v.* § 149).

In its chemical properties nitrocellulose has much of the inertness of cellulose. It is very resistant to water and acids. Certain substances de-nitrate nitrocellulose, reconverting it into cellulose. Among these is ammonium sulphide, employed in the artificial silk industry.

291. Starch, $(C_6H_{10}O_5)_n$.—Starch is found in all green plants. Granules (chloroplasts), containing the mixture of coloured substances known as *chlorophyll*, in some unexplained manner cause the carbon dioxide of the air and the water of the cell contents to react, eliminating oxygen and forming monosaccharides and disaccharides. These are polymerised to starch which is accumu-

lated in various parts of the plants as a storage material. The process of starch formation in plants is further discussed in § 300.

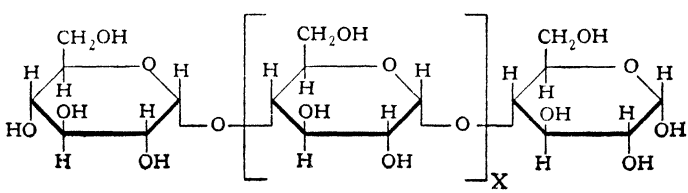
292. Manufacture of Starch.—Starch is made from a variety of plants. The most important of these are potatoes and cereal grains, *e.g.*, rice, wheat, maize, etc. The table below shows the chief forms of starch and their sources.

The method of manufacturing starch from potatoes may be taken as typical of the methods employed. The potatoes are washed and fed into a rapidly rotating cylinder furnished with saw blades on its interior surface. The potatoes are rasped to a pulp consisting of

Sources of Starch.	Uses of Product.
Potato, Wheat, Rice	Manufacture of glucose and dextrins. Laundry work. Sizing of textiles.
Maize	Foodstuff (cornflour).
Arrowroot	Foodstuff.
Cassava	Foodstuff (tapioca); industrial.
Sago	Foodstuff.

the fibrous matter and the broken walls of the cells, etc., together with the starch granules originally contained in them. The pulp is washed on brass-wire sieves, which retain the coarser fibre and let the starch granules pass. The milky suspension of starch is allowed to settle: the sediment consists of pure starch covered with a layer of fine fibre, etc., which has passed the sieves. The fibre is scraped off. The settling process is repeated, fibre is again removed and the starch is centrifuged and then dried in the air or by gentle heating in ovens.

293. Constitution of Starch.—Starch is generally thought to consist of two substances, the readily soluble *amylose* and the paste-forming and less soluble *amylopectin*. Both forms of starch have a highly complex molecule, the structure of which is now known. Both amylose and amylopectin consist of aggregates of conjugated glucose residues each of which contains some 24 to 30 glucose units. The structure of these can be indicated by:



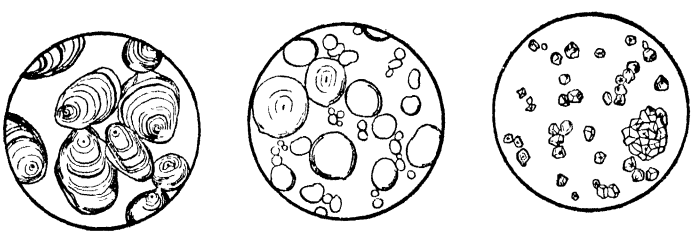
The chain length was elucidated by methylation, hydrolysis and the determination of the percentage of tetramethyl glucose just as in the case of cellulose. The type of linkage figured above would give a chain curved on itself and would not give straight thread-like molecules like those of cellulose. Some of the differences between starch and cellulose may arise from this cause. Its close resemblance to glycogen, the formula of which is discussed on p. 295, corresponds to a close resemblance in structure.

294. Properties of Starch.—Starch occurs as minute granules, having a characteristic appearance under the microscope (Fig. 47). They are built up of concentric shells surrounding a nucleus, but differ much in shape and size according to their source.

Starch is quite insoluble in cold water or any other cold solvent, though it absorbs up to 35 per cent. of water from the air with great readiness. When heated with water the particles swell up and finally, at 65°—85° C., form a thick opalescent colloidal solution which sets to a jelly when cold.

When starch is heated alone it is first transformed into dextrin (*q.v.* § 297) which on further heating decomposes, giving a variety of products similar to those obtained by the distillation of wood.

Starch is easily recognised by the intense blue colour imparted to it by iodine in presence of iodide ions (usually provided by potassium iodide). The compound is a loose one, the colour being destroyed



Potato. Wheat. Rice.

FIG. 47.—Starch Grains (× 200).

by heating but reappearing on cooling. A bright yellow colour is given to starch by bromine.

The hydrolysis of starch takes place in several stages. When boiled with dilute mineral acids it first forms *'soluble starch,'* apparently differing from ordinary starch only in its solubility in water; further treatment produces gum-like substances known as *dextrins* (§ 297) which are then hydrolysed to the disaccharide *maltose* and this finally breaks down to *d*-glucose.

$(C_6H_{10}O_5)_n$ → Starch. → Soluble starch. → Dextrins. → $C_{12}H_{22}O_{11}$ Maltose.

$2C_6H_{12}O_6$ ← *d*-Glucose.

Starch is hydrolysed by several enzymes. Diastase, contained in seeds and malt, converts it into maltose but does not hydrolyse it further. Ptyalin, however, which is contained in saliva, hydrolyses starch to glucose.

The digestion of starch is accomplished by means of the ptyalin of the saliva and also by the action of the pancreatic juices (*v.* § 301).

Expt. 67.—*Hydrolysis of Starch.*—Prepare a starch paste by bringing 50 c.c. of water to the boil and stirring in about 0·5 g. of starch which has been shaken to a thin milk with 5 c.c. of water. Pour 10 c.c. of the liquid into each of four test-tubes. When they have cooled to about 35° C., add to the first 1 c.c. of dilute sulphuric acid, to the second about 1 c.c. of saliva, to the third a little malt ground up with cold water. Leave the fourth untreated. Place the test-tubes in a beaker of water maintained at 35° C. by a small flame and test their contents from time to time by removing drops and mixing them with weak iodine solution. After a short time the first three no longer give a blue colour, showing that the starch has been hydrolysed.

Expt. 68.—*Reactions of Starch.*—(1) Examine (*a*) starch grains, (*b*) section of potato with a microscope.

(2) Mix some potato starch to a cream with water and add boiling water, stirring well. Leave a portion to cool, when it will set to a jelly.

(3) Dilute a portion of starch paste made as above. Add a few drops of iodine. Note blue colour. Heat: note disappearance of colour, and reappearance on cooling.

(4) Hydrolysis of starch (see Expt. 67).

295. Uses of Starch.—Starch is employed:

(1) Industrially as a means of manufacturing glucose, dextrin, and starch esters. It is also used in laundry work and in textile manufacture for finishing, stiffening and glazing textiles.

(2) As a foodstuff. Maize starch constitutes *cornflour*. The starch of arrowroot is used in invalid foods, etc. Cassava starch is used as tapioca and the starch of the sago palm as sago. The chief constituent of all cereal foods (*e.g.*, bread, etc.) is starch.

296. Starch Esters. Like cellulose, starch contains hydroxyl groups and forms esters. Starch nitrate, known as nitro-starch, has been used as an explosive, while starch acetate, known as 'feculose,' forms a transparent gelatin-like substance, used in the manufacture of sweets and also as a 'size' for coating paper.

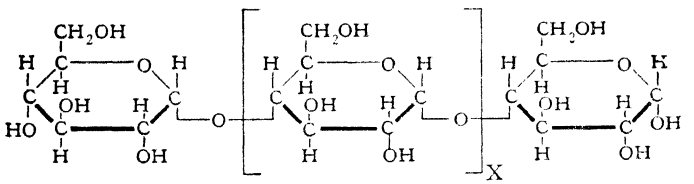
297. Dextrins $(C_6H_{10}O_5)_n$.—Dextrins are produced when starch is heated alone or hydrolysed to a limited extent with acids or diastase. Several different dextrins exist, probably corresponding to successive stages in the breaking-down of the starch molecule. *Erythrodextrin*, the most complex, gives a red coloration with iodine. Further hydrolysis yields *achroödextrin* which gives no coloration with iodine, and *maltodextrin*. These are, in all probability, complex mixtures.

They are gum-like substances soluble in water.

They are of practical importance, being employed in gums, pastes and sizes, under the name of British gum or starch-gum. They are also used by textile printers as 'vehicles' for colours.

298. Glycogen, $(C_6H_{10}O_5)_n$.—Glycogen is found in the tissues of the body, notably the liver and the muscles. Its production and functions are discussed in § 301.

Glycogen is hydrolysed to *d*-glucose by enzymes or acids. Haworth (1932) has produced evidence that its formula is



where X may be about 10 and the M.W. about 1,600. Note that the difference from cellulose is only in its stereoisomerism and also in the length of the chain.

It is a powder closely resembling soluble starch. It gives a purplish-red colour with iodine. It is very readily hydrolysed to *d*-glucose.

299. Inulin, $(C_6H_{10}O_5)_n$.—Inulin is a storage material resembling starch and is contained in dahlia tubers, artichokes and some other plants.

It gives a yellow colour with iodine, and is hydrolysed to *d*-fructose.

300. Production of Carbohydrates by Plants.—The only ultimate source of carbohydrates is the green plant, and the formation of sugars, starch and cellulose by the plant is at once one of the most important and least well understood problems of Biology and Organic Chemistry.

The green plant requires only certain inorganic salts, water, carbon dioxide, oxygen and light in order to synthesise the numerous and varied compounds contained in it.

The seat of the process of converting carbon dioxide and water into sugars is in the green portions of the plant—normally the leaf. The cells of the leaf contain chloroplasts, small bodies containing a mixture of several complex pigments known as chlorophyll.

While the steps by which the photosynthesis takes place are not known it is clear that the process involves:

(1) The utilisation of carbon dioxide and evolution of oxygen.

(2) The production of a monosaccharide or disaccharide. The

carbohydrates first formed in the photosynthesising leaf include *d*-glucose, *d*-fructose, sucrose and usually starch. The probability seems to be that *d*-glucose is first formed together with *d*-fructose and that these condense to form sucrose which is further polymerised to starch. The evidence as to which sugar is the first to be formed is conflicting and the point is uncertain. The scheme suggested would be:

$$6CO_2 + 6H_2O = \underset{\text{Glucose and /or fructose.}}{C_6H_{12}O_6} + 6O_2 \uparrow$$

and then

$$2C_6H_{12}O_6 = \underset{\text{Sucrose.}}{C_{12}H_{22}O_{11}} + H_2O$$

$$nC_{12}H_{22}O_{11} = 2\underset{\text{Starch.}}{(C_6H_{10}O_5)_n} + nH_2O$$

but all that is *certain* is that monosaccharides, disaccharides and starch are produced from carbon dioxide and water in the green plant under the influence of light. The plant stores the carbohydrate material usually as starch but sometimes (as in most monocotyledons) as sucrose. When required, the starch is hydrolysed by an enzyme to maltose and finally to glucose. This is built up by a process, of the nature of which we are ignorant, into cellulose which forms the main constituent of the cell walls of the plant:

$$nC_6H_{12}O_6 = (C_6H_{10}O_5)_n + {}_nH_2O.$$

Numerous theories, but little supported by experimental evidence, have been advanced to explain the synthesis of sugars by the green leaf. The most popular of these supposes (1) that carbon dioxide and water under the action of light yield formaldehyde and oxygen:

$$CO_2 + H_2O = CH_2O + O_2.$$

(2) That this formaldehyde polymerises to a sugar:

$$6CH_2O = C_6H_{12}O_6.$$

It was formerly supposed that when carbon dioxide was bubbled through water containing certain coloured substances, some formaldehyde was produced, but this work has not been substantiated and the first stage of the process is merely conjectural. Furthermore, although formaldehyde can be made to polymerise to *dl*-acrose, the sugars actually formed in the leaf are the *d*-isomerides and not the *dl*-isomerides as the theory would indicate. It would seem then that this theory is not supported by the experimental evidence.

Carbon dioxide, chlorophyll and water alone form no sugar when illuminated. The protein portion of the chloroplast evidently takes some part in the process and we have at present only a sketchy idea of the structure of dead protein, and no conception of the structure or chemical reactions of the far more complex living protein.

301. Carbohydrates in the Animal Economy.—Starch and cane sugar form a considerable part of the human diet. When starch is swallowed the enzyme *ptyalin* in the saliva converts it, in part at least, into maltose in the stomach. In the small intestine other enzymes contributed by the pancreas come into play (amylopsin, diastase, maltase, invertase, etc.). By their action all carbohydrates are broken down into monosaccharides, chiefly *d*-glucose.

The glucose is absorbed into the blood. It is removed therefrom either by storage or by oxidation. A great part of the glucose, $C_6H_{12}O_6$, is in some manner built up into glycogen $(C_6H_{10}O_5)_n$ which much resembles starch. This is made and stored in the liver, and to a smaller extent in the muscles. It is again slowly hydrolysed to glucose by an enzyme *glycogenase* and this glucose is allowed to enter the circulating blood when the organism requires it. A more permanent means of storage is conversion into fat, which can be reconverted into carbohydrates and utilised.

The blood normally contains a small proportion of glucose and any considerable increase or decrease of this quantity produces serious disorders.

Glucose appears to be of value to the organism mainly as a source of heat and of muscular and chemical energy. The glycogen stored in the muscles is converted during exercise into lactic acid and by this process yields the energy of muscular contraction:

$$\underset{\text{Glycogen.}}{(C_6H_{10}O_5)_n} + nH_2O \rightarrow \underset{\rightarrow \text{ Lactic acid.}}{2nC_3H_6O_3}.$$

The lactic acid is then reconverted into glycogen and water, the necessary energy being provided by the oxidation of some of the glycogen to carbon dioxide and water:

$$(C_6H_{10}O_5)_n + 6nO_2 \rightarrow 6nCO_2 + 5nH_2O.$$

In the disease *diabetes mellitus* the sugars ingested are not utilised, and accumulate in the blood and are excreted in the urine. The disease is due to a deficiency in or destruction of the catalytic substance, insulin, secreted by certain portions of the pancreas, and the disease is now treated by carefully regulated administration of

this substance. The detection of glucose in the urine, which is of the first importance in the diagnosis of this disease, is commonly carried out by testing with Benedict's solution (§ 272).

301a. Action of Enzymes on the Carbohydrates.—Carbohydrates undergo many reactions under the catalytic action of *enzymes*, of which some account is given in Appendix II. The chief types of enzyme action are:—

(1) The action of *hexosidases* in bringing about the hydrolysis of disaccharides to monosaccharides. *Saccharase* (invertase), an enzyme present in yeast, causes cane sugar to be hydrolysed to glucose and fructose (§ 281). *Maltase* present in germinating seeds converts maltose into glucose. The action of the glucoside-splitting enzymes such as *emulsin* and *salicase* (§ 273) is similar.

(2) The action of *polyases* in splitting up polysaccharides into disaccharides is of importance. *Amylase* (diastase) found in malt and in the pancreatic juices causes hydrolysis of starch to maltose.

(3) The action of 'zymase' and other enzymes, produced by yeast and certain bacteria, on solutions of hexoses such as glucose causes the important fermentations considered in the next paragraph.

301b. Modes of Fermentation of Glucose.

(1) *Alcoholic fermentation.* The process of alcoholic fermentation described in § 36–37 is much more complex than the simple equation

$$C_6H_{12}O_6 = 2C_2H_6O + 2CO_2$$

would indicate. Numerous substances not indicated in the equation are formed, notably glycerol and various esters. The entire mechanism has not been elucidated but the scheme given below represents the present state of knowledge.

(1) Glucose reacts with phosphates (which are necessary if fermentation is to occur) to form hexose diphosphate; the enzyme *phosphatase* brings this about.

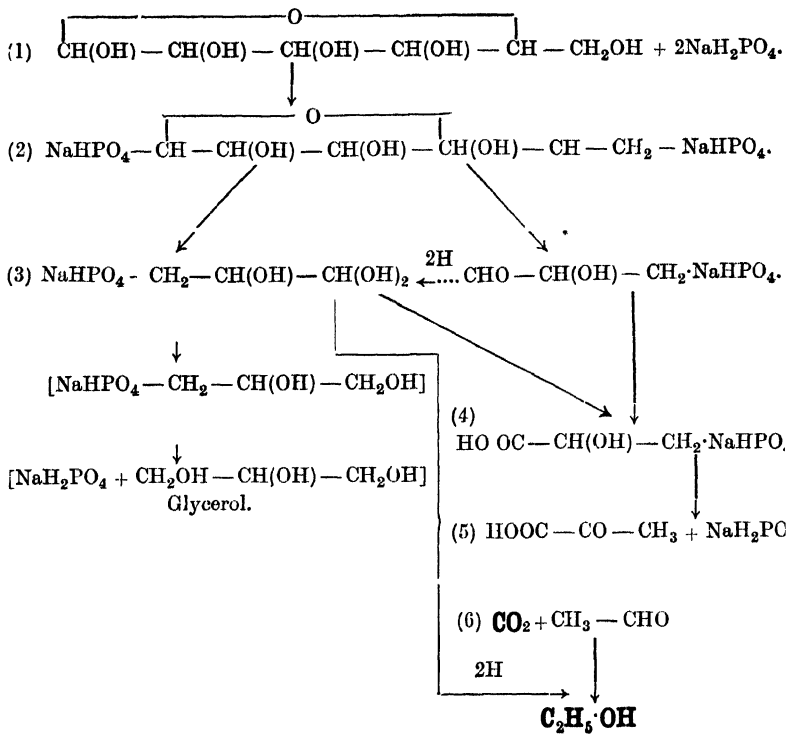
(2) Hexose diphosphate is split, under the influence of *zymohexase* into two molecules of a triose phosphate, probably glyceraldehyde phosphate.

(3) One of these reduces the other, giving glyceryl phosphate and glyceric acid phosphate.

(4) The glyceric acid phosphate is converted to pyruvic acid.

(5) The pyruvic acid is decomposed, by the aid of the enzyme, carboxylase, to acetaldehyde and *carbon dioxide.*

(6) The acetaldehyde is reduced by part of the glyceraldehyde phosphate to *alcohol.*



The main reaction is represented by solid arrows, and the minor reactions by broken arrows.

(2) *Fermentation in presence of sulphites.*—Under these conditions the acetaldehyde is not reduced by the glyceraldehyde and the reactions indicated by the broken arrows occur, the final result being

$$C_6H_{12}O_6 = C_3H_8O_3 + C_2H_4O + CO_2$$

This method has been used in the manufacture of glycerol (*q.v.*).

(3) *Fermentation in Presence of Alkalis.*—Under these conditions acetic acid (1 mol.), alcohol (1 mol.) and glycerol (2 mols.) are formed, and the reactions are the same as the last except that two molecules of acetaldehyde give one of alcohol and one of acetic acid.

$$CH_3{\cdot}CHO + H_2O + CH_3{\cdot}CHO = CH_3{\cdot}CH_2OH + CH_3{\cdot}CO{\cdot}OH.$$

(4) *Lactic Fermentation* (v. § 231).
(5) *Citric Fermentation* (v. § 251).
(6) *Butyric Fermentation* (v. § 80).

QUESTIONS

(1) In what respects do glucose and fructose resemble an aldehyde and a ketone respectively? Why do we believe that they do not contain a —CHO and a —CO— group?

(2) How would you distinguish a solution of glucose from a solution of cane sugar?

(3) What are phenylhydrazones and osazones? Compare the reactions of phenylhydrazine with glucose and with fructose.

(4) How are (*a*) glucose, (*b*) sucrose manufactured?

(5) What meaning do you attach to the terms pentose, hexose, disaccharide, polysaccharide? Name a member of each class and suggest reasons for placing it in that class.

(6) What is known about the formula of cellulose? Into what commercially useful derivatives can it be converted by chemical reagents?

(7) How is starch (*a*) produced by plants, (*b*) prepared in a pure condition commercially? What products are formed by its hydrolysis? How is this brought about (*a*) in the laboratory, (*b*) in the process of digestion?

(8) Discuss the part played by carbohydrates in the life of plants and animals.

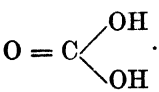
(9) What methods other than direct extraction from animal and plant tissues can be employed to make (*a*) *d*-glucose, (*b*) *d*-fructose, (*c*) maltose?

(10) Some of the carbohydrates have reducing properties and some have not. How is this fact explained by their formulæ?

CHAPTER XX

DERIVATIVES OF CARBONIC ACID

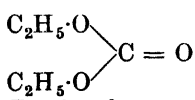
302. Carbonic Acid.—When carbon dioxide is dissolved in water, the solution has all the properties of a dibasic acid and, although it cannot be isolated, carbonic acid, H_2CO_3, is presumed to be formed. The structural formula of carbonic acid is considered to be



Organic derivatives of the acid can be prepared, though not generally from the acid itself.

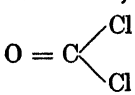
The most important of these are:

(1) Esters of carbonic acid, *e.g.*,



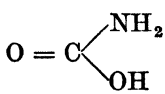
Ethyl carbonate.

(2) Acid chloride of carbonic acid,



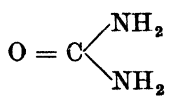
Carbonyl chloride.

(3) Amides of carbonic acid,

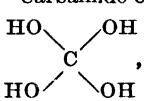


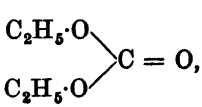
Carbamic acid.

and



Carbamide or urea

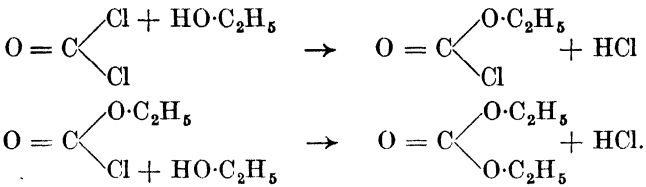
303. Orthocarbonic Acid,  , does not exist, nor are metallic salts of it known, but ethyl orthocarbonate, $C(O{\cdot}C_2H_5)_4$, and guanidine,  , are regarded as derivatives of this acid.

304. Esters of Carbonic Acid.—Ethyl carbonate,  ,

is made by the action of ethyl iodide on silver carbonate,

$$2C_2H_5I + Ag_2CO_3 = 2AgI + (C_2H_5)_2CO_3.$$

It can also be made by the action of alcohol on ethyl chloroformate (§ 306), which is itself made from carbonyl chloride and alcohol:



It is a pleasant-smelling liquid boiling at 126° C. and has the usual properties of an ester. The carbonates of some other alkyl radicals are known.

305. Carbonyl Chloride, Phosgene, $COCl_2$.—Carbonyl chloride may be regarded as the acid chloride of carbonic acid, $CO(OH)_2$. It is prepared by the direct reaction of carbon monoxide and chlorine,

$$CO + Cl_2 = COCl_2,$$

or by the action of fuming sulphuric acid on carbon tetrachloride. The details of its preparation and properties are usually considered in works on inorganic chemistry.

It is an extremely poisonous gas with an irritating odour. It is readily condensed to a liquid boiling at 8·2° C. Its reactions are those of an acid chloride.

With water, it forms carbon dioxide and hydrochloric acid:

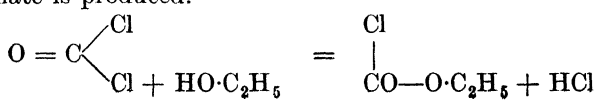
$$COCl_2 + H_2O = CO_2 + 2HCl.$$

With alcohol it gives ethyl chloroformate (§ 306, below), and with ammonia it gives urea (§ 309).

It was found of considerable use as a poison gas in the war of 1914–1918. It had a delayed action on the heart which necessitated the withdrawal of even slightly affected troops for a twenty-four hours' rest.

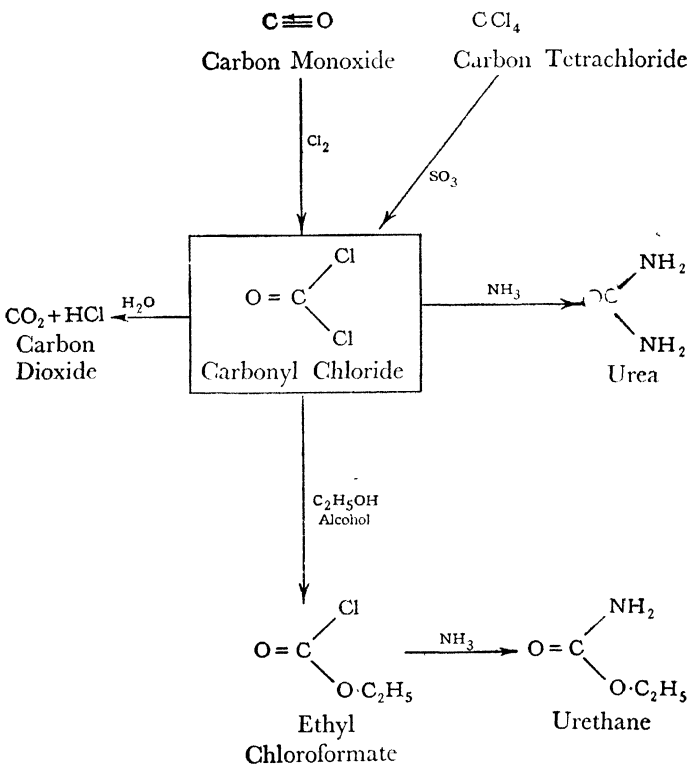
306. Chloroformates, 'Chlorocarbonates,' Cl·CO·O·R.—While chloroformic acid, Cl·CO·OH, is unknown, esters derived from it are known.

When carbonyl chloride reacts with ethyl alcohol, ethyl chloroformate is produced:—



It is a liquid boiling at 93° C., and has a very irritating odour. In trichloromethyl chloroformate, $CCl_3 \cdot O \cdot CO \cdot Cl$, this property is much accentuated, and it was much used as a lachrymator in the war of 1914–1918.

REACTIONS OF CARBONYL CHLORIDE



Since it contains the $-\overset{\overset{O}{\|}}{C}-Cl$ group, it is an acid chloride as well as an ester. This is shown in its reaction with water giving alcohol, carbon dioxide and hydrogen chloride, also in its reaction with alcohol to give ethyl carbonate (§ 304). It also reacts with ammonia,

giving an amide, ethyl aminoformate or carbamate, known also as urethane, and used in medicine.

307. Carbamates.—Carbamic acid, $\begin{matrix}NH_2\\|\\CO—OH\end{matrix}$, which may be regarded as the acid amide of carbonic acid (cf. oxamic acid, § 210), does not exist free. Carbamates are, however, known. Ordinary ammonium carbonate consists of a mixture of ammonium carbamate and bicarbonate. Ammonium carbamate, $NH_2—CO—ONH_4$ may be extracted from it with alcohol, which does not dissolve the carbonate. It is unstable, and when gently heated breaks up into ammonia and carbon dioxide.

$$O=C\begin{matrix}NH_2\\O\cdot NH_4\end{matrix} \quad = \quad CO_2 + 2NH_3$$

308. Urethane, Ethyl Aminoformate, $\begin{matrix}NH_2\\|\\CO—O\cdot C_2H_5\end{matrix}$.—When ethyl chloroformate is treated with ammonia, urethane is formed:

$$\begin{matrix}Cl\\|\\CO\cdot OC_2H_5\end{matrix} + NH_3 = \begin{matrix}NH_2\\|\\CO\cdot OC_2H_5\end{matrix} + HCl.$$

It may also be made by the reaction of urea nitrate, sodium nitrite and alcohol.

It is a solid, melting at 50° C. and boiling at 184° C. It has been used in medicine as a hypnotic. In larger doses, it acts as an anæsthetic. It is also employed in the injection treatment of varicose veins.

Hedonal, which is methyl-propyl-carbinyl carbamate, $\begin{matrix}CH_3\\C_3H_7\end{matrix}\!\!>\!CH\cdot O\cdot CO\cdot NH_2$, has been used to some extent as a hypnotic.

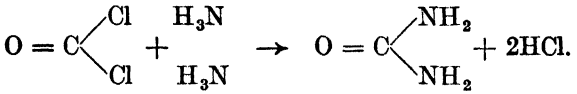
309. Urea, Carbamide, $OC\begin{matrix}NH_2\\NH_2\end{matrix}$.—Urea is a substance of considerable importance, as being the chief vehicle of nitrogen excretion from the bodies of warm-blooded animals. Its compounds with acyl radicals, the *ureides*, are also of physiological importance.

Preparation.—(1) Urea can be made from urine. Human urine contains a variable percentage of urea which averages about 2 per cent. under normal conditions.

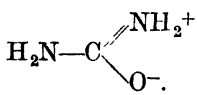
Expt. 69.—*Preparation of Urea from Urine.*—Urine (1 litre)

is concentrated to a small bulk on the water-bath in the fume cupboard and then filtered. A hot, saturated solution of oxalic acid is added and the sparingly soluble urea oxalate is filtered off. This is boiled with powdered chalk, giving insoluble calcium oxalate and urea. The filtered solution is decolorised by boiling with animal charcoal and evaporated till it crystallises.

(2) Urea is synthesised by the action of ammonia on carbonyl chloride:



This reaction indicates that the formula given for urea is the correct one, though other reactions (p. 306) indicate the zwitterion formula



(3) The first synthesis of an organic compound from inorganic materials was accomplished by Wöhler in 1828. He found that a solution of ammonium cyanate was transformed on warming into a solution of urea:

$$NH_4{\cdot}NCO = CO(NH_2)_2$$

Expt. 70.—*Synthesis of Urea.*—50 G. of finely powdered potassium ferrocyanide are well dried in the steam-oven. When a specimen heated in a test-tube evolves no moisture whatever, drying is complete. Meanwhile, 37·5 g. of dry, finely powdered potassium dichromate are weighed out and well mixed with the still warm ferrocyanide. An iron dish is strongly heated by a large burner and the mixture is poured on to it 5 g. at a time.

As each portion of ferrocyanide is oxidised to cyanate, the mass glows brightly, and when incandescence has ceased the residue is pushed to the cooler edge of the dish and a fresh portion added. The residue is powdered when warm, and the powder is boiled and well stirred for three minutes with a mixture of 200 c.c. of alcohol, 45 c.c. of water and 25 c.c. of methyl alcohol. The filtered liquid is at once mixed with a solution of 25 g. of ammonium sulphate in 40 g. of hot water. Potassium sulphate is precipitated and filtered off. The alcohol is now distilled off on the water-bath. The residue containing inorganic salts and urea is transferred to an evaporating dish and evaporated to dryness on the water-bath. The dry residue is boiled with 96 per cent. alcohol, and the solution filtered

while hot. Urea crystallises from the filtrate on cooling, and if necessary, evaporation.

The above method avoids the use of potassium cyanide. The oxidation of the latter by fusing it with lead oxide affords a ready means of preparing potassium cyanate, which may be converted into urea by treatment with ammonium sulphate, as described above.

Urea is now manufactured in large quantities as a fertiliser. The process adopted is the action of liquid ammonia on liquid carbon dioxide under a pressure of *ca.* 200 atm. Ammonium carbonate is first formed and the equilibrium reaction

$$(NH_4)_2CO_3 \rightleftharpoons (NH_2)_2CO + 2H_2O$$

results in the formation of a large proportion of urea.

310. Constitution of Urea.—The formation of urea by method (2) above indicates the formula $O=C\begin{smallmatrix}NH_2\\NH_2\end{smallmatrix}$, which explains its reactions fairly adequately.

The fact that urea is a monoacid base is not however accounted for by the above formula. Werner suggested the formula $HN=C\begin{smallmatrix}NH_3,\\O\end{smallmatrix}$ but this is not in accord with present views concerning the valency of nitrogen, which is never penta-covalent in amines and the zwitterion formula $H_2N-C\begin{smallmatrix}NH_2^+\\O^-\end{smallmatrix}$ is now preferred (see § 227).

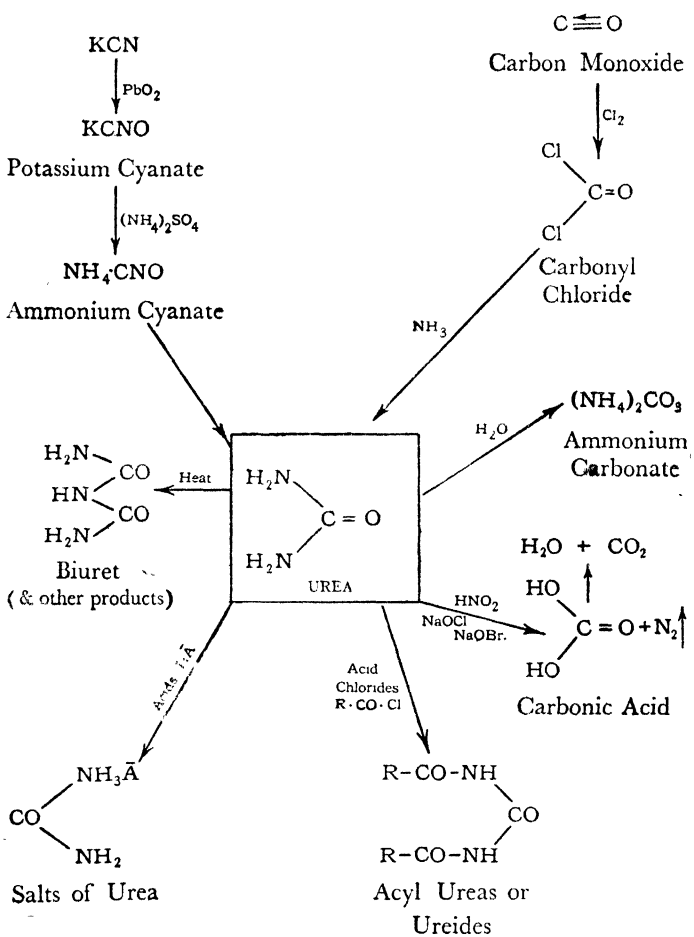
311. Physical Properties of Urea.—Urea forms long needle-like crystals. It is odourless and has a slight saline taste. It melts at 132° C., decomposing on stronger heating. Urea is very soluble in water and readily soluble in alcohol, but is almost insoluble in ether.

312. Chemical Properties of Urea.—When urea is heated above its melting-point the chief products are cyanuric acid, ammonia and biuret:

$$3\left[H_2N\begin{smallmatrix}>CO\\H_2N\end{smallmatrix}\right] = 3NH_3 + (HO\cdot CN)_3$$

$$H_2N\begin{smallmatrix}>CO\\H_2N\end{smallmatrix} + H_2N\begin{smallmatrix}>CO\\H_2N\end{smallmatrix} = NH_3 + H_2N\begin{smallmatrix}>CO\\NH\\>CO\\H_2N\end{smallmatrix}$$

REACTIONS OF UREA



Biuret, when dissolved in dilute caustic soda and mixed with a little dilute copper sulphate solution, gives a pink to violet coloration —the so-called 'biuret reaction.'

Urea behaves in a manner intermediate between those of an amine and an amide.

It is definitely basic, and forms salts with acids in which only one $-NH_2$ group reacts.

Urea nitrate, $H_2N—CO—NH_3NO_3$, is sparingly soluble in nitric acid; urea oxalate, $\begin{matrix} NH_2{\cdot}CO{\cdot}NH_3{\cdot}O{\cdot}CO \\ | \\ NH_2{\cdot}CO{\cdot}NH_3{\cdot}O{\cdot}CO \end{matrix}$, is sparingly soluble in water (1 : 23) and alcohol.

Like other amides, urea is hydrolysed by boiling with alkalis or

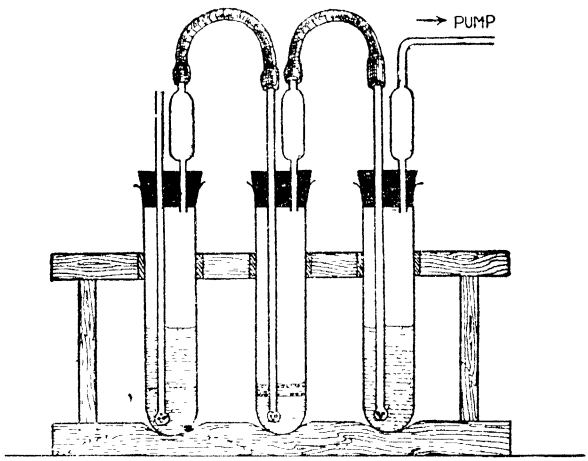


FIG. 48.—Determination of Urea by means of Urease.

acids or by heating with water under pressure. Carbon dioxide and ammonia (or salts of these) are formed:

$$CO(NH_2)_2 + H_2O = CO_2 + 2NH_3.$$

The action of acids and alkalis in solution is slow, but the same hydrolysis is rapidly brought about by various enzymes known as *ureases*. A bacterium, the *micrococcus ureæ*, always present in stables, urinals, etc., where urea abounds, rapidly causes it to form ammonium carbonate. Certain seeds also contain urease, and one of these, the *soya-bean*, is commonly used in determining urea in urine, by converting it into ammonia which is absorbed in standard acid. The advantage of the method is its *specific character*, none of the other nitrogen products, of which a variety are present, being affected by urease.

Three test-tubes are arranged, as in Fig. 48, and connected to a pump by means of which a rapid current of air can be drawn through them. In the first is placed water, and into the second is measured 1 c.c. of urine, a drop or two of liquid paraffin or caprylic alcohol, to prevent frothing, 1 c.c. of urease

obtained by digesting soya-bean meal with cold water[1] for some hours, and 5 c.c. of a phosphate buffer solution of *p*H value 7—8. The tube is at once closed and 25 c.c. of 0·02*N*-hydrochloric acid is measured into the third test-tube. After a quarter of an hour the air current is passed for half a minute to carry off any free ammonia formed. 5 g. of solid potassium carbonate are now placed in the second test-tube and air is drawn through at first rather slowly and then as rapidly as is possible without causing undue splashing or foaming. The alkali liberates free ammonia, which is carried over into the standard acid. After fifteen minutes, the acid in the third test-tube is titrated. Each equivalent of acid neutralised by the ammonia indicates the presence of ½ g.-molecule of urea in the urine taken.

Urea reacts with nitrous acid, giving carbon dioxide and nitrogen:

$$CO\begin{matrix}NH_2 + HNO_2\\ \\ NH_2 + HNO_2\end{matrix} = CO_2 + 3H_2O + 2N_2.$$

Hypochlorites and hypobromites also produce carbon dioxide and nitrogen. The urea in urine was formerly estimated by adding to a known volume of it a solution of bromine in excess of caustic potash. Nitrogen is evolved and measured, the carbon dioxide reacting with the caustic potash:

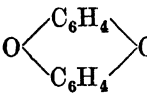
$$O = C\begin{matrix}NH_2 + 3KOBr + 2KOH = N_2 + 3KBr + 3H_2O\\ \\ NH_2 \qquad\qquad\qquad\qquad\qquad\qquad + K_2CO_3.\end{matrix}$$

The method is subject to a good deal of error, and has been largely replaced by methods of determining urea as ammonia. It is, however, still used for rough determinations.

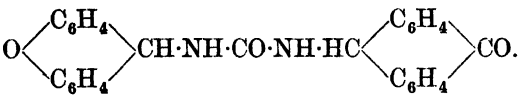
The apparatus employed is shown in Fig. 49. A solution of potassium hypobromite made by dissolving 8·8 c.c. bromine in 100 c.c. of 40 per cent. potassium hydroxide solution is placed in the bottle, and a measured volume of urine in the small test-tube. On mixing, Nitrogen is evolved and is measured in the graduated tube. One g.-molecule of nitrogen corresponds to one molecule of urea. The disadvantage of the method is first, that urea does not evolve the theoretical quantity of nitrogen, and secondly, that the other nitrogenous substances present in urine also evolve small quantities of nitrogen.

Urea is commonly recognised by the biuret test (p. 307). A sensitive test, also sometimes used to determine urea, is its reaction

[1] The actual meal can be used, or, much better, the dry tablets of urease supplied by chemical retailers. The tablets are dissolved just before use.

with xanthydrol,  , which gives an insoluble

crystalline dixanthylurea:



Uses of Urea.—Urea is greatly used as a fertiliser, and in addition is now employed in making urea resins, by treatment with formaldehyde (cf. § 354). The resins so obtained are transparent or translucent and colourless, and are much used for making light, unbreakable, brightly coloured ornaments, tableware, etc.

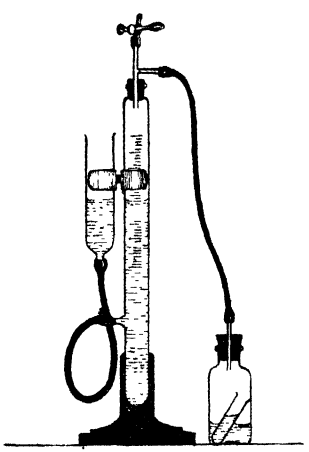


FIG. 49.—Determination of Urea by Potassium Hypobromite.

Expt. 71.—*Reactions of Urea.*—(1) Heat a portion: note smell of ammonia. Dissolve white residue in sodium hydroxide solution: add 1 drop copper sulphate solution: a pinkish violet coloration (biuret reaction) is produced.

(2) To strong solutions of urea add (*a*) dilute nitric acid (1 : 3), (*b*) solution of oxalic acid. Crystalline precipitates of urea nitrate and oxalate.

(3) Boil with NaOH, no ammonia evolved. Heat a portion with solid caustic soda or soda-lime: ammonia comes off freely.

(4) To bromine water add caustic soda drop by drop till solution is light yellow. Add a solution of urea. Nitrogen is evolved.

(5) Make a solution of sodium nitrite and add an excess of cold dilute hydrochloric acid. To the blue solution of nitrous acid add a solution of urea. Nitrogen is briskly evolved.

(6) To some urea add about twice its bulk of acetyl chloride and a minute crystal of iodine. Heat. HCl is evolved and acetylurea is formed. Dissolve the product in boiling water; acetylurea crystallises out on cooling.

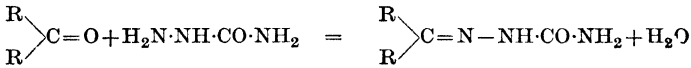
313. Semicarbazide, $H_2N{\cdot}CO{\cdot}NH{\cdot}NH_2$.—Semicarbazide has come into prominence as a means of preparing easily recognisable derivatives of aldehydes, ketones, sugars, etc., its action being analogous to that of phenylhydrazine (§ 272, 409).

Semicarbazide is prepared by reducing nitrourea, which is itself prepared by the action of concentrated sulphuric acid on urea nitrate.

$$H_2N{\cdot}CO{\cdot}NH_3NO_3 - H_2O = H_2N{\cdot}CO{\cdot}NH{\cdot}NO_2$$

$$H_2N{\cdot}CO{\cdot}NH{\cdot}NO_2 + 6H = H_2N{\cdot}CO{\cdot}NH{\cdot}NH_2 + 2H_2O.$$

When semicarbazide hydrochloride and a substance containing a carbonyl group are brought together in alcoholic solution the *semi-carbazone* is formed and is precipitated as a crystalline solid by addition of water.

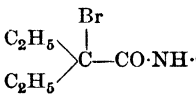


Ketone. Semicarbazide. Semicarbazone.

They have the advantage over phenylhydrazones in that they are readily hydrolysed into their components and are thus useful for purifying aldehydes, ketones, etc.

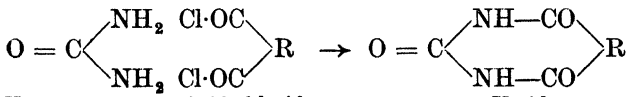
THE UREIDES

314. Acylureas and Ureides.—Urea reacts with acid chlorides, forming acyl derivatives. Thus with acetyl chloride a derivative $CH_3CO{\cdot}NH{\cdot}CO{\cdot}NH_2$, acetylurea, is formed. Bromodiethylacetylurea,



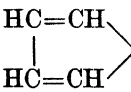
is known as *uradal*, and is a useful hypnotic.

Ureides.—Urea reacts with the acid chlorides of certain dibasic acids forming compounds called ureides:



Urea. Acid chloride. Ureide.

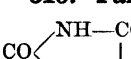
These ureides have acidic properties, the hydrogen of the =NH group being replaceable by metals. The =NH group shows basic properties in the secondary amines, *e.g.* $(CH_3)_2NH$, dimethylamine, but when attached to an acidic electronegative group such as =CO, it shows acidic properties. In other compounds, such as pyrrole,



it shows both basic and acidic properties.

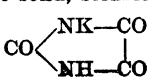
Among the ureides are several important drugs, and also several substances found in the animal body, probably as stages in the degradation of protein to urea.

315. Parabanic Acid, Oxalylurea.—Parabanic acid, oxalylurea,

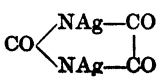


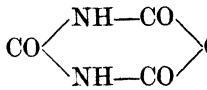
, can be made by oxidising uric acid with nitric acid or by the action of oxalyl chloride on urea (*v. supra*).

It is a crystalline solid, soluble in water. It forms salts such as

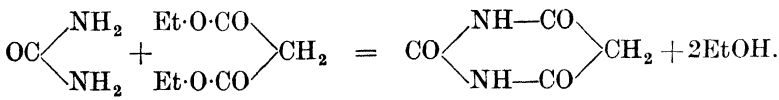


and

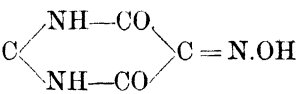


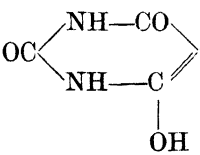
316. Barbituric Acid, Malonylurea.—Barbituric acid,  , is of importance, since some of its derivatives have been employed in medicine as hypnotics.

It is prepared by the condensation of malonic ester and urea in presence of sodium ethoxide

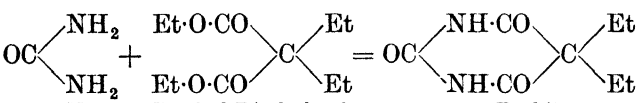


Barbituric acid forms colourless crystals, soluble in water. The $>CH_2$ group is very reactive. Thus with nitrous acid, the interesting acid violuric acid (*iso*nitrosomalonylurea) is produced.

This acid is of interest as being colourless in the solid state while forming intensely coloured solutions and salts. The acid, which is colourless, is thought to have the formula 

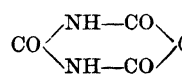
thus being an oxime (§ 70); its strongly coloured solutions probably have the formula  , and are true nitroso-compounds (cf. § 129).

317. Barbitone (veronal), a very well-known hypnotic, is diethylmalonylurea; it is made by the reaction of diethylmalonic ester (prepared as in § 259) with urea, in presence of sodium ethoxide:



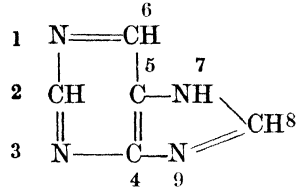
Urea + Diethyl Diethylmalonate. Barbitone.

Luminal, phenylethylmalonylurea, is used as a sedative in the treatment of epilepsy, etc. *Nembutal*, sodium methyl-butyl-barbiturate, is now much used for inducing anæsthesia.

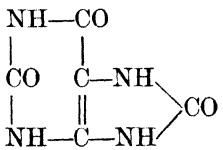
318. Alloxan,  , is mesoxalyl urea, and can be made by oxidising uric acid. Alloxan and its derivative *alloxantin* take part in the important murexide test (Expt. 72) for uric acid.

THE PURINES

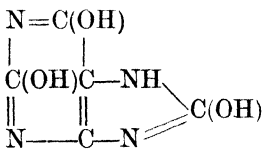
319. Purine.—Many ureides containing two molecules of urea are known. These are called the *purines*, and a number of them are animal or plant products. They are regarded for the purpose of nomenclature as being derived from *purine*, the formula of which is given below. The atoms of the rings are numbered 1–9, as shown:



320. Uric Acid, $C_5H_4N_4O_3$.—Uric acid is the most important of the purines. It has the formula:



but it also exists in an enolic form (§§ 256–257), as:



and can therefore be called 2 : 6 : 8 trihydroxypurine.

Occurrence and Preparation.—Uric acid is found in small quantities in the urine of carnivora; the urine of herbivora contains hippuric acid (benzoylglycocoll, § 457) instead. Human urine contains approximately 0·05 per cent.

The excrement of birds and snakes contains a large proportion of uric acid.

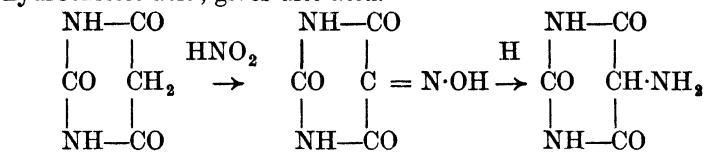
Sodium urate accumulates in the tissues of gouty persons. The exact connection between the gouty condition and the formation of uric acid is not clearly understood. It is possible that uric acid is an intermediate product in the decomposition of waste protein tissues to urea—the normal means of nitrogen excretion.

Uric acid is commonly prepared from serpents' excrement, which is nearly pure uric acid, or from guano, the excrement of sea birds, which, being used as a fertiliser, is easily available.

The guano is boiled with dilute alkali. The hot solution is filtered and the resulting solution of urate decomposed by hydrochloric acid.

Uric acid has been synthesised by various methods, of which the

following, due to Fischer, shows its composition most clearly. Barbituric acid (§ 316) is converted into violuric acid (*ibid*) which is reduced to amino-barbituric acid. This is treated with potassium cyanate and gives pseudo-uric acid, which, when heated with hydrochloric acid, gives uric acid:



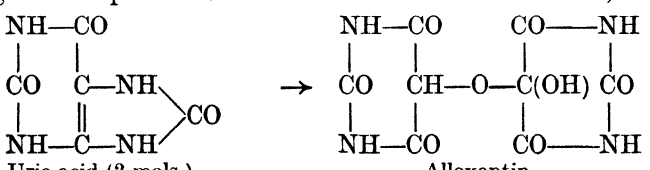
Amino-barbituric acid. Pseudo-uric acid. Uric acid.

Properties.—Uric acid is a white powder almost insoluble in water and insoluble in alcohol and ether.

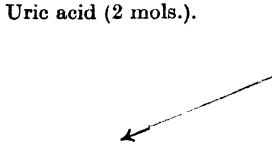
It is a weak dibasic acid and the urates usually met with are the acid salts. Sodium and potassium urates are very sparingly soluble and form the chalky deposits formed in the joints, etc., of gouty subjects. Lithium urate is more soluble; lithia water is therefore used as a remedy for gout.

When uric acid is oxidised it can form a variety of products, all ureides, *e.g.*, alloxan, barbituric acid, parabanic acid, etc. When reduced it gives xanthine (*q.v.* § 321).

Uric acid is recognised by the *murexide test.* This is performed by adding a few drops of concentrated nitric acid to the uric acid, evapor-



Uric acid (2 mols.). Alloxantin.



Murexide.

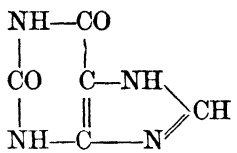
ating to dryness on the water-bath and adding a little ammonia. A strong purple coloration due to *murexide* indicates the presence of uric acid.

Alloxantin is first formed by oxidation of the uric acid and gives murexide with ammonia.

Uric acid is also detected in the sediment from urine by the characteristic forms of its crystals, which gather as rosettes and dumb-bell-shaped aggregations of microscopic crystals.

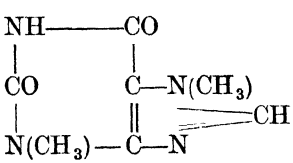
Expt. 72.—*Murexide Reaction.*—To a few mg. of uric acid contained in a porcelain basin add a few drops of concentrated nitric acid and evaporate to dryness on the water-bath. A yellowish residue (alloxantin) remains. Moisten this with ammonia: it changes to the purple *murexide* or ammonium purpurate. On adding sodium hydroxide the colour becomes blue.

321. Xanthine.—Several important alkaloids are derived from xanthine, which may be regarded as the keto-form of 2 : 6-dihydroxypurine:

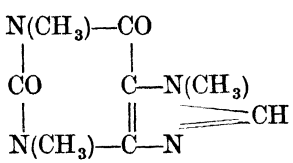


Xanthine much resembles uric acid, but, unlike it, has basic properties owing to the —NH— group in position 7, which is not adjacent to an acidic carbonyl group and therefore does not have its basic properties neutralised.

The two important alkaloids—*theobromine* found in cacao beans, and *caffeine* found in tea and coffee—are methylxanthines:



Theobromine
(3 : 7-dimethylxanthine)



Caffeine
(1 : 3 : 7-trimethylxanthine)

Theobromine is not of practical importance, but caffeine is of interest both as the active principle of tea and coffee, and as a useful drug.

322. Caffeine, Theine, 1 : 3 : 7-Trimethylxanthine.—Caffeine is contained in tea to the extent of 2·5–3 per cent., and in coffee to the extent of 1·5 per cent. It is extracted on the commercial scale from damaged tea by extraction with boiling water or alcohol. The solution contains chiefly caffeine and tannin. The latter is precipi-

tated by means of lead acetate. The filtered solution is concentrated and caffeine crystallises out.

Expt. 73.—*To Prepare Caffeine from Tea.*—Boil a quarter of a pound of tea with 500 c.c. of water for twenty minutes. Strain through cloth or a large loose tuft of glass wool placed in a funnel. Wash the tea leaves with 150 c.c. of boiling water. Add to the hot filtrate a strong solution of basic lead acetate, made by boiling lead acetate solution with lead monoxide. Filter at once from precipitated tannin, etc., using a large filter. The solution contains excess of lead acetate. Boil it and add dilute sulphuric acid as long as any precipitate is produced. Allow the heavy precipitate to settle. Pour off the clear brownish liquid and boil with animal charcoal to decolorise it. Filter again, allow to cool, transfer to a separating funnel and shake vigorously with four successive portions (40 c.c.) of chloroform. Distil off the chloroform on the water-bath. Dissolve the solid residue in about 25 c.c. of hot water. Evaporate on the water-bath till crystals appear. On cooling, long hair-like crystals of caffeine are formed.

Caffeine forms long white felted needles with a bitter taste, sparingly soluble in water. When heated it sublimes.

It forms salts with acids; the citrate and hydrochloride are used in medicine. The physiological action of caffeine is, first, to stimulate the higher faculties—a function which perhaps has brought about the popularity of tea as a beverage. Medicinally it is employed to relieve headache and also as a diuretic.

DERIVATIVES OF THIOCARBONIC ACID

323. Thiocarbonic acid (trithiocarbonic acid), H_2CS_3, is an unstable brown oily substance. Its salts, the trithiocarbonates, are stable.

The most important organic derivatives of thiocarbonic acid are the *xanthates* and *thiourea*.

Potassium xanthate is obtained by the action of alcoholic potash (which contains potassium ethoxide) on carbon disulphide:

$$S=C(=S) + O(K)-C_2H_5 \;=\; S=C(OC_2H_5)(SK)$$

It crystallises in colourless needles.

Xanthic acid, $S=C(OC_2H_5)(SH)$, breaks up on gentle warming into alcohol and carbon disulphide.

The part played by xanthates in the artificial silk industry (§ 289) is of great industrial importance.

324. Thiourea, Thiocarbamide, $S=C\begin{<}NH_2\\NH_2\end{>}$, is made by methods analogous to those used for urea. Thus it can be made by heating ammonium thiocyanate. The reaction is reversible, only some 25 per cent. of thiourea being formed at equilibrium.

$$NH_4{\cdot}SNC \rightleftharpoons NH_2{-}CS{-}NH_2.$$

In its general properties it much resembles urea, giving salts with acids, alkyl derivatives, thio-ureides, etc.

Allylthiourea, $C_3H_5{\cdot}NH{\cdot}CS{\cdot}NH_2$, is made by the action of ammonia on mustard oil (§ 176), allyl isothiocyanate. It is known as *thiosinamine* and is used in medicine for softening and removing scar tissue.

DERIVATIVES OF ORTHOCARBONIC ACID

325. Ethyl Orthocarbonate, $C(O{\cdot}C_2H_5)_4$.—Orthocarbonic acid, H_4CO_4, does not exist, but its ester, ethyl orthocarbonate, is made by the action of sodium ethoxide on chloropicrin (trinitrochloromethane):

$$Cl{-}C(NO_2)_2{-}NO_2 + 4Na{\cdot}OC_2H_5 = C_2H_5{-}O{-}C(O{-}C_2H_5)_2{-}O{-}C_2H_5 + NaCl + 3NaNO_2$$

The esters of orthocarbonic acid are stable substances having the general behaviour of esters. Hydrolysis gives a carbonate and an alcohol:

$$C(O{\cdot}C_2H_5)_4 + 2KOH + H_2O = K_2CO_3 + 4C_2H_5OH.$$

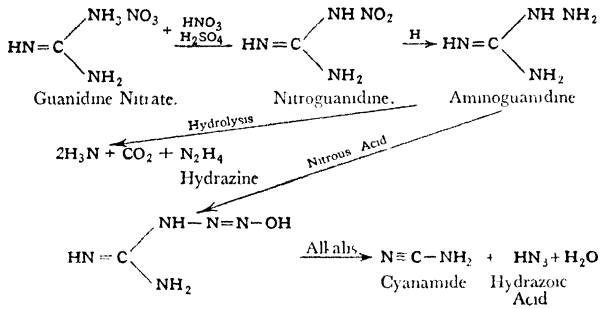
There is no true amide of orthocarbonic acid, $C(NH_2)_4$. An iminoamide, $HN=C\begin{<}NH_2\\NH_2\end{>}$, is known and is called guanidine.

326. Guanidine, CN_3H_5, $HN=C\begin{<}NH_2\\NH_2\end{>}$.—Guanidine can be made by heating ammonium thiocyanate to 180—190° C. Thiourea is formed (§ 324), and reacts with the residual ammonium thiocyanate, giving guanidine *iso*-thiocyanate and hydrogen sulphide.

$$\begin{>}NH_2\\NH_2\end{>}CS + NH_4{\cdot}CNS = \left[\begin{>}NH_2\\NH_2\end{>}C=\overset{+}{N}H_2\right]CNS^- + H_2S.$$

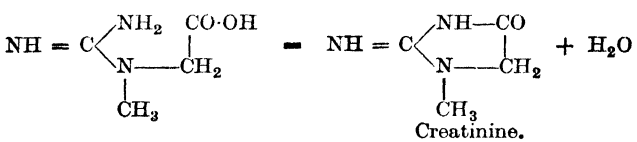
Guanidine is a strong base which forms salts even with weak acids. It is easily hydrolysed to urea and ammonia.

Guanidine is of some interest as a means of preparing hydrazine and hydrazoic acid, by the reactions given below:



327. Creatine, $HN=C\begin{matrix}NH_2\\ N\cdot CH_2\cdot CO\cdot OH\\ |\\ CH_3\end{matrix}$, may be regarded as **methyl-**guanido-acetic acid. It is found to the extent of 1—3 per cent. in the muscles of animals, and is therefore present in extract of meat.

It forms colourless crystals containing water of crystallisation. When heated with acids it forms *creatinine*.



328. Creatinine is of importance as a constituent of urine, a total of 1—2 g. per day being excreted by an average man.

It crystallises in anhydrous prisms. It is a strong base forming numerous salts.

The function of creatine and creatinine in the animal economy is still uncertain.

QUESTIONS

(1) What are the urethanes? How are they prepared and what uses have they in medicine?

(2) Give two methods by which urea can be made from inorganic materials only. How would you try to show that the urea made in this way was free from ammonium salts?

(3) How may urea be detected and estimated?

(4) How far does urea resemble (*a*) an amine, (*b*) an amide? What formulæ for urea have been suggested, and how are they supported by its chemical reactions?

(5) What is a *ureide*? How is barbituric acid prepared? What is peculiar about its reactions and what derivatives of it have found a use in medicine?

(6) What are the formulæ of uric acid and caffeine? On what evidence is the formula of uric acid based? Why do we call them both purines?

(7) 5 c.c. of urine, when treated with a concentrated alkaline solution of a hypobromite, yielded 39·1 c.c. of nitrogen measured at 15° C. and 770 mm. pressure. Calculate the percentage of urea present.

(8) How is urea estimated by means of urease? 1 c.c. urine treated with soya-bean urease evolved enough ammonia to reduce the strength of 25 c.c. acid, into which it was passed, from 0·02N to 0·005N. Calculate the percentage of urea in the urine.

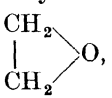
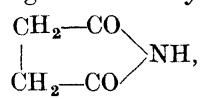
PART II

CARBOCYCLIC COMPOUNDS

CHAPTER XXI

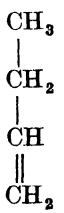
POLYMETHYLENES AND BENZENE

POLYMETHYLENES

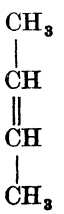
329. Carbocyclic Compounds.—Cyclic compounds containing closed chains of atoms have already been discussed. Among these we may mention ethylene oxide,  , succinimide,  , uric acid, etc. These compounds, which have a ring system composed of more than one kind of atom, are said to be *heterocyclic*. A great number of organic compounds have, however, closed chains made up of carbon atoms only. Compounds containing such a structure are said to be *carbocyclic*.

The simplest of these are the polymethylenes, isomeric with the olefines and having the formula C_nH_{2n}.

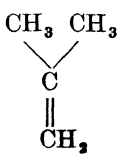
As an example let us take the compound C_4H_8. This formula can be written in the following ways:—



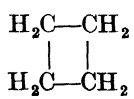
I.



II.



III.



IV.

Four compounds of the formula C_4H_8 are, in fact, known. Three are typical olefines, having the properties associated with the double bond. They are reduced easily to butane or *iso*butane, they react with bromine in the cold giving dibromides and are readily oxidised by permanganates. Their formation from the various butyl chlorides (§ 54) leads us to assign to them the formulæ I, II and III respectively:

The fourth compound of formula C_4H_8 is made by the action of sodium on $\alpha\delta$-dibromobutane. Now the action of sodium on a paraffin halide is to withdraw the halogen atoms and let the residual CH_2 groups combine (cf. preparation of ethane, § 25). This reaction then leads us to the cyclic formula IV:—

$$\begin{array}{l} CH_2—CH_2—Br \\ | \qquad\qquad\quad \\ CH_2—CH_2—Br \end{array} + 2Na = \begin{array}{l} CH_2—CH_2 \\ |\quad | \\ CH_2—CH_2 \end{array} + 2NaBr.$$

The properties of the compound bear out this formula. It has none of the properties of an olefine. Hydrogen halides, permanganates, etc., have no effect on it, while the halogens form substitution products (*e.g.*, C_4H_7Br) and not addition products. It seems clear then that the double bond $>C=C<$ cannot be contained in this compound, and the formula $\begin{array}{l} H_2C—CH_2 \\ |\quad | \\ H_2C—CH_2 \end{array}$ is the only possible one.

The various compounds which contain closed chains of methylene ($-CH_2-$) groups are called *polymethylenes*.

330. General Methods of Preparation of Polymethylenes.—(1) Polymethylenes are made by the reaction already mentioned—the action of sodium on dibromides of the paraffins:—

$$H_2C\begin{array}{l}\diagup CH_2\cdot Br \\ \diagdown CH_2\cdot Br\end{array} + 2\,Na = H_2C\begin{array}{l}\diagup CH_2 \\ \diagdown CH_2\end{array} + 2NaBr$$

1 : 3-Dibromopropane. Trimethylene.

(2) When the calcium salt of a dibasic acid is distilled a cyclic ketone is formed (cf. p. 125). Thus calcium adipate yields ketopentamethylene, or *cyclo*pentanone,

$$\begin{array}{l} CH_2—CH_2—CO—O \\ | \qquad\qquad\quad \diagdown \\ CH_2—CH_2—CO—O \end{array} Ca = \begin{array}{l} CH_2—CH_2 \\ |\quad \diagup \\ CH_2—CH_2 \end{array} CO + CaCO_3$$

This compound can be reduced by hydrogen iodide at high temperatures to pentamethylene. This method is of value only for 5-, 6- and 7-membered rings.

(3) Numerous methods are available for making compounds of the polymethylenes (for these hydrocarbons form acids, halides, amines, etc., like the paraffins). Most of these are based on the malonic ester or similar syntheses (§§ 258, 259).

Polymethylenes are constituents of petroleum.

The general properties of the polymethylenes resemble those of

the paraffins (§ 29), trimethylene being exceptional and behaving more like an olefine.

331. Relative Stability of the Polymethylenes.—If we assume that the valencies of the carbon atom are symmetrically distributed in space, there should be an angle of 109° 28′ between two valency bonds. This arrangement puts all four bonds at the maximum distance from each other. Since these valency bonds are actually the orbits of electrons any deformation of this arrangement should set up a state of strain and a ring compound should be the more stable the more nearly the angles of the valency bonds in the rings approximate to 109° 28′. If we work out the angles corresponding to regular polygons composed of carbon atoms we obtain the following results:

		Divergence from 109° 28′.
Trimethylene	60°	49° 28′
Tetramethylene	90°	19° 28′
Pentamethylene	108°	1° 28′
Hexamethylene	120°	− 10° 32′
Heptamethylene	128° 34′	− 19° 6′
Octamethylene	135°	− 25° 32′

It should follow then that, if the atoms in a cyclic compound form plane polygonal rings pentamethylene should be the most stable, and the other polymethylenes less stable. Trimethylene should be markedly the least stable of these hydrocarbons. This is approximately true. The trimethylene ring is easily ruptured and the properties of this hydrocarbon are much more like those of an olefine. The differences of stability between the remaining polymethylenes are not so marked. The above considerations constitute Baeyer's Strain Theory. More recent work indicates that other factors besides the angle between the carbon atoms of the rings influence their stability and except in the case of trimethylene it is not certain that the polygons of atoms form plane rings. A six-membered ring, for example, if bent as in Fig. 50, will be strainless, the angles between the valency bonds being in fact 109° 28′, and it appears clear that all rings with six or more carbon atoms are buckled in some such way as the above and are therefore strainless. We may expect then a rapid increase of stability as we pass from

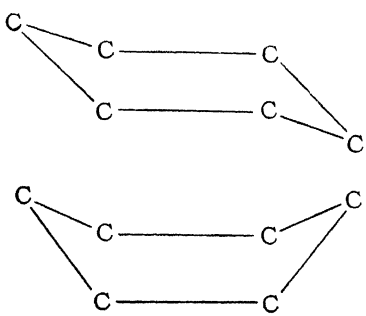


FIG. 50.—Strainless 6-membered Rings.

trimethylene to pentamethylene, the higher members being all equally stable, and this is in accordance with the observed facts.

332. Trimethylene, *cyclo*Propane, $\begin{matrix}CH_2\\|\\CH_2\end{matrix}\!\!>\!CH_2$.—Trimethylene is made by the action of sodium on $\alpha\gamma$-dibromopropane.

$$H_2C\!<\!\begin{matrix}CH_2\cdot Br\\CH_2\cdot Br\end{matrix} + 2Na = H_2C\!<\!\begin{matrix}CH_2\\|\\CH_2\end{matrix} + 2NaBr.$$

It is a gas which is easily condensed to a liquid.

It is less reactive than the olefines but more so than the other polymethylenes. Thus it reacts with bromine to give $\alpha\gamma$-dibromopropane, $BrH_2C\cdot CH_2\cdot CH_2Br$, with hydrogen iodide to give propyl iodide, and with hydrogen (in presence of finely divided nickel at 80° C.) to give propane. It does not react with potassium permanganate solution.

These reactions are less vigorous than those of the corresponding olefine, propylene, $CH_3\cdot CH=CH_2$. On the other hand the higher and more stable polymethylenes do not react with hydrogen iodide or with hydrogen.

333. Hexamethylene, *cyclo*Hexane, Hexahydrobenzene, C_6H_{12}.—Hexamethylene can be made by treating $\alpha\eta$-dibromohexane with sodium:—

$$\begin{matrix}CH_2\cdot CH_2\cdot CH_2\cdot Br\\|\\CH_2\cdot CH_2\cdot CH_2\cdot Br\end{matrix} + 2Na = \begin{matrix}CH_2\cdot CH\cdot{}_2CH_2\\|\quad\quad|\\CH_2\cdot CH_2\cdot CH_2\end{matrix} + 2NaBr.$$

It is, however, always made by the reaction of hydrogen and benzene vapour in presence of finely divided nickel heated to 200–250° C.

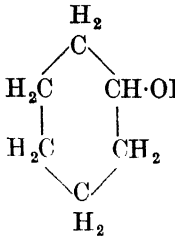
*cyclo*Hexane is a colourless liquid smelling like petroleum ether. It boils at 81° C.

It resembles a paraffin hydrocarbon in its inertness. It is attacked by bromine only at 150° C.; nitric acid slowly oxidises it to adipic acid.

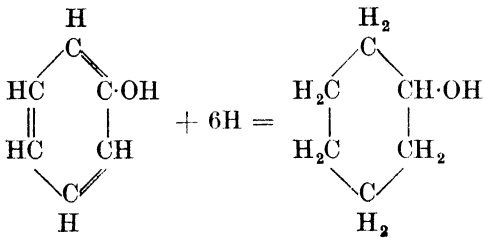
$$\begin{matrix}&CH_2&\\CH_2&&CH_2\\|&&|\\CH_2&&CH_2\\&CH_2&\end{matrix} + 5O = \begin{matrix}&CH_2&\\CH_2&&CO\cdot OH\\|&&\\CH_2&&CO\cdot OH\\&CH_2&\end{matrix} + H_2O$$

*cyclo*Hexane is a constituent of petroleum. It is used as a solvent and as a source of adipic acid, used in the manufacture of baking powders and of 'Nylon' polymers.

334. ***cyclo*Hexanol.**



—*cyclo*Hexanol is made commercially by passing a mixture of phenol vapour and hydrogen over finely-divided nickel at 170° C.:—

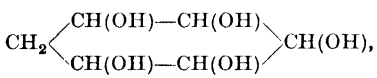


It is a liquid, boiling at 160° C., with an odour like amyl alcohol.

In its chemical properties it resembles an aliphatic secondary alcohol. It is incorporated with some of the soaps used in the textile industry in order to increase their detergent action.

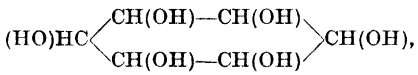
335. Other Hydroxy-polymethylenes.—Many of these are known.

Quercitol,



is a solid optically active substance which occurs in acorns and some other vegetable products.

Inositol,



occurs in several stereoisomeric forms. These are found in numerous animal and vegetable products. Their resemblance in structure to the sugars (§ 265) should be noted.

AROMATIC COMPOUNDS

336. Classification of Cyclic Compounds.—An enormous number of derivatives of the hydrocarbon benzene, C_6H_6, are known. The earliest of these to be discovered were naturally occurring substances, chiefly of pleasant smell, and a distinction was then drawn between the 'aromatic' compounds derived from benzene and the 'aliphatic'[1] compounds derived from the paraffin hydrocarbons. The names have been retained in common use, for the benzene compounds differ so

[1] Greek ἄλειφαρ, fat.

much from the open-chain compounds that they obviously form a well-separated class.

The classification of organic compounds into aliphatic and aromatic compounds soon proved inadequate and the following systen of classification has gradually been adopted.

(1) *Open-chain* or *aliphatic compounds*:

(2) *Cyclic compounds*:

Sub-divided into
- (i) *Carbocyclic* compounds having ring systems composed solely of carbon atoms.
  - Sub-divided into
    - (*a*) *Aromatic* compounds containing one or more benzene rings.
    - (*b*) *Alicyclic* compounds containing other ring systems.
- (ii) *Heterocyclic* compounds containing ring systems made up of more than one kind of atom.

BENZENE

337. Discovery and Manufacture of Benzene.—Benzene was first discovered in 1825 by Faraday in liquids condensed from the vapours formed when oils and fats were destructively distilled.

It was later prepared by the distillation of benzoic acid—obtained from gum benzoin—with lime.

It may be synthesised by various methods (§ 339), but none of these is of practical use. It is now manufactured from coal-tar.

The hydrocarbon benzene occurs in considerable quantity in coal-tar. In the manufacture of illuminating gas and of coke, enormous quantities of coal are distilled at a temperature of *ca.* 1,000° C. When coal is distilled under these conditions the products are:—

(*a*) A gas containing methane, hydrogen, carbon monoxide, ethylene, etc.
(*b*) An aqueous solution containing ammonia, ammonium sulphide and other ammonium salts.
(*c*) Coal-tar.
(*d*) A non-volatile residue of coke.

The benzene is mostly condensed when the gases evolved from the coal are first cooled, and so forms a part of the coal-tar. A certain amount passes on as vapour and is often recovered from the gas by scrubbing it with creosote oil (*v.* below) which dissolves it. The creosote oil is distilled to separate the benzene.

The coal-tar is a black, somewhat viscous liquid, and consists of an exceedingly complex mixture of hydrocarbons, phenols, etc. It

contains more than 200 recognisable chemical compounds, but the chief products contained in the tar in commercially valuable quantities are:—

(1) Benzene and methyl-benzenes (toluene, xylene).
(2) Phenols (hydroxy-benzenes) (phenol, cresols).
(3) Naphthalene.
(4) Anthracene.
(5) A complex mixture of higher hydrocarbons with some free carbon, known as *pitch*.

These products are separated by distillation. The tar is run into large iron stills heated as a rule by direct firing. The vapours are condensed and collected in five fractions.

B.P.	Product	Chief Constituents
Up to 110°		Water, benzene, toluene.
110–210°	Light oil	Benzene, toluene, xylene, naphthalene.
210–240°	Carbolic oil	Phenol, naphthalene.
240–270°	Creosote oil	Cresols.
270–	Anthracene oil	Anthracene.

The recovery of phenol, naphthalene, etc., is discussed under the heading of these substances.

Benzene is obtained from the light oil. This contains 60–65 per cent. of benzene and methyl-benzenes with 12–15 per cent of naphthalene, 8–10 per cent. of phenol, and 1–3 per cent. of basic substances such as pyridine. The oil is agitated with sulphuric acid which removes the bases and also most of the thiophen, C_4H_4S (§ 551), which is a troublesome impurity. It is then washed with sodium hydroxide which removes the phenol. The oil is distilled, the vapours being passed through a dephlegmator similar to that used in the distillation of alcohol (Column A, Fig. 19). The issuing vapours are condensed and form three fractions, benzene (C_6H_6) boiling at 80° C., toluene ($C_6H_5{\cdot}CH_3$) boiling at 110° and xylene [$C_6H_4(CH_3)_2$] boiling at 140°. Further purification is carried out, if needed, by treatment with sulphuric acid and redistillation.

338. Structure of Benzene.—The hydrocarbon benzene, C_6H_6, and its substitution products, $C_6H_{6-n}X_n$, form a considerable part of the subject-matter of organic chemistry.

The assignment of a formula to benzene is therefore most important.

The facts which guide us in arriving at the structure of benzene are the following:—

(1) Benzene is an unsaturated compound which can react additively with 2, 4 or 6, but not with more atoms of hydrogen (§ 342). The final product, hexahydrobenzene C_6H_{12}, is a polymethylene and can be synthesised by the action of sodium on $\alpha\eta$-dibromohexane. The reaction of benzene with hydrogen may therefore be written:

$$C_6H_6 + 6H = \begin{array}{c} CH_2 \\ \diagup \quad \diagdown \\ CH_2 \quad CH_2 \\ | \qquad | \\ CH_2 \quad CH_2 \\ \diagdown \quad \diagup \\ CH_2 \end{array}$$

This indicates (but does not prove) that benzene is a cyclic compound.

(2) If benzene were a straight-chain compound the formula, containing only one hydrogen atom per atom of carbon, would have double or treble linkages like those of an olefine or acetylene. Benzene is, it is true, unsaturated, but reacts additively with halogens and oxidising agents only with great difficulty.

Two straight-chain compounds, C_6H_6, *dipropargyl*,

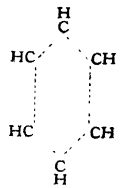
$$HC \equiv C - CH_2—CH_2—C \equiv CH,$$

and hexa-$\Delta^{\alpha\epsilon}$-diene-Δ^{γ}-inene,

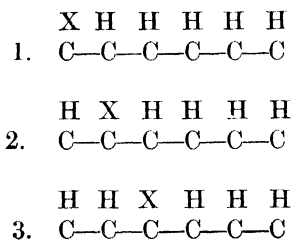
$$H_2C = CH—C \equiv C - CH = CH_2,$$

both isomeric with benzene, are known. Both of these are entirely unlike benzene in chemical properties, being very reactive and easily oxidisable. Presumably then benzene is not a straight-chain compound.

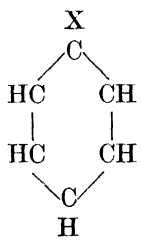
(3) Benzene forms only one monosubstitution product. Thus only one chlorobenzene C_6H_5Cl exists. It is possible to make this substance by such methods as to ensure that six specimens have been prepared with the halogen atom on a *different* carbon atom in each case. All six are identical. This indicates that all six carbon atoms are alike and that one hydrogen atom is attached to each. If this were not so one carbon atom must have at least two hydrogen atoms and another none, in which event the chlorine atom could be placed in different positions relatively to these, giving different compounds (cf. the various chloropentanes, diagram, § 54). This evidence and that of (1) indicates the formula:



the dotted lines leaving the question of valency arrangement open.

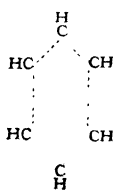


A straight-chain 6-carbon hydrocarbon would give at least three monosubstitution products.

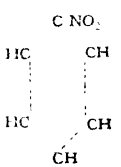


A ring compound gives only one, for if X is placed on any other carbon atom, the formula has merely to be rotated to reproduce that given above.

This hexagon formula is borne out by the numbers of di- and tri-substitution products, which correspond precisely with what can be predicted from a cyclic formula. The nitrobenzenes may be taken as examples. A formula



will yield one mononitrobenzene



for all six CH groups are identical and symmetrically situated. From this compound one should be able to obtain three different dinitrobenzenes I, II, III. One of these (I) should be able to yield *two* trinitrobenzenes, another (II) should yield three, while the

third (III) should yield only one tri-substitution product.[1] The fact that this state of affairs is actually found is the strongest evidence for a hexagonal cyclic formula.

BENZENE SUBSTITUTION PRODUCTS

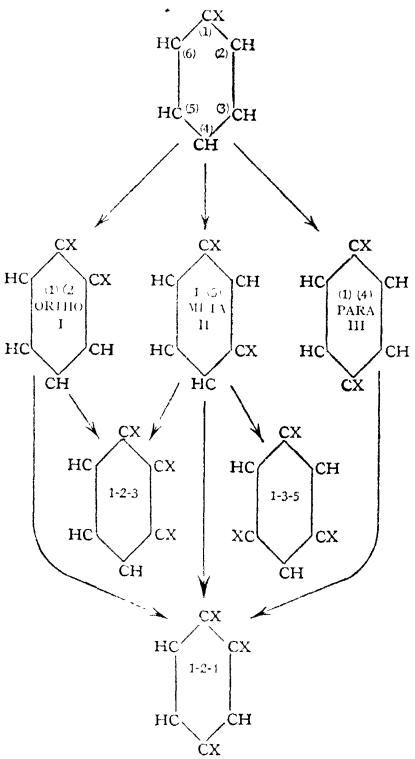
One mono-substitution product

can yield

three disubstitution products

which yield

two, three and one of the three trisubstitution-products, respectively.

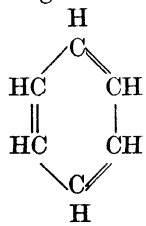


A ring formula for benzene then explains (1) the formation of hexamethylene from it (2) the difference in chemical properties from any olefine or acetylene hydrocarbon; (3) the number of substitution products formed.

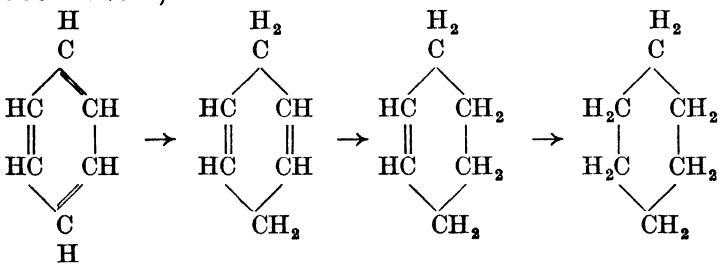
The difficulty which such a formula presents is that it represents the carbon atom as being tervalent and the question of the fate of the fourth valency bond of the carbon atoms is not wholly solved.

[1] These considerations only apply when the substituent groups are identical as in the trinitrobenzenes, $C_6H_3(NO_3)_3$.

Kekulé, the originator of the ring formula for benzene, suggested that double and single linkages alternated thus:



This formula is generally adopted still and explains most of the reactions of benzene very satisfactorily. It explains first of all why benzene forms additive compounds with hydrogen of formulæ C_6H_8, C_6H_{10} and C_6H_{12}, but not C_6H_7, C_6H_9 or C_6H_{11} (cf. § 166 on the double bond).



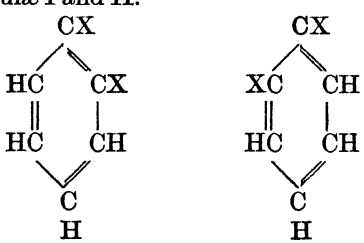
Benzene. Dihydrobenzene. Tetrahydrobenzene. Hexahydrobenze.

It also explains the fact that benzene forms a *triozonide*. Compounds with a double linkage $>C = C<$ form unstable compounds with ozone, known as *ozonides* of formula $>C\text{——}C<$ (O, O, O). Benzene reacts

with ozone giving an ozonide of formula $C_6H_6(O_3)_3$ and therefore may be supposed to contain three double linkages in its molecule.

The objections to this formula are:

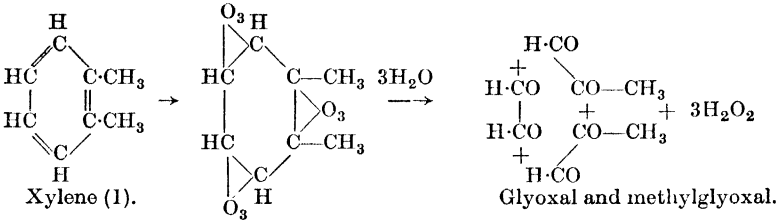
(1) The fact that two substitution compounds (say, dichlorobenzenes) of formulæ I and II.

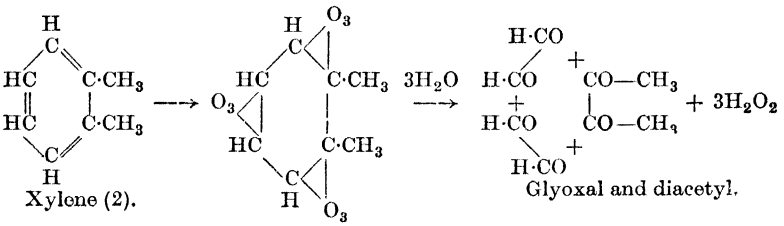


I. II.

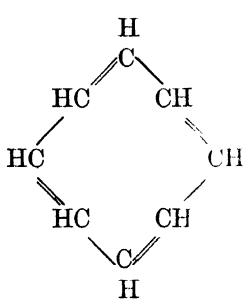
should exist but do not do so. An attempt to avoid this difficulty is made by suggesting that the double bonds continuously oscillate between one carbon atom and the next, so that I and II are merely phases of a constantly changing arrangement.

Evidence has been obtained of the existence of two forms of *o*-xylene (dimethyl benzene), corresponding to these oscillations of the valency bonds. When *o*-xylene is treated with ozone it gives a mixture of two ozonides (§ 181), which when hydrolysed gives glyoxal, diacetyl and methylglyoxal. If xylene existed only as formula I or II, only *two* of these three products could be obtained.

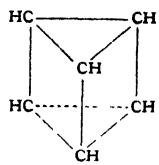




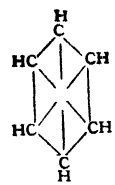
(2) Benzene is so much less reactive than the olefines (*v.* p. 327 above) that it is difficult to believe that it contains a double linkage. Moreover *cyclo*-octatetrene, which has a formula analogous to the Kekulé formula for benzene, does not resemble benzene and does resemble the olefines.



Naturally many attempts have been made to suggest a better formula. Ladenburg's prism formula (III) and any three-dimensional formulæ are ruled out, since they would make some of the substitution products asymmetric and therefore optically active. None of the benzene substitution products shows asymmetry.



III.



IV.

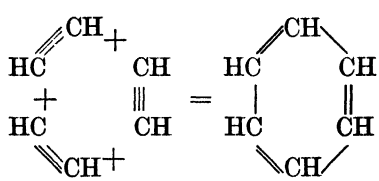
The centric formula (IV) of Armstrong and Baeyer represents the fourth valency as directed to the middle of the ring. The chief objection to it is that it postulates a new type of valency for the special case of the benzene derivatives. The theories of Thiele and of Ingold are perhaps beyond the scope of this work. It is clear that the benzene ring presents a case in which the ordinary methods of representing formulæ do not provide an adequate picture of the mode of linkage, and the bonds linking the six carbon atoms are best regarded as intermediate in character between the ordinary single and double bond.

In practice the Kekulé formula (I) is ordinarily adopted and, if it is remembered that the linkage depicted as ethylenic differs greatly in reactivity from the double linkage in an olefine, the formula serves well to explain the properties of benzene.

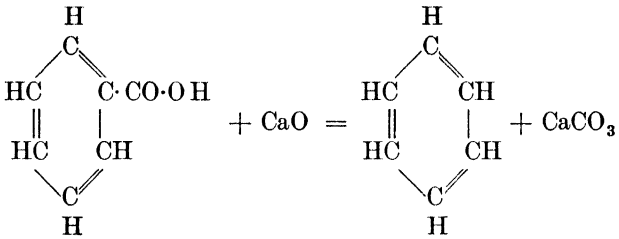
Some of the physical properties of organic compounds, *e.g.*, molecular refractivity, magnetic rotation, parachor, etc., have been found to depend on the nature and number of the linkages contained in the molecule. The results of studies of these properties, on the whole, are in favour of the Kekulé formula.

339. Preparation of Benzene.—Benzene can be prepared by the following reactions:—

(1) Acetylene, when passed through a heated tube, yields some benzene:



(2) When benzoic acid is distilled with lime, benzene is formed:



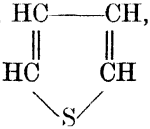
This method may be used to prepare very pure benzene.

(3) When benzenediazonium chloride (§ 399) is heated with alcohol it yields benzene, the alcohol being oxidised to aldehyde:

$$C_6H_5{\cdot}N_2{\cdot}Cl + C_2H_6O = C_6H_6 + N_2 + HCl + C_2H_4O.$$

Expt. 74.—*Preparation of Benzene.*—Grind 5 g. of benzoic acid with 10 g. of calcium oxide. Place the mixture in a large test-tube connected to a U-tube cooled by immersion in water. Heat the mixture till no more vapours are evolved. The liquid condensing is benzene, usually with some impurities resulting from decomposition by heat.

Burn a portion and note its smoky flame.

340. Purification of Benzene.—Very pure benzene is best prepared from the commercial product by repeatedly shaking it with small quantities of sulphuric acid to remove thiophen, 

which is not easily removed in any other way. The product is fractionated and then partly frozen. The unfrozen liquid retains most of the impurities, and the crystals separating at 5° C. are very pure benzene.

341. Physical Properties of Benzene.—Benzene is a colourless liquid with a characteristic smell. Though it has no visible colour, it shows absorption bands in the ultra-violet portion of the spectrum, a fact of some interest in connection with the many coloured substances containing benzene rings (§ 401). The vapour is somewhat poisonous.

Benzene freezes at 5·4° C., and is a useful substance for cryoscopic molecular weight determination. It boils at 80·4° C. under normal pressure. It is lighter than water (sp. gr. 0·884/15° C.). Benzene does not dissolve appreciably in water, but is miscible with anhydrous alcohol and other organic solvents. It is an excellent solvent for most organic substances, and it also dissolves phosphorus, iodine and, to a small extent, sulphur.

342. Chemical Properties of Benzene.—Benzene burns readily

with a bright and very smoky flame. Its chemical reactions may be grouped as:

(1) formation of substitution products $C_6H_{6-n}X_n$,

(2) formation of addition products $C_6H_6X_n$,

(3) reactions involving disintegration of the ring.

Substitution Products.—Chlorine and bromine, *in bright sunshine*, form addition products, *e.g.*, $C_6H_6Cl_6$ (*v.* below). Under ordinary conditions, however, halogen atoms are *substituted* for the hydrogen atoms. The action is very slow unless certain substances, 'carriers' or catalysts, are present. The substances which can be used as carriers are numerous. Among the best are iodine, molybdenum chloride and ferric chloride for chlorine, and aluminium bromide for bromine.

Mono-chlorobenzene is prepared by bubbling chlorine through boiling benzene containing about 1 per cent. of iodine, the benzene vapour being condensed and returned by a reflux condenser,

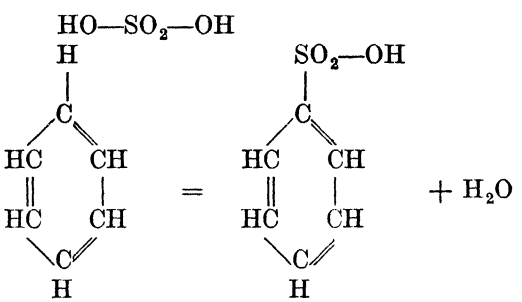
$$C_6H_6 + Cl_2 = C_6H_5Cl + HCl.$$

If the chlorination is continued for a sufficient period, di-, tri-, tetra-, penta- and hexa-chlorobenzenes are produced of formulæ $C_6H_4Cl_2$, $C_6H_3Cl_3$, $C_6H_2Cl_4$, C_6HCl_5 and C_6Cl_6. These are further discussed in Chapter XXII.

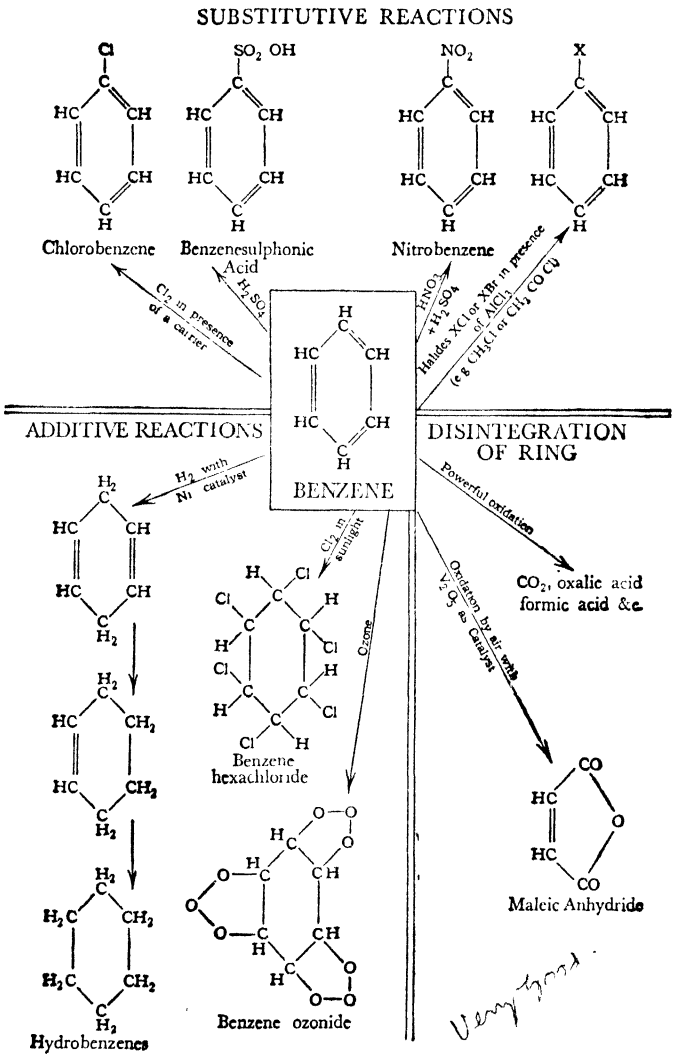
Bromobenzene is readily prepared on the laboratory scale, by the method described in Expt. 75, § 348.

The radical C_6H_5- is known as phenyl, and accordingly chloro- and bromo-benzene may also be called phenyl chloride and bromide. Phenyl must be carefully distinguished from benzyl, $C_6H_5{\cdot}CH_2-$ (§ 442).

Benzene is readily attacked by hot concentrated sulphuric acid or by cold fuming sulphuric acid (solution of sulphur trioxide in sulphuric acid), benzenesulphonic acid, $C_6H_5{\cdot}SO_2{\cdot}OH$, being formed and water being eliminated. Di- and tri-sulphonic acids can be made by the use of heat and fuming acid. The benzenesulphonic acid is isolated by means of its soluble calcium or barium salt, as described in § 351.

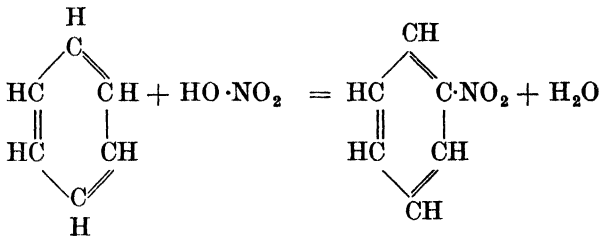


REACTIONS OF BENZENE



Nitric acid alone reacts but slowly with benzene, but a mixture of nitric acid and sulphuric acid readily converts benzene into nitrobenzene, $C_6H_5NO_2$. An excess of the acids brings about the forma-

tion of dinitrobenzenes, $C_6H_4(NO_2)_2$. Trinitrobenzenes are not readily formed. The preparation of nitrobenzene and dinitrobenzene is described in §§ 368, 370.



Nitrobenzene is readily converted by reduction into aminobenzene or *aniline*, which may be converted into a great variety of benzene compounds. The conversion of benzene into nitrobenzene is therefore of much practical importance.

The reaction of benzene with halides in presence, of aluminium chloride (Friedel–Crafts reaction) furnishes us with a number of substitution products. An intermediate compound of benzene, the halide and aluminium chloride is produced, which on addition of water breaks up, giving hydrogen chloride, aluminium chloride and the substitution product of benzene. The total effect of the reaction may be expressed by the equation

$$C_6H_6 + Cl{\cdot}X = C_6H_5X + HCl.$$

Thus we may prepare ethylbenzene by the reaction of ethyl chloride, aluminium chloride and benzene:

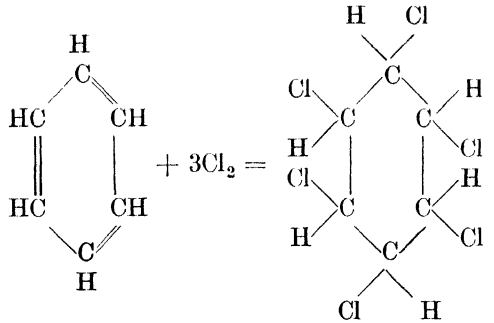
$$C_6H_6 + C_2H_5Cl = C_6H_5{\cdot}C_2H_5 + HCl.$$

Acetophenone may be prepared by the action of acetyl chloride on benzene and aluminium chloride:

$$C_6H_6 + Cl{\cdot}CO{\cdot}CH_3 = C_6H_5{\cdot}CO{\cdot}CH_3 + HCl.$$

Additive Reactions.—Benzene can be reduced to dihydrobenzene, C_6H_8, tetrahydrobenzene, C_6H_{10}, and hexahydrobenzene, C_6H_{12}. The reduction is readily brought about by passing a mixture of hydrogen and the vapour of benzene over freshly reduced metallic nickel. Hexahydrobenzene is identical with hexamethylene (§ 333), and is a very stable hydrocarbon resembling the paraffins in its general behaviour. Di- and tetra-hydrobenzene are, however, more reactive than benzene, and rather resemble the olefines.

Chlorine and bromine in direct sunlight convert benzene into benzene hexachloride or hexabromide, the former of which is used as the insecticide *gammexane*:

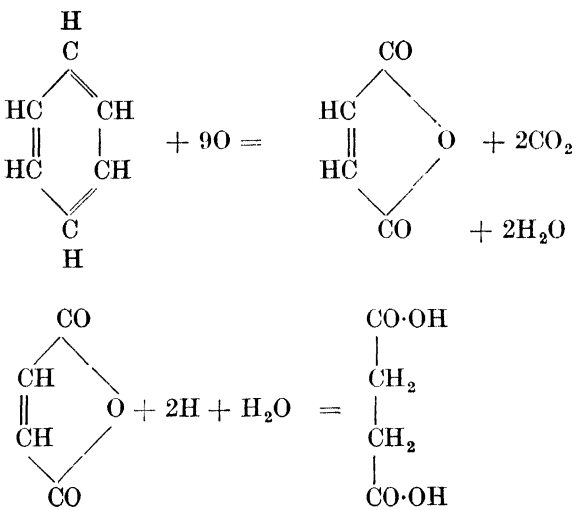


This should be contrasted with their substituting action (p. 334) in ordinary light and in presence of catalysts.

Reactions Disintegrating the Benzene Ring.—The benzene ring is a very stable structure, and only very drastic treatment breaks it up.

Oxidation with potassium permanganate give formic, oxalic and propionic acid, together with other products.

Recently the oxidation of benzene vapour by air in presence of heated vanadium pentoxide has been used to make maleic anhydride, which can be reduced to succinic acid, used in making certain dyes:



QUESTIONS

(1) On what evidence is a cyclic structure for benzene based? How can this structure be reconciled with the quadrivalency of carbon?

(2) How many mono-, di-, and tri-chlorobenzenes are known? What light does this throw on the structure of benzene?

(3) In what respect does benzene resemble and differ from (*a*) the paraffin hydrocarbons, (*b*) the olefines? How are their likenesses and differences explained by its formula?

(4) What effect have hydrogen, chlorine, sulphuric acid, nitric acid, oxidising agents, on benzene under various conditions of reaction?

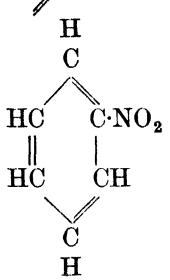
(5) Describe the preparation of benzene (1) from coal-tar on the manufacturing scale, (2) in the laboratory, (3) from an aliphatic compound.

CHAPTER XXII

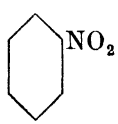
SUBSTITUTION PRODUCTS OF BENZENE

HALIDES : SULPHONIC ACIDS : PHENOLS

343. Halogen Derivatives of Benzene.—We have already seen that chlorine and bromine replace the hydrogen atoms in benzene, giving chloro- and bromo-benzenes. Benzene forms twelve different chloro-benzenes and bromo-benzenes, most of which, however, are of little importance. It is, however, of interest to see the possibilities of isomerism in the benzene ring, and in §344 a list is given of the possible chloro-benzenes. In this table the common practice is adopted of depicting the benzene ring as a hexagon, an unoccupied angle being understood to contain a $\rangle CH$ group and an occupied angle a carbon atom, $\rangle C-$. Thus the compound



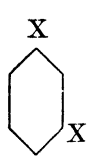
is written



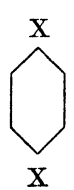
344. Nomenclature of Benzene Substitution Products.—The three disubstitution products of benzene are known as ortho-, meta- and para-derivatives. The arrangement of the groups in each case is that shown below:



ortho-



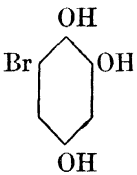
meta-



para-

More complex derivatives are named by giving the carbon atoms of the ring the numbers 1—6. The atom numbered 1 is that which

gives the lowest numerical total for the substituents. Thus the compound



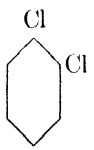
is called 1-bromo-2 : 3 : 5-hydroxybenzene (not 3-bromo-1 : 4 : 5-hydroxybenzene).

The Chlorobenzenes

One monochlorobenzene:



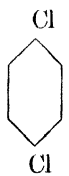
Three dichlorobenzenes:



(ortho).

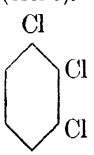


(meta).

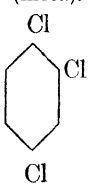


(para).

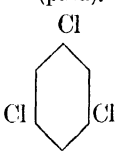
Three trichlorobenzenes:



(1 : 2 : 3).

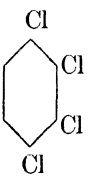


(1 : 2 : 4).

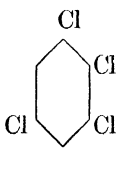


(1 : 3 : 5) or symmetrical.

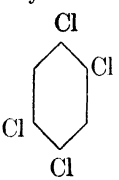
Three tetrachlorobenzenes:



(1 : 2 : 3 : 4).

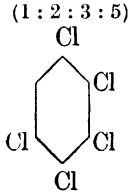


(1 : 2 : 3 : 5).

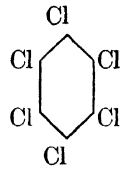


(1 : 2 : 4 : 5).

One pentachlorobenzene:



One hexachlorobenzene:



The student should convince himself by trial that no other chlorobenzenes can exist.

HALOGEN DERIVATIVES OF BENZENE

345. Comparison of Alkyl and Phenyl Halides.—The compounds in the aliphatic series which most resemble the halogen substituted benzenes are the alkyl halides. Thus ethyl bromide, C_2H_5Br, and phenyl bromide, C_6H_5Br, have a similar constitution. The chief difference in their chemical behaviour is the much greater stability of the phenyl compound. Phenyl bromide will undergo only a few of the reactions of ethyl bromide and requires much higher temperatures and longer reaction times. Accordingly, the phenyl halides are much less useful synthetically than the alkyl halides.

346. Monochlorobenzene, Phenyl Chloride, C_6H_5Cl.—(1) Monochlorobenzene is prepared by direct chlorination of benzene in presence of a 'halogen carrier,' which acts as a catalyst. Iodine, phosphorus, iron and molybdenum chloride have all been used.

$$C_6H_6 + Cl_2 = C_6H_5Cl + HCl.$$

Benzene mixed with a carrier, best a mixture of finely divided iron and ferric chloride, is heated to boiling on the water-bath in a flask fitted with an inlet tube for chlorine and a reflux condenser with exit tube to the shaft of the fume chamber. Chlorine, best from a cylinder, is bubbled through it in a brisk stream. The chlorobenzene, which boils at 131·8° C., is easily separated from residual benzene (b.p., 80·4° C.).

(2) Chlorobenzene can be prepared by the action of phosphorus pentachloride on phenol (hydroxybenzene). Note that while the trichloride will convert ethyl alcohol into ethyl chloride (§ 56) the more reactive pentachloride is needed to convert phenol into phenyl chloride:

$$C_6H_5{\cdot}OH + PCl_5 = POCl_3 + HCl + C_6H_5Cl.$$

(3) Chlorobenzene is very conveniently made from benzenediazonium chloride in presence of cuprous chloride (Sandmeyer reaction, § 399):

$$C_6H_5{\cdot}N_2{\cdot}Cl = C_6H_5Cl + N_2.$$

Properties.—Chlorobenzene is a colourless liquid heavier than and insoluble in water, boiling at 131·8° C.

It is very stable and will not react with caustic potash or with metallic salts in general. It reacts, like an alkyl halide, with sodium methoxide at high temperatures, giving anisole, phenyl methyl ether,

$$C_6H_5Cl + NaOCH_3 = C_6H_5—O—CH_3 + NaCl.$$

Sodium or, better, finely divided copper-bronze removes the halogen atom with some difficulty, a complex mixture of higher hydrocarbons being the product. The chief product is diphenyl (§ 474).

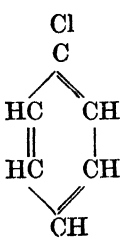
The only important reaction of chlorobenzene is its formation of a Grignard reagent.

When treated with magnesium (for method, see Expt. 45, § 162) it yields phenylmagnesium chloride:

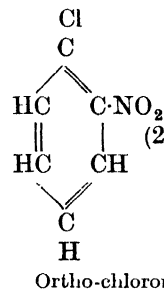
$$C_6H_5Cl + Mg = C_6H_5{\cdot}Mg{\cdot}Cl,$$

and from this a variety of products, alcohols, ketones, acids, etc., can be made (cf. § 163).

The reagents which attack benzene attack chlorobenzene. Thus nitric acid at 0° C. converts it into three different chloronitrobenzenes, the para-compound being predominant.

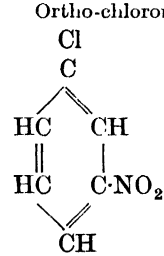


$+ HNO_3 \rightarrow H_2O +$



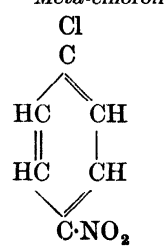
(29·9 per cent.)

Ortho-chloronitrobenzene.



(0·3 per cent.)

Meta-chloronitrobenzene.



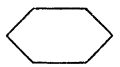
(69·8 per cent.)

Para-chloronitrobenzene.

It is to be noted that the three isomerides are formed in very different proportion.

347. Orientation Rule for Benzene Substituents.—It is found that, when a monosubstituted benzene derivative is converted into a disubstituted derivative as above, the product is either almost wholly a mixture of the ortho- and para-compounds or almost wholly the meta-compound. Several rules have been devised to predict whether the ortho- and para- or the meta-compound will be formed. It is found to depend almost entirely on the group already present, and not on the second substituent.

Recently a rule has been devised by Hammick and Illingworth, which appears to be almost without exceptions.

"If in the benzene derivative  X—Y, Y is in a higher group of the periodic table than X, or if, being in the same group, Y is of lower atomic weight than X, then a second atom or group of atoms that enters the nucleus will do so in the meta-position to the group XY. In all other cases, including that in which the group XY is a single atom, a second entering atom or group goes to the ortho- and para-positions."

The rule may be exemplified by the following cases:—

Compound.	Formula.	Group of periodic table of X.	Group of periodic table of Y.	*Substituting group* goes to
Nitrobenzene . .	$C_6H_5 \cdot NO_2$	5	6	meta-
Chlorobenzene .	$C_6H_5 \cdot Cl$	7	none	ortho- and para-
Benzene sulphonic acid.	$C_6H_5 \cdot SO_3H$	6 (A.W.32)	6 (A.W.16)	meta-
Benzoic acid . .	$C_6H_5 \cdot CO \cdot OH$	4	6	meta-
Cyanobenzene. .	$C_6H_5 \cdot CN$	4	5	meta-
Phenol . . .	$C_6H_5 \cdot OH$	6	1	ortho- and para-
Anisole . .	$C_6H_5 \cdot O \cdot CH_3$	6	4	ortho- and para-
Toluene . . .	$C_6H_5 \cdot CH_3$	4	1	ortho- and para-
Aniline . . .	$C_6H_5 \cdot NH_2$	5	1	ortho- and para-

The work of Lapworth, Ingold, and Robinson has cleared up the theoretical basis of these rules by the use of the idea of the shifting of electrons through the influence of the first substituent.

348. Monobromobenzene.—Bromobenzene is readily prepared from bromine and benzene, which are heated with a 'carrier', under a reflux condenser,

$$C_6H_6 + Br_2 = C_6H_5Br + HBr.$$

Expt. 75.—*Preparation of Bromobenzene.*—The apparatus shown in Fig. 51 is set up.[1] The funnel should only just dip below the surface of the water. In the flask place 30 g. benzene, 72 g. bromine (24 c.c.), and about 10 drops of pyridine, C_5H_5N, which acts as a carrier. Heat to 25°—30°, when hydrogen bromide is freely evolved and passes into the beaker and is absorbed. When the action becomes less vigorous (1 hr.) heat to 65°—70° C. and continue to heat till very little HBr is evolved. Cool the contents of the flask and purify by shaking with an equal volume of sodium hydroxide solution. The lower layer, which should be colourless, is run off into a flask and left to stand over calcium chloride till it is no longer cloudy. It is then distilled; the portion boiling between 140° C. and 170° C. is collected and redistilled. The portion coming over between 150° and 160° C. is bromobenzene.

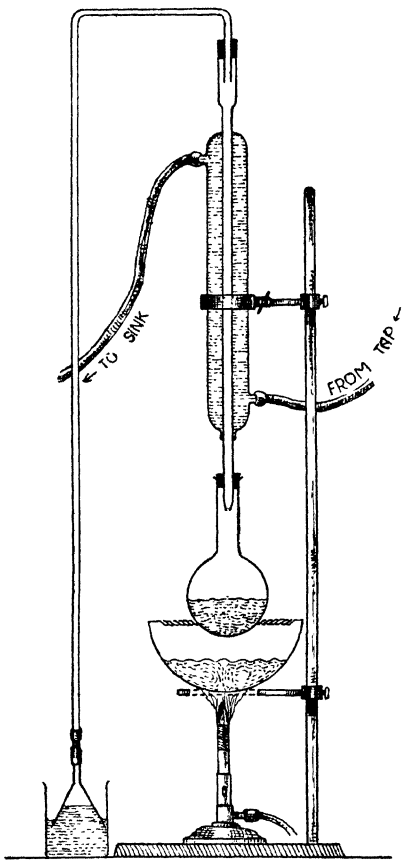


FIG. 51.—Preparation of Bromobenzene.

The Sandmeyer reaction (§ 399) may also be employed to make bromobenzene.

Bromobenzene much resembles chlorobenzene. It is a colourless liquid boiling at 156·6° C. and of *d.* 1·5.

349. Monoiodobenzene, Phenyl iodide, C_6H_5I, can be made by heating benzene and iodine with a carrier, *e.g.*, ferric chloride; but is better made by the action of potassium iodide on benzenediazonium chloride (§ 399),

$$C_6H_5N_2Cl + KI = C_6H_5I + KCl + N_2$$

[1] A thermometer should be added, its bulb dipping in the liquid.

It is a colourless heavy liquid boiling at 188·4° C. It has *d.* 1·84 and is insoluble in water.

It is more reactive than chloro- or bromo-benzene. Thus sodium amalgam and alcohol reduce it to benzene:—

$$C_6H_5I + 2H = C_6H_6 + HI.$$

It shows a tendency to form compounds in which the iodine atom is ter- and quinque-valent.

Thus chlorine reacts with a solution of phenyl iodide in chloroform giving a yellow crystalline phenyl iododichloride, $C_6H_5ICl_2$. Alkalis convert this into iodosobenzene, C_6H_5IO. This compound or phenyl iodide itself can be oxidised by Caro's acid (H_2SO_5) to iodoxybenzene, $C_6H_5IO_2$, an explosive peroxide-like compound.

350. Other Halogen Substitution Products of Benzene.—Di-, tri- and poly-chlorobenzenes can be obtained by direct chlorination of benzene, carried on for a sufficient period in presence of an energetic carrier (*e.g.*, $MoCl_5$). They are stable substances. *p*-Dichlorobenzene has been used as a soil fumigant and as a remedy against moths, wood-worms etc. Similar bromine compounds are known and also compounds in which both chlorine and bromine are substituted.

Hexachlorobenzene, C_6Cl_6, and *hexabromobenzene*, C_6Br_6, are of some interest as being halides of carbon. They are solids which can be distilled without decomposition.

BENZENESULPHONIC ACIDS.

The sulphonic acids of the paraffins cannot readily be made by the action of sulphuric acid on the hydrocarbons. Benzenesulphonic acid is, however, very readily prepared and of some importance for the manufacture of phenol.

351. Benzenesulphonic Acid.—Benzenesulphonic acid is made by heating benzene with concentrated sulphuric acid:—

$$C_6H_6 + HO{\cdot}SO_2{\cdot}OH \rightleftharpoons C_6H_5{\cdot}SO_2{\cdot}OH + H_2O.$$

The mixture is diluted with water and separated from unchanged benzene, if any, and neutralised with barium carbonate. Barium benzenesulphonate is soluble in water, while barium sulphate is insoluble. The filtered solution may be decomposed with the exact quantity of sulphuric acid and again filtered. The clear solution is evaporated and crystals of benzenesulphonic acid separate.

Expt. 76.—*Preparation of Potassium Benzenesulphonate.*—Set up the apparatus shown in Fig. 26. Place in the flask (250 c.c.), 50 c.c. of benzene and 50 c.c. of concentrated sulphuric acid. Heat to boiling and shake at short intervals until almost

all the top layer of benzene has disappeared (6 hr. or more). Allow to cool. Dilute by pouring slowly and with good stirring into a litre of water in a large evaporating basin. Heat to boiling and add, a little at a time, with good stirring, powdered chalk (about 50 g.). When no further effervescence occurs filter hot by suction though a large filter paper. The resulting solution of calcium benzenesulphonate is boiled down to 500 c.c. bulk, and concentrated potassium carbonate solution is added till the addition just ceases to produce any precipitate of calcium carbonate. To ascertain this, small specimens may have to be filtered and tested from time to time. The liquid is filtered from calcium carbonate by suction and concentrated until a sample crystallises on cooling. The separated crystals are sucked dry on a filter funnel and dried by pressing with absorbent paper.

Benzenesulphonic acid forms small crystals soluble in water. It is a stable substance. It can be broken up into benzene and sulphuric acid only by drastic treatment (*e.g.*, heating to 150—180° C. with concentrated hydrochloric acid under pressure):—

$$C_6H_5{\cdot}SO_2{\cdot}OH + H_2O = C_6H_6 + H_2SO_4.$$

In general it reacts as a fairly strong acid. It forms salts with the metals. With phosphorus pentachloride it gives benzenesulphonyl chloride, $C_6H_5{\cdot}SO_2{\cdot}Cl$. Benzenesulphonic acid (or its salts) can be converted into a salt of phenol by fusion with potassium hydroxide or other alkali:—

$$C_6H_5{\cdot}SO_2{\cdot}OK + 2KOH = C_6H_5{\cdot}OK + K_2SO_3.$$

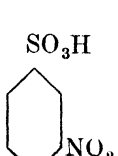
This reaction is further discussed in § 354.

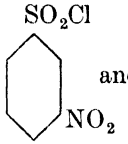
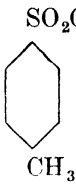
When distilled with potassium cyanide it gives phenyl cyanide (benzonitrile):—

$$\begin{matrix} C_6H_5{\cdot}SO_2OK \\ + \\ CNK \end{matrix} = C_6H_5{\cdot}CN + K_2SO_3.$$

Benzenesulphonic acid then differs from the benzene halides in containing a group which is fairly readily replaceable.

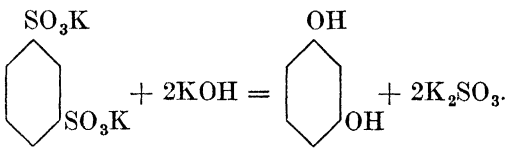
Nitric acid gives chiefly *m*-nitrobenzenesulphonic acid (cf. § 347):—



m-Nitrobenzenesulphonyl chloride  and *p*-toluenesulphonyl chloride  are employed as a means of separating primary and secondary amines. Their derivatives with primary amines[1] are soluble in sodium hydroxide solution, while their derivatives with secondary amines are not.

352. Di- and Tri-sulphonic Acids.—These are produced by the action of hot fuming sulphuric acid on benzene.

Benzene-m-*disulphonic acid* is the chief product obtained when benzene is treated with fuming sulphuric acid. When it is fused with caustic potash it gives *m*-dihydroxybenzene or *resorcinol* (§ 357):—



In general it behaves much as does the monosulphonic acid.

PHENOLS.

353. List and Nomenclature.—When one or more hydroxyl groups are substituted for the hydrogen atoms of the benzene ring, the products are called phenols.

They are analogous to the aliphatic alcohols, but differ widely from them in many respects.

The phenols are classified as monohydric, dihydric, trihydric, etc., according to the number of hydroxyl groups attached to the benzene ring.

Of the theoretically possible simple phenols which contain no substituent group other than hydroxyl, all are known, and include

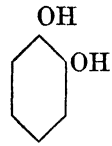
Monohydric Phenol.

Phenol (carbolic acid), monohydroxybenzene, C_6H_5OH 

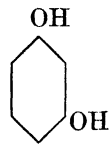
[1] *Vide* §§ 85, 384 for action of acid chlorides on amines.

Dihydric Phenols.

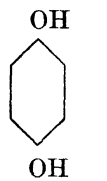
Pyrocatechol, *ortho*dihydroxybenzene, $C_6H_4(OH)_2$
catechol,



Resorcinol, *meta*dihydroxybenzene, $C_6H_4(OH)_2$

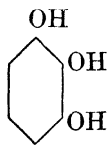


Quinol, *para*dihydroxybenzene, $C_6H_4(OH)_2$

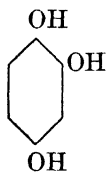


Trihydric Phenols.

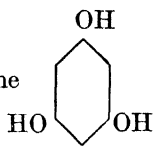
Pyrogallol, 1 : 2 : 3-trihydroxybenzene



Hydroxyquinol, 1 : 2 : 4-trihydroxybenzene



Phloroglucinol, 1 : 3 : 5-trihydroxybenzene



Higher Phenols.—Three tetrahydroxybenzenes (1 : 2 : 3 : 4; 1 : 2 : 3 : 5; 1 : 2 : 4 : 5), one pentahydroxybenzene and one hexahydroxybenzene are known. They are not of importance.

Numerous phenols containing other groups besides hydroxyl are known. Among the most important are the methylphenols or cresols, $CH_3 \cdot C_6H_4 \cdot OH$ (§§ 430—432), the nitro-phenols (§ 375), and salicylic acid, $HO \cdot C_6H_4 \cdot CO \cdot OH$ (§ 459).

354. Phenol, Carbolic Acid, $C_6H_5 \cdot OH$.—Phenol is a constituent of coal-tar. It is made from this product and also synthetically from potassium benzenesulphonate.

Manufacture from Coal-tar.—The tar is distilled as described in § 337; most of the phenol comes over in the 'carbolic oil,' distilling

between 210° and 240° C. The oil contains hydrocarbons (toluene, xylene, naphthalene, etc.) as well as phenol. The oils are agitated with dilute sodium hydroxide solution. Phenol forms sodium phenoxide ('carbolate') $C_6H_5{\cdot}ONa$, which dissolves in the aqueous solution. Any cresol (methyl-phenol) also dissolves, forming sodium cresylate, $CH_3{\cdot}C_6H_4{\cdot}ONa$. The solutions are drawn off from the residual oil. Phenol is a very weak acid and accordingly the solution of its salt so obtained can be decomposed by carbon dioxide under pressure:

$$2C_6H_5{\cdot}ONa + CO_2 + H_2O = 2C_6H_5{\cdot}OH + Na_2CO_3.$$

The mixture of phenol and some cresol so obtained, being sparingly soluble in water, settles out as an oil which is then carefully distilled in a fractionating apparatus.

The lower-boiling fractions contain mostly phenol, which crystallises out on cooling, while the higher fractions consist chiefly of cresols which are liquids and do not crystallise. Complete separation is difficult owing to the nearness of the boiling points of phenol (181·3° C.) and of the cresols (188°—200° C.).

A certain amount of phenol is manufactured from benzene by converting it into sodium or potassium benzenesulphonate and fusing this with alkali as described below. The process is not greatly used, except where phenol is required to be quite free from cresols.

It is also prepared in the U.S. by the Raschig process, wherein chlorobenzene is heated with an alkali to a high temperature. It should be noted, however, that phenol cannot be made by the action of alkalis on chloro- or bromo-benzene under laboratory conditions.

Preparation.—(1) Benzene is converted into potassium benzenesulphonate as described in Expt. 76 (§ 351). This is then fused with potassium hydroxide and the potassium salt of phenol so obtained is then decomposed with hydrochloric acid:

$$C_6H_5{\cdot}SO_2{\cdot}OK = C_6H_5{\cdot}OK + K_2SO_3 + H_2O$$
$$+ 2HO{\cdot}K$$

$$C_6H_5{\cdot}OK + HCl = C_6H_5{\cdot}OH + KCl.$$

Expt. 77.—*Preparation of Phenol.*—In a nickel basin place 20 g. caustic potash and 3 c.c. of water. Melt by gentle heating and stir in 12 g. of potassium benzenesulphonate, using as stirrer a thermometer with its bulb protected, as shown in Fig. 52, by a glass tube. Allow the temperature to rise to 240°—250° C., but do not let it exceed the latter figure. After an hour allow the mass to cool and dissolve it in a little water.

Acidify the liquid with conc. HCl and extract with three successive small portions of ether. Dry the ethereal solution over anhydrous sodium sulphate, and distil off the ether on the water-bath. Let the water out of the condenser and distil over the phenol (175°—185° C.) with the free flame.



FIG. 52.—Thermometer Protected by Glass Tube.

(2) Phenol may be prepared by heating an aqueous solution of a benzenediazonium salt (*v.* § 399, Expt. 92, cf. Expt. 97):

$$C_6H_5{\cdot}N_2{\cdot}Cl + HO{\cdot}H = C_6H_5OH + N_2 + HCl.$$

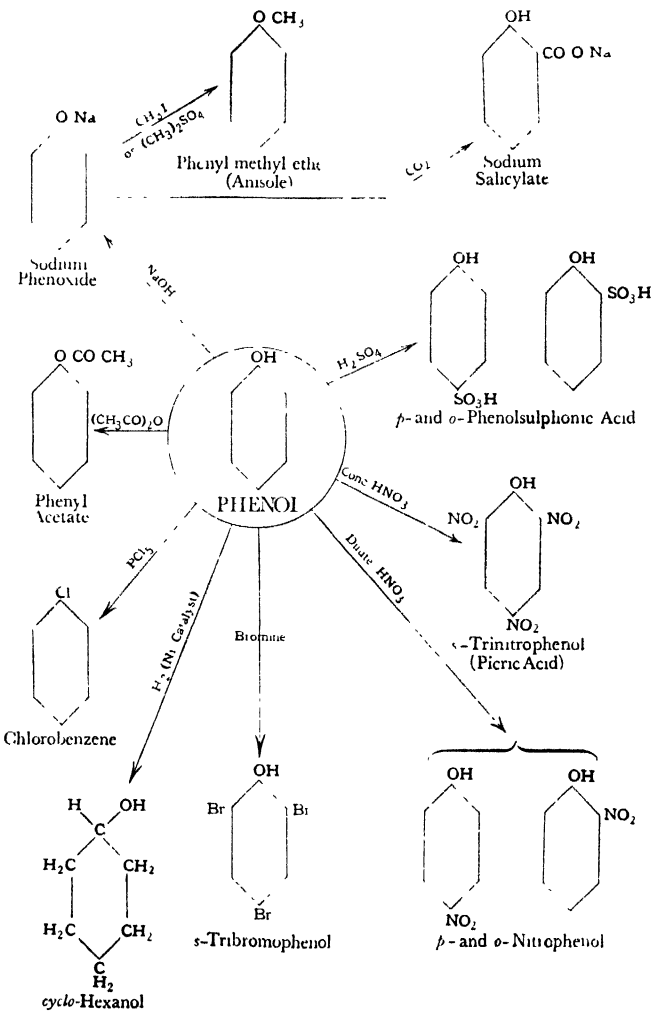
The method is not of value for making phenol but is useful for preparing some other hydroxybenzene-compounds.

Physical Properties.—Phenol forms colourless crystalline needles. Pure phenol is not deliquescent, but even traces of impurities cause it to liquefy in moist air. It has a characteristic odour and sweetish taste. It is poisonous (see below). It melts at 43° C. to a liquid which boils at 181·3° C. Phenol is slightly heavier than water (*d.* 1·049/50° C.). Phenol on addition of water first forms a hydrate melting at 17·2° C. It forms with water at ordinary temperatures two liquid layers, the upper one a solution of phenol in much water, the lower a solution of water in much phenol. As the temperature is raised the aqueous layer dissolves more phenol and the phenolic layer more water. At 84° C. he composition of the two layers becomes identical and a single solution is formed; at and above this temperature, molten phenol and water are miscible in all proportions. Phenol is readily soluble in almost all organic solvents.

Physiological Action.—Phenol coagulates proteins and is therefore destructive to living tissues. If applied to the skin it causes a white scar to be formed and later produces a sore. It renders the skin numb for some hours after application. Solutions of phenol should therefore not be used as dressings in spite of their antiseptic properties. It is an excellent disinfectant and antiseptic, being cheap, non-corrosive and a powerful destroyer of bacteria. It has, however, been somewhat supplanted by the cresols (§ 430).

When swallowed in doses of more than a few grams phenol causes

REACTIONS OF PHENOL.



death. Deaths have also been caused by absorption from wound-dressings.

Chemical Properties.—Phenol is a hydroxyl compound of weakly

acidic character and its properties may be regarded as intermediate between those of an alcohol and those of an acid.

Phenol dissolves in solutions of sodium or potassium hydroxides forming phenoxides, *e.g.*, C_6H_5OK. It dissolves only slightly in ammonia and does not react with sodium carbonate. It is a very weak acid and cannot be satisfactorily titrated with alkalis.

The hydroxyl group of phenol is much less reactive than that of the alcohols. Phenol, however, forms both ethers and esters. Phenyl methyl ether or *anisole* is obtained by heating sodium phenoxide with a methyl halide (or sulphate):

$$C_6H_5{\cdot}O{\cdot}Na + ICH_3 = C_6H_5{\cdot}O{\cdot}CH_3 + NaI.$$

This method resembles Williamson's synthetic method for making ethers. Phenyl ethyl ether or *phenetole* can be made in an analogous manner.

The esters of phenol are difficult to form and are readily hydrolysed. Phenyl acetate, $C_6H_5{\cdot}O{\cdot}CO{\cdot}CH_3$, can be made by heating phenol, acetic anhydride and sodium acetate (cf. § 86). Triphenyl phosphate, used as a constituent of cellulose lacquers, etc., is discussed in § 416a.

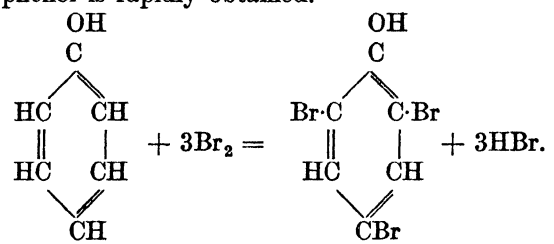
Phenol, like other hydroxy-compounds, reacts with phosphorus pentachloride. Chlorobenzene is formed:

$$C_6H_5{\cdot}OH + PCl_5 = C_6H_5Cl + POCl_3 + HCl.$$

The presence of the hydroxyl group renders the rest of the benzene ring much more reactive. Phenol reacts very readily with halogens, sulphuric acid and nitric acid and forms substitution products.

Phenol is very readily attacked by the halogens, products with from one to five halogen atoms in the molecule being obtained.

If bromine water is added to a solution of phenol a precipitate of *s*-tribromophenol is rapidly obtained:

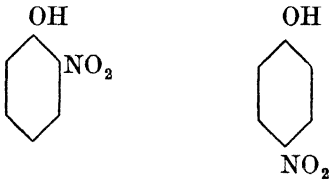


This reaction can be used for estimating phenol. A standard solution of bromine[1] is prepared. To a known volume of it a

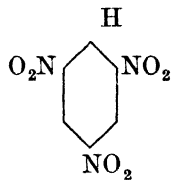
[1] Better a standard solution of potassium bromide and bromate (5 KBr + $KBrO_3$) to which is added, first the phenol, then dilute sulphuric acid. Bromine is liberated (5 KBr + $KBrO_3$ + $3H_2SO_4$ = $3K_2SO_4$ + $3H_2O$ + $3Br_2$) and reacts with the phenol. The residual bromine is estimated as described on p. 353.

measured volume of phenol solution is added. To the resulting solution, after a quarter of an hour, potassium iodide is added in excess and the iodine liberated by the residual bromine is titrated with sodium thiosulphate. Alternatively the standard bromine solution can be added until a drop of the product liberates iodine from starch-iodide paper.

Phenol reacts very readily indeed with nitric acid. Dilute nitric acid gives *o*- and *p*-nitrophenol:



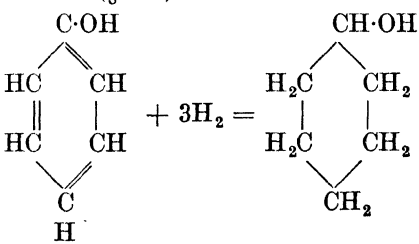
while concentrated nitric acid, best in presence of sulphuric acid, converts it into picric acid, symmetrical trinitrophenol:



These reactions are further discussed under the nitrophenols (§§ 375—378).

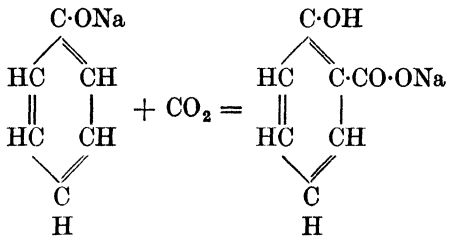
Phenol is resistant to oxidation, but powerful oxidising agents either convert it into simple aliphatic substances such as oxalic acid, or into more complex compounds containing more than one benzene ring.

Phenol cannot be reduced by any of the usual reducing agents. It is, however, reduced on the commercial scale to *cyclo*-hexanol, which is used as a solvent for cleaning purposes under the name of *hexaline*. Phenol vapour together with hydrogen is led over heated nickel at 160°—180° C. (§ 334).



Considerable quantities of phenol are used in the manufacture of salicylic acid (*o*-hydroxybenzoic acid) which is employed in making aspirin and other drugs and also in dye-manufacture.

Carbon dioxide is passed over dry sodium phenoxide at 130° C. and forms sodium salicylate (*v.* § 459).



Phenol readily forms *condensation products* with various substances. Some of these are important dyes. Phenolphthalein affords a good example of such a product (§ 490).

Formaldehyde and phenol react when heated together in presence of a trace of alkali, forming the valuable synthetic resin known as Bakelite. The product is at first soluble in alcohol and readily fusible. In this state it may be moulded into any required shape; on baking, it becomes insoluble and infusible. Quantities approaching 15,000 tons yearly are used mainly for electrical fittings, artificial amber and various ornamental materials. Its structure and exact chemical composition are not known.

Other uses of phenol are in the Reimer–Tiemann reaction (§§ 451, 459) and in the preparation of azo-dyes (§ 402).

Tests.—Phenol is detected by the violet colour it gives to ferric chloride solution, or, more satisfactorily, by the pale yellow precipitate of tribromophenol given when bromine is added to its solutions.

Expt. 78.—*Reactions of Phenol.*—(1) Mix phenol crystals with twice their volume of water. Note formation of two liquid layers. Heat: note that these coalesce at higher temperatures and separate out again on cooling.

(2) Dissolve phenol in caustic soda solution. Acidify the solution of sodium phenoxide. Phenol separates. Pass CO_2 through a portion; the same effect is produced, showing the weakness of phenol as an acid.

(3) To a solution of phenol add bromine solution. Tribromophenol is precipitated.

(4) Warm with dilute nitric acid. Note yellow solution containing nitrophenols, etc. Make solution alkaline. Dilute the yellow solution of the sodium salt of nitrophenol largely and acidify: note the diminution in colour due to formation of free nitro-phenol.

(5) Dissolve phenol in conc. sulphuric acid and warm. Cool and dilute cautiously. No phenol separates out, owing to formation of phenol-sulphonic acid.

(6) To a solution of phenol add ferric chloride solution. Violet coloration.

(7) Dissolve a single crystal of sodium nitrite in 3 c.c. conc. sulphuric acid by very gentle warming. Add 0·25 g. phenol. The colour changes through brown to blue. Pour into water: a cherry-red solution is obtained

which changes to blue on addition of sodium hydroxide. The colour changes are due to the formation of nitrosophenol (Liebermann's nitroso-reaction).

355. Phenol Ethers.—The compounds anisole, $C_6H_5{\cdot}O{\cdot}CH_3$, and phenetole, $C_6H_5{\cdot}O{\cdot}C_2H_5$, may be regarded as esters of phenol acting as an acid, or ethers of phenol acting as an alcohol. They resemble the ethers perhaps more closely than the esters.

Anisole, $C_6H_5{-}O{-}CH_3$, may be prepared by passing a current of methyl chloride vapour over heated sodium phenoxide:

$$C_6H_5{\cdot}O{\cdot}Na + Cl{\cdot}CH_3 = C_6H_5{\cdot}O{\cdot}CH_3 + NaCl$$

or by heating phenol and methyl alcohol with potassium hydrogen sulphate:

$$C_6H_5{\cdot}OH + HO{\cdot}CH_3 = C_6H_5{\cdot}O{\cdot}CH_3 + H_2O.$$

The first method of preparation is analogous to Williamson's reaction (§§ 101—102), the second to the ordinary method of making ethyl ether.

Anisole is a colourless liquid which boils at 154° C. It can be nitrated to ortho- and para-nitroanisole and these can be reduced to anisidine, $CH_3{\cdot}O{\cdot}C_6H_4{\cdot}NH_2$, which yields valuable azo-dyes.

Oil of Aniseed is almost all *p*-propenylanisole, ***anethole***,

$$CH_3{\cdot}O{\cdot}C_6H_4{\cdot}CH = CH{\cdot}CH_3.$$

It can be made by treating *p*-allylanisole,

$$CH_3{\cdot}O{\cdot}C_6H_4{\cdot}CH_2{\cdot}CH = CH_2,$$

with alcoholic potash.

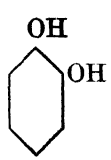
Phenetole, $C_6H_5{\cdot}O{\cdot}C_2H_5$, is made by methods analogous to those employed for making anisole, *e.g.*, heating potassium phenoxide with ethyl iodide.

It boils at 172° C. and closely resembles anisole. It can be nitrated, and the product then reduced to *p*-phenetidine, $C_2H_5{\cdot}O{\cdot}C_6H_4{\cdot}NH_2$, which, when diazotised and coupled with β-naphthol, yields red dyes of great brilliancy.

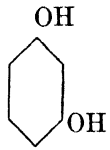
DIHYDRIC PHENOLS

The three dihydric phenols are:

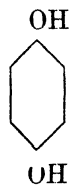
o-Dihydroxybenzene, Pyrocatechol



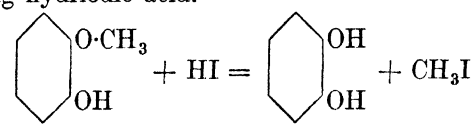
m-Dihydroxybenzene, Resorcinol



p-Dihydroxybenzene, Quinol or Hydroquinone

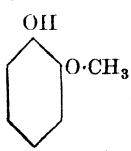


356. Pyrocatechol, $C_6H_4(OH)_2$, is usually made from guaiacol, which occurs in beech-wood tar and is its methyl ether, by heating it with fuming hydriodic acid:

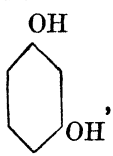


It can also be made by preparing phenol-*o*-sulphonic acid and fusing this with potash—the yield is poor, however.

It forms colourless crystals melting at 104° C. and boiling at 240° C. It is very soluble in water. It is not a substance of importance.

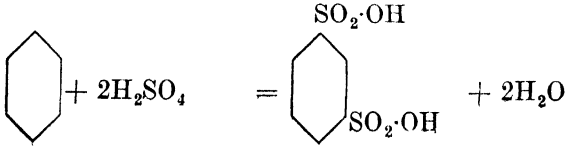
Guaiacol, 

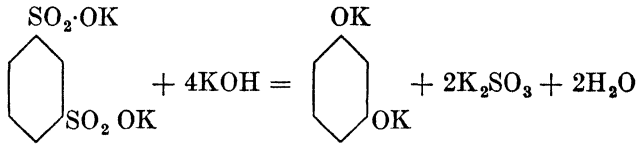
, is obtained by fractionating beech-wood tar and purifying the product by forming the potassium salt, recrystallising this and decomposing it by acids.

357. Resorcinol, 

, is of some importance in the manufacture of dyes (cf. §§ 402, 491, Expts. 93, 105).

It is made synthetically by heating benzene with fuming sulphuric acid until the *m*-disulphonic acid is produced. This is then heated with caustic soda or potash to 270° C. for eight hours.





The melt is dissolved in water and acidified, liberating resorcinol:

$$C_6H_4(OK)_2 + 2HCl = C_6H_4(OH)_2 + 2KCl.$$

The resorcinol is extracted from the liquid by means of ether.

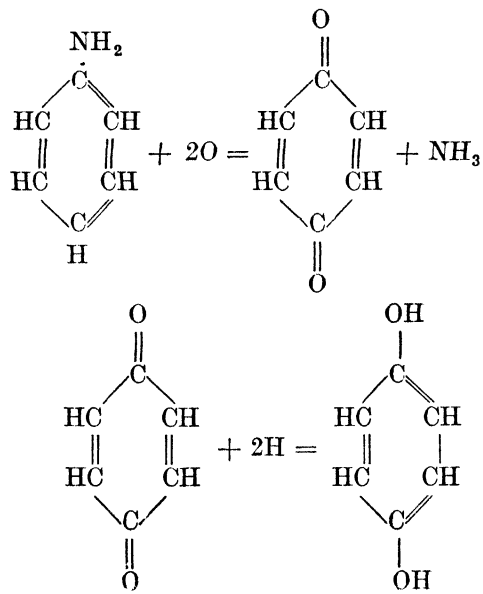
Resorcinol forms white needle-like crystals which are odourless and have a sweetish taste. It melts at 118° C. and boils at 276·5° C. It is exceedingly soluble in water. Resorcinol is poisonous in large doses. It is an antiseptic and has been used considerably in ointments for certain skin diseases.

Resorcinol resembles phenol in forming salts with alkalis It gives a precipitate of tribromoresorcinol with bromine water. Its chief importance is in the formation of the dyes fluorescein and eosin (§§ 491, 492).

Hexylresorcinol, $C_6H_{13}{\cdot}C_6H_3(OH)_2$, has been used as an antiseptic.

358. Quinol, Hydroquinone, $C_6H_4(OH)_2$.—Hydroquinone, *p*-dihydroxybenzene, is made by oxidising aniline, $C_6H_5NH_2$, with potassium dichromate and sulphuric acid.

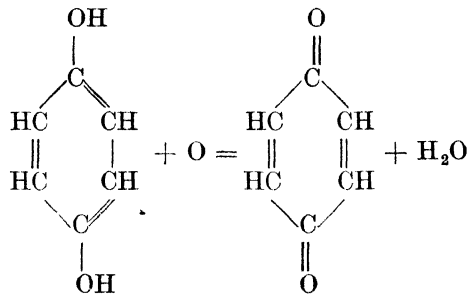
The aniline is oxidised to quinone (and quinhydrone) which are then reduced to hydroquinone by means of sulphur dioxide:



The name hydroquinone is derived from its formation from quinone by reduction.

Hydroquinone forms colourless crystals which melt at 169—170° C. to a liquid boiling at 285° C. It is soluble in water, though less so than the other dihydroxybenzenes.

It is distinguished from these by being a powerful reducing agent. Even mild oxidising agents convert it into quinone (§ 365):

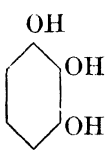


Its use as a developer in photography depends on this property. Other phenols used for this purpose include pyrogallol, $C_6H_3(OH)_3$; metol, rodinal and amidol are aminophenols with the NH_2 and OH in the para- or 1 : 4 position. These aminophenols are, like hydroquinone, readily oxidisable to quinone.

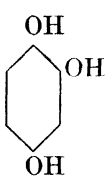
TRIHYDRIC PHENOLS, $C_6H_3(OH)_3$

There are three trihydroxybenzenes:

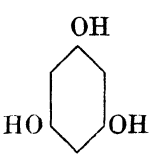
Pyrogallol, 1 : 2 : 3-trihydroxybenzene



Hydroxyquinol, 1 : 2 : 4-trihydroxybenzene



Phloroglucinol, 1 : 3 : 5-trihydroxybenzene



359. Pyrogallol, $C_6H_3(OH)_3$, is made by heating gallic acid

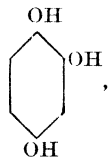
(trihydroxybenzoic acid, § 465) with water at 200–210° C. under pressure:—

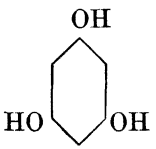
$$C_6H_2(OH)_3{\cdot}CO{\cdot}OH = C_6H_3(OH)_3 + CO_2.$$

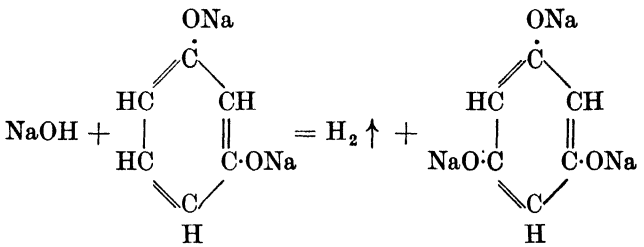
Gallic acid is obtained by hydrolysing tannin, which is a derivative of the former substance (§ 464).

Pyrogallol forms white crystals readily soluble in water. It melts at 132° C. and boils at 210° C. with some decomposition. It has acidic properties like other phenols and forms salts with alkalis. The solution of pyrogallic acid in caustic soda or potash rapidly turns brown in air, absorbing oxygen and being converted into numerous products mostly of a complex character. A little carbon monoxide is evolved, which has to be allowed for where the solution is used in gas analysis. One gram of pyrogallol in alkaline solution will absorb about 190 c.c. of oxygen.

Pyrogallol is a strong reducing agent and can be used as a photographic developer. The brown colour it imparts to the fingers, plates, etc., has led to its being superseded by quinol and the aminophenols.

360. Hydroxyquinol, $C_6H_3(OH)_3$,  , is not of importance. It resembles hydroquinone in its strong reducing powers.

361. Phloroglucinol, $C_6H_3(OH)_3$,  , is of some importance to the biologist. It occurs as glucosides in many plants. It can be made by fusing resorcinol with caustic soda:



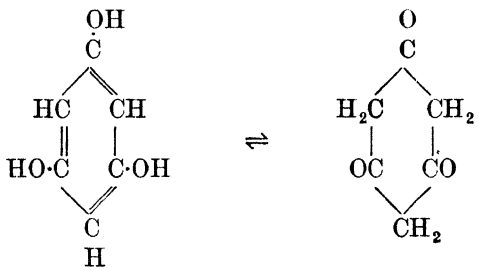
Sodium salt of phloroglucinol.

and acidifying the product.

Phloroglucinol melts at 217–219° C. and sublimes. It is readily soluble in water and other solvents.

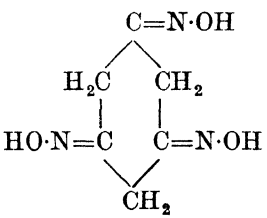
It finds a use in botany, etc., in detecting woody substances. If a pine-shaving or other wood is moistened with hydrochloric acid it gives a violet-red colour with phloroglucinol. The latter can therefore be used to detect lignified cells in micro-sections of plant tissues.

Phloroglucinol is remarkable in behaving as a ketone in many of its reactions. It is supposed to be tautomeric, and to exist in the two forms:



1 : 3 : 5-Trihydroxybenzene. Triketohexamethylene.

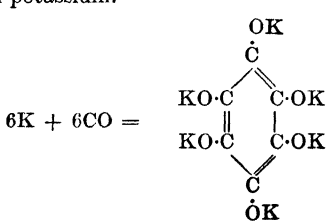
Thus it gives a tri-oxime:



POLYHYDRIC PHENOLS

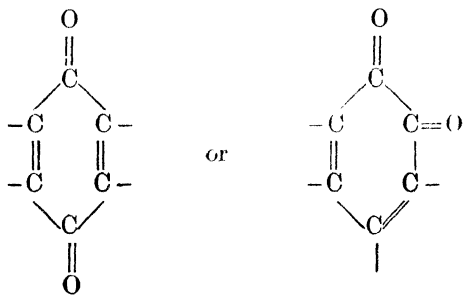
362. Phenols with More than Three Hydroxyl Groups.—The tetra- and penta-hydroxybenzenes are not of practical importance.

Hexahydroxybenzene, $C_6(OH)_6$, is of interest since its potassium salt was obtained as a highly explosive compound in the now obsolete manufacture of potassium by heating potassium carbonate with carbon; and was a source of danger. It was apparently produced by the action of carbon monoxide on the strongly heated potassium.



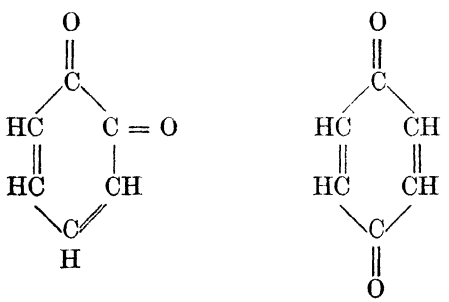
QUINONES

363. The Quinones.—Quinones contain the structure:



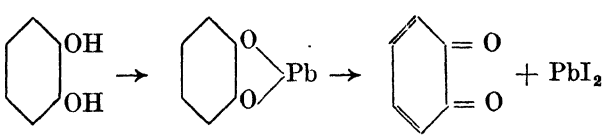
Naphthaquinone and anthraquinone are important substances, but only the benzoquinones will be considered here.

Two benzoquinones exist, namely, ortho- and para-benzoquinone. *p*-Benzoquinone is a much more stable and important substance than *o*-benzoquinone: *m*-quinones cannot exist.



o-Benzoquinone. *p*-Benzoquinone.

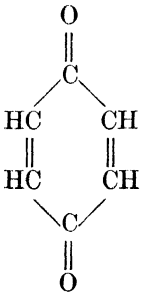
364. *o*-Benzoquinone, which has the formula shown above, is made by the action of iodine on the lead salt of pyrocatechol:



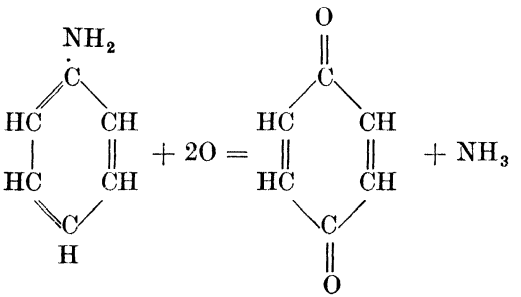
Pyrocatechol. Lead salt. *o*-Benzoquinone.

It exists in two forms, one colourless, the other red. It is a powerful oxidising agent, being readily reduced to pyrocatechol.

365. ***p*-Benzoquinone,**

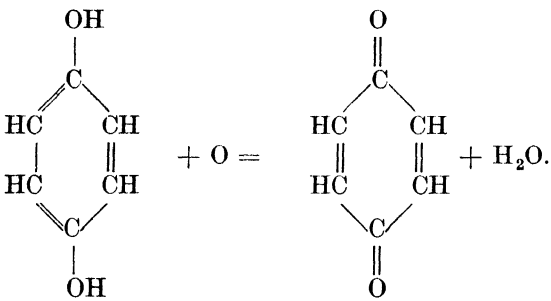


p-Benzoquinone is commonly known simply as 'quinone.' It can be made by oxidising numerous phenols and amines, but is commonly prepared by oxidising aniline with chromic acid, or electrolytically:



On the laboratory scale, 250 c.c. of water may be mixed with 45 c.c. of concentrated sulphuric acid and 10 c.c. of aniline added. The solution is well cooled and a concentrated solution of sodium dichromate slowly added. The resulting solution is shaken with ether, which extracts the quinone. On evaporation of the ether, yellow crystals of *p*-benzoquinone separate.

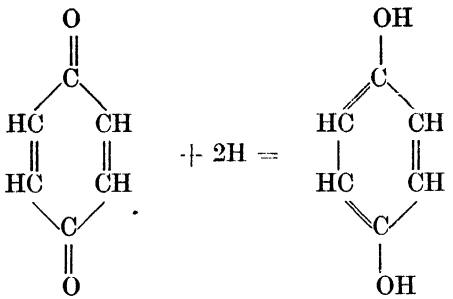
It is also readily prepared by oxidising hydroquinone.



On the commercial scale, benzene itself has been oxidised electrolytically to quinone.

Properties.—*p*-Benzoquinone forms yellow prismatic crystals, which melt at 115·7° C. It is sparingly soluble in cold water.

When heated, it decomposes and forms hydroquinone and quinhydrone (*q.v.*, below). Benzoquinone is readily reduced to hydroquinone, and is therefore an oxidising agent:

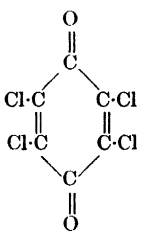


Benzoquinone forms oximes, a fact which is evidence of its containing a $>C=O$ group.

Benzoquinone, it will be noted, has not the alternating single and double linkages which are found in the benzene formula. It is probably in consequence of this that it shows olefinic properties, readily taking up either two or four atoms of bromine. The connection of the quinonoid structure with colour is discussed in §§ 401, 484.

366. Quinhydrone, $C_6H_4O_2 + C_6H_4(OH)_2$, is a loose compound of quinone and hydroquinone. It forms lustrous green prismatic crystals. It is readily oxidised to quinone and reduced to hydroquinone. It finds a use in the determination of oxidation potentials.

367. Tetrachloroquinone, Chloranil,



is made by the action of potassium chlorate and hydrochloric acid on many organic compounds. It forms yellow crystals and acts as an oxidising agent.

QUESTIONS

(1) How many chlorobenzenes are theoretically possible? Write their formulæ and give their distinctive names.

(2) Describe the preparation of bromobenzene. How does it differ from ethyl bromide in its reactions?

(3) When a mono-substitution product of benzene is converted into a di-substitution product, what factors influence the position in the ring assumed by the two groups? What compounds are formed when (*a*) toluene, $C_6H_5 \cdot CH_3$, (*b*) nitrobenzene, (*c*) chlorobenzene, (*d*) benzoic acid, $C_6H_5 \cdot CO \cdot OH$, are converted into their nitro-derivatives?

(4) How would you prepare potassium benzenesulphonate? Into what products could you convert it, and how?

(5) In what respects do the phenols resemble the alcohols?

(6) Describe the commercial preparation of phenol from coal-tar. How can it be made from benzene?

(7) How does phenol react with sulphuric acid, nitric acid, sodium hydroxide, bromine, phosphorus pentachloride?

(8) Which of the higher phenols are strong reducing agents? What is common to their molecular structure?

CHAPTER XXIII

NITROBENZENES AND NITROPHENOLS

NITROBENZENES

THE nitrobenzenes are readily prepared and afford a most convenient source of other benzene compounds. Mononitrobenzene and *m*-dinitrobenzene are the most important: the trinitrobenzenes are difficult to prepare. Higher nitrobenzenes containing four or more nitro-groups have not been prepared, though tetranitroaniline, $C_6H_2(NO_2)_4 \cdot NH_2$, exists.

368. Nitrobenzene, Mononitrobenzene, $C_6H_5 \cdot NO_2$.—Nitrobenzene is always prepared by *nitration* of benzene, *i.e.*, the direct action of a mixture of sulphuric acid and nitric acid on the hydrocarbon:

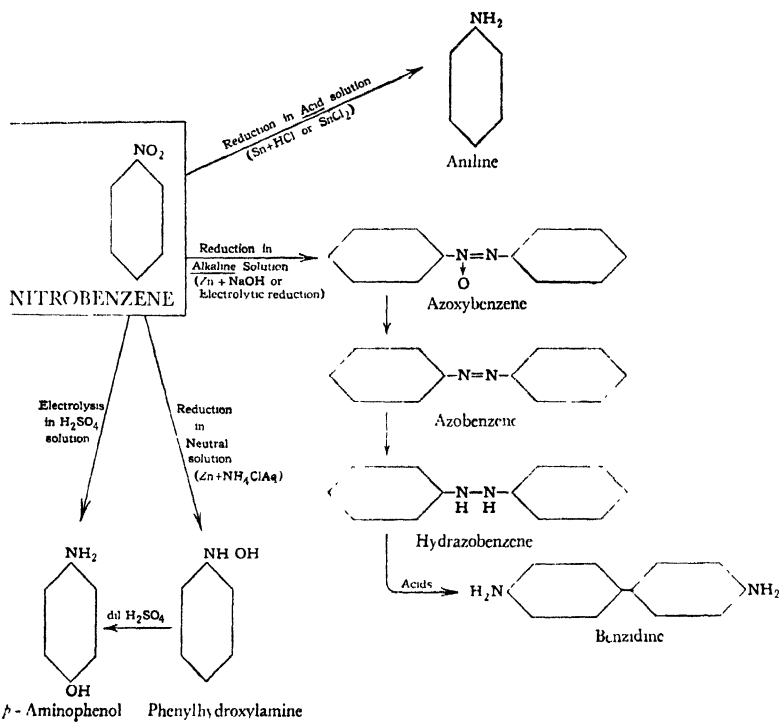
$$C_6H_6 + HNO_3 = C_6H_5 \cdot NO_2 + H_2O.$$

The function of the sulphuric acid appears to be the removal of the water which would otherwise dilute the nitric acid and decrease the speed of the reaction. The laboratory method of preparation is given below; on the large scale a similar process is employed, provision being made for mechanical stirring and for adequate cooling of the mixture by coils of lead pipe through which water circulates.

Expt. 79.—*Preparation of Nitrobenzene.*—In a 250 c.c. flask place 80 c.c. of ordinary concentrated nitric acid (sp. gr. 1·4) and add 120 c.c. of concentrated sulphuric acid, stirring well. Set the flask to cool under the tap. Place 50 c.c. of benzene in a 500 c.c. flask. Add the acid to it 1 or 2 c.c. at a time, *shaking well* between each addition. When the temperature of the mixture reaches 55° C. cool it after each addition so as to ensure that the temperature does not rise above this figure. If the temperature rises too high some dinitrobenzene will be formed. When all the acid has been added, heat the flask on the water-bath for about half an hour, shaking well at intervals. Cool, pour into a separating funnel and run off the lower layer which is the spent acid. Wash the upper layer by shaking it in the separating funnel with water, then with dilute sodium carbonate solution and then again with water. Note that the nitrobenzene is denser than these solutions and will be the *bottom* layer. Run

off the nitrobenzene into a small flask containing a few lumps of calcium chloride and shake gently. When the liquid is no longer at all cloudy pour it off into a distilling flask and distil with an air condenser as in Fig. 30. Collect the fraction distilling between 204° C. and 207° C. Any residue is dinitrobenzene (Yield *ca.* 60 g.).

REDUCTION OF NITROBENZENE



Nitrobenzene can also be made by the action of nitrous acid on benzenediazonium chloride (§ 399) and by oxidation of aniline. The methods are not of practical value.

Physical Properties.—Nitrobenzene is a yellow liquid with a strong odour of oil of bitter almonds. It freezes at 5·8°C. and boils at 208°C. It is heavier than water ($d = 1{\cdot}204$). Nitrobenzene is poisonous, but is frequently employed for perfuming cheap soaps, etc. Its chief use, however, is in the manufacture of aniline.

Chemical Properties.—Nitrobenzene burns readily, but, unlike some of the nitro-compounds containing three nitro-groups in the benzene ring, is not explosive.

It is a comparatively stable substance, not being affected by the action of acids, alkalis, or oxidising agents.

Nitric acid in presence of sulphuric acid converts it into *m*-dinitrobenzene:

$$C_6H_5{\cdot}NO_2 + HNO_3 = C_6H_4(NO_2)_2 + H_2O$$

(*v.* Expt. 81, § 370).

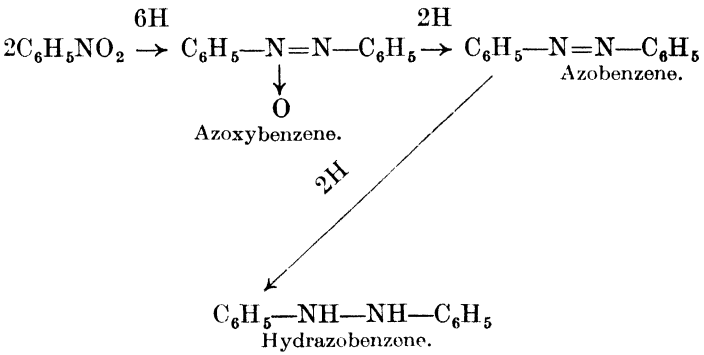
The most important feature of nitrobenzene is the action of reducing agents upon it. A variety of compounds can be produced, their nature depending upon the reducing agent employed.

The action of reducing agents in *acid solution* (*e.g.*, zinc or tin and hydrochloric acid, stannous chloride in presence of hydrochloric acid) is to convert it into aniline. All nitro-compounds can be reduced to amines in this way:

$$C_5H_5{\cdot}NO_2 + 6H = C_6H_5{\cdot}NH_2 + 2H_2O.$$

The practical details are given under aniline (Expt. 85, § 381)

With *alkaline* reducing agents, (*e.g.*, zinc dust and caustic soda), azoxybenzene, azobenzene and hydrazobenzene (§§ 406, 408, 407) are successively produced.



Reduction in *neutral solution* gives phenylhydroxylamine, $C_6H_5{\cdot}NH{\cdot}OH$, while electrolytic reduction (carried out as described in § 229) can give *p*-aminophenol, $HO{\cdot}C_6H_4{\cdot}NH_2$, in presence of sulphuric acid, and other products in acid or alkaline alcoholic solution.

This complex behaviour of nitrobenzene is summed up in the table on p. 366. The reactions of chief importance are the formation of

aniline and to a lesser extent of hydrazobenzene, which is commercially converted into benzidine which is of great value in the dye industry.

Nitrobenzene is employed as an oxidising agent in the manufacture of fuchsine (§ 487) and in Skraup's synthesis of quinoline derivatives (§ 569).

Expt. 80.—*Reactions of Nitrobenzene.*—(1) Note odour and insolubility in water.

(2) Warm a drop with stannous chloride dissolved in concentrated HCl. Note disappearance of droplets of nitrobenzene and formation of crystals of the double compound of aniline hydrochloride and tin chloride. Cool: add excess conc. NaOH. Add the solution containing free aniline to bleaching powder solution. Violet coloration confirms the presence of aniline. The carbylamine test (§ 382) can also be employed to detect the aniline.

(3) Warm a drop with caustic soda solution and add zinc dust gradually, and boil. Note yellow colour due to azoxybenzene and azobenzene. This disappears on further addition of zinc dust, owing to reduction to colourless hydrazobenzene.

369. Dinitrobenzenes.—The action of nitric acid on nitrobenzene yields almost exclusively *m*-dinitrobenzene, in agreement with Hammick's rule (§ 347). The ortho- and para-derivatives are made indirectly.

370. *m*-Dinitrobenzene, $C_6H_4(NO_2)_2$.—*m*-Dinitrobenzene is readily prepared by nitrating benzene with boiling fuming nitric acid, or, better, by nitrating nitrobenzene:

$$C_6H_5{\cdot}NO_2 + HNO_3 = C_6H_4(NO_2)_2 + H_2O.$$

Expt. 81.—*Preparation of* m-*dinitrobenzene.*—Place 40 g. (27 c.c.) of fuming nitric acid[1] (sp. gr. 1·5) in a 500 c.c. flask and gradually add 40 g. (22 c.c.) of concentrated sulphuric acid. To the mixture add 35 g. (30 c.c.) nitrobenzene 5 c.c. at a time. Shake well between each addition. Heat for twenty minutes on the water-bath and pour a few drops of the liquid into cold water. If it solidifies to a hard (not pasty) yellow solid, the reaction is complete. If not, the heating should be continued. Pour the hot contents into 500 c.c. of cold water, stirring well meanwhile. Filter off the solid at the pump, wash it well. The moist dinitrobenzene may be dried in an air-oven at 50–60° C. or may be recrystallised.

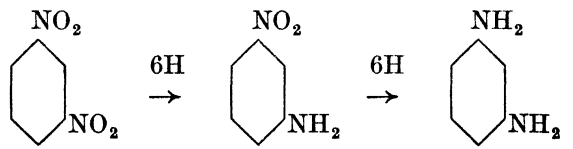
Recrystallisation.—Place the dinitrobenzene, dried as far as possible by pressing on absorbent paper, in a beaker with five times its weight (*ca.* 250 c.c.) of alcohol. Heat on the water-

[1] Considerable care is necessary in handling fuming nitric acid, owing to its very powerful and rapid corrosive action on the skin.

bath, stirring well, till all has dissolved, adding more alcohol if needed. Cool thoroughly. The dinitrobenzene separates as colourless needles which are filtered off at the pump, washed with a little alcohol and dried by pressing on a porous plate or absorbent paper.

m-Dinitrobenzene forms colourless needle-like crystals. It melts at 90° C. and boils at 297° C.

Its chemical properties resemble those of nitrobenzene. Mild reduction, such as the action of ammonium sulphide, easily converts it into *m*-nitroaniline, but the second nitro-group is only reduced with difficulty. Energetic reduction with tin and hydrochloric acid will, however, form *m*-diaminobenzene, usually called meta-phenylenediamine.



m-Dinitrobenzene. *m*-Nitroaniline. *m*-Phenylenediamine.

371. *o*-Dinitrobenzene.—*o*-Dinitrobenzene is made from *o*-nitroaniline (§ 386). It forms colourless plates melting at 117° C. Its general properties are much like those of *m*-dinitrobenzene. It differs, however, in that one nitro-group is easily replaced by $-NH_2$, or $-OH$ on treatment with ammonia or caustic soda.

372. *p*-Dinitrobenzene.— *p*-Dinitrobenzene is made from *p*-nitroaniline (§ 386). It forms colourless needles melting at 172° C. Its properties resemble those of *m*-dinitrobenzene in most respects.

373. *s*-Trinitrobenzene.[1]—Symmetrical or 1 : 3 : 5-trinitrobenzene is made by the prolonged action of fuming nitric and fuming sulphuric acid on dinitrobenzene:

$$C_6H_4(NO_2)_2 + HNO_3 = C_6H_3(NO_2)_3 + H_2O.$$

It is a white substance melting at 122° C. It gives a deep yellow colour with alkalis and so perhaps has some acidic properties (cf. the nitrophenols below). It has been used as an indicator in titrating very weak acids.

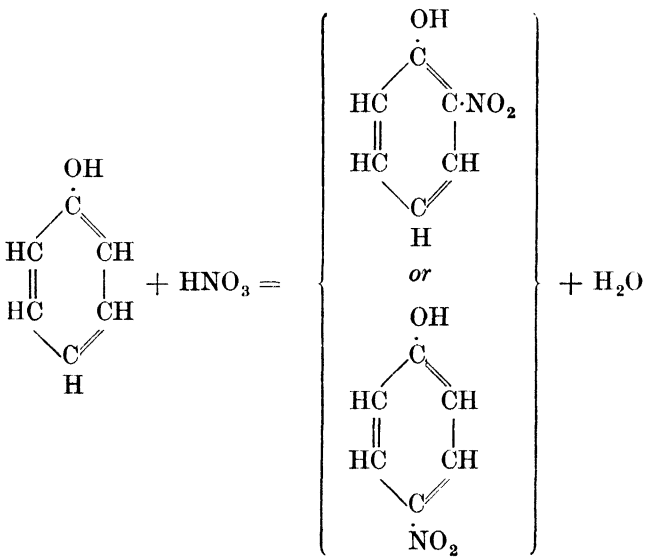
374. Nitro-compounds containing other Groupings.—Most benzene substitution products are more easily nitrated than benzene itself, and so give rise to numerous nitro-compounds. Of these the important nitrophenols will be considered here: the nitroanilines and nitrotoluenes in §§ 386 and 435 respectively.

375. Preparation of the Nitrophenols.—Phenol is acted on by nitric acid with peculiar ease, yielding *o*- and *p*-nitrophenol. *m*-Nitrophenol is obtained from *m*-nitroaniline (§§ 386, 399).

[1] The prefix *s*- indicates that the substituent groups in a compound are symmetrically distributed. Thus, as above, 1 : 3 : 5-trinitrobenzene is distinguished from the 1 : 2 : 3- and 1 : 2 : 4- compounds by this prefix.

o- and *p*-Nitrophenol are both obtained by the action of cold dilute nitric acid on phenol. They are separated by taking advantage of the fact that the ortho-compound is volatile enough to be distilled in steam, while the para-compound remains behind.

The nitration may also be conveniently accomplished by means of a mixture of sodium nitrate and sulphuric acid.



Expt. 82.—*Preparation of* o- *and* p-*Nitrophenol.*—Dissolve 60 g. of sodium nitrate in 150 c.c. of warm water. Cool and add 75 g. (42 c.c.) of concentrated sulphuric acid, stirring well. Cool the mixture to 25° C. and place it in a 500 c.c. beaker, preferably fitted with a mechanical stirrer as in Fig. 36, and standing in a trough containing cold water. Melt 37·5 g. of phenol with 5 c.c. of alcohol and transfer it to a warmed dropping funnel. Allow the melted phenol to drop into the well-stirred acid at such a rate that the temperature does not rise above 25–28° C. Leave the mixture, preferably with continuous mechanical stirring for about 2 hr. The mixture is then poured into ½ litre of water contained in a litre-flask. The aqueous layer is poured off and the dark oily liquid shaken with more water, which is again poured off. The oil is covered with 250 c.c. of water and a steam distillation apparatus is set up (*v.* § 381). A steam-can is fitted with a safety tube and wide delivery tube. This is connected to the flask containing the mixed *o*- and *p*-nitrophenols by a wide delivery tube (5 mm. internal diameter) so bent as to force the steam to the bottom

of the flask. (Fig. 53, p. 380.) The flask is inclined in order to prevent splashing into the condenser and gently heated to prevent too much condensation. The issuing steam is led to a condenser and receiver. The water in the condenser should be allowed to become warm in order to prevent blockage by solid *o*-nitrophenol.

Distillation is continued as long as any nitrophenol comes over. The distillate is then cooled and filtered at the pump and the crystals of pure *o*-nitrophenol are washed and dried on absorbent paper.

The black residue in the flask contains *p*-nitrophenol mixed with some tarry matter. It is repeatedly boiled with numerous portions of water (200 c.c. each). The nitrophenol dissolves, leaving most of the tarry matter behind. The extract is somewhat dark in colour and is boiled with animal charcoal in a large basin for half an hour and then filtered through a large filter, previously moistened. The filtrate is made alkaline with caustic soda, then concentrated to 75 c.c. and if necessary again filtered through a moist filter paper. The solution is well cooled and the crystals of the sodium salt of *p*-nitrophenol are filtered off, redissolved in hot water and acidified with concentrated hydrochloric acid. *p*-Nitrophenol crystallises out. It may be recrystallised from pure water.

Physical Properties.—The three nitrophenols have so many properties in common that they are best discussed together. Their physical properties are given in the table below:—

	Appearance.	M.P.	B.P. and volatility.
o-Nitrophenol .	Pale yellow needles	44° C.	214° C. ⎫ volatile in
m-Nitrophenol .	Thick yellow crystals	96° C.	dec. ⎭ steam.
p-Nitrophenol .	Colourless needles	114° C.	dec. not volatile in steam.

They are all nearly insoluble in cold water.

Chemical Properties.—The nitrophenols react both as nitro-compounds and as phenols. Thus they are easily reduced to amino-phenols (§ 388):

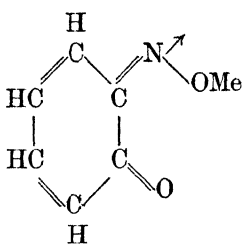
$$HO{\cdot}C_6H_4{\cdot}NO_2 + 6H = HO{\cdot}C_6H_4{\cdot}NH_2 + 2H_2O$$

The latter are much used in the dye-industry and their preparation is the chief industrial use of the nitrophenols. The presence of the nitro-group increases the acidic character of the $-OH$ group and they are much stronger acids than phenol. Thus, unlike the latter, they decompose carbonates.

A most interesting fact is that the nitrophenols, though but faintly coloured, give two series of salts with alkalis—one yellow, the other red. The ortho-compounds form two series of ethers (or esters), $NO_2 \cdot C_6H_4 \cdot OR$ (where R is an alkyl radical), one of which, made by the usual methods, is colourless, while the other, made by the action of the silver salt of the phenol on an alkyl halide, is red and very unstable.

It is supposed that the free nitrophenols have the ordinary formula $C_6H_4\begin{<}{OH}{NO_2}$, and that their colourless esters have the formula $C_6H_4\begin{<}{OR}{NO_2}$. The red esters, on the other hand, are believed to have a quinonoid formula (§§ 363, 401).

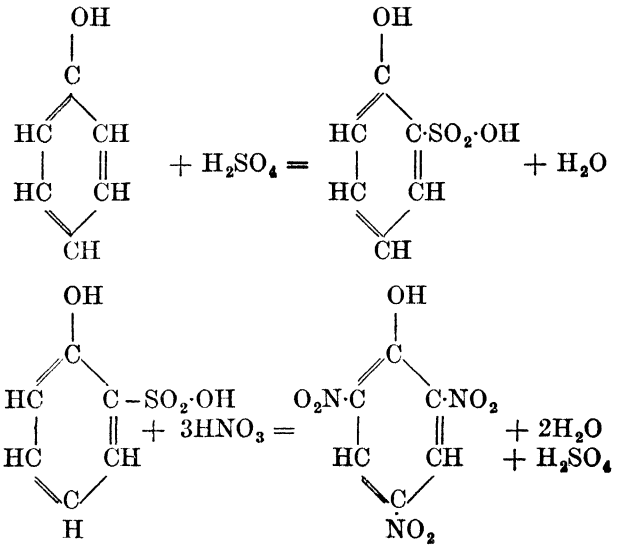
e.g.,



It is only in the solid state that the two series of salts, red and yellow, are known, and it is probable that the difference between them is one of crystal structure only. In solution the salts of the nitrophenols are yellow and the formation of a bright yellow salt from a colourless acid makes it possible to use *p*-nitrophenol as an indicator. The colour change takes place at a *p*H value of 5·0 to 7·0; it is therefore an indicator of a type intermediate between methyl-orange and litmus.

376. Dinitrophenols, $C_6H_3(NO_2)_2OH$.—These are prepared by carefully regulated nitration of phenol. They are not of importance.

377. Picric Acid, Trinitrophenol, $C_6H_2(NO_2)_3OH$.—Picric acid is of importance as an explosive, a dye, and also in analytical work. It is obtained when a great variety of substances, many proteins, indigo, resins, etc., are treated with concentrated nitric acid. It is now always made from phenol. The action of nitric acid on phenol is rather violent, and it is usual to convert it into phenol-sulphonic acid first by treating it with concentrated sulphuric acid.



Manufacture.—Equal weights of phenol and sulphuric acid are heated and stirred till the product is wholly soluble in water, showing that the phenol has been converted into phenolsulphonic acid. Nitric acid is then run into the well-cooled and well-stirred product. On cooling the mixture, picric acid crystallises. It is recrystallised from water and converted into sodium picrate. From this the picric acid is separated by decomposing it with dilute sulphuric acid.

The laboratory preparation is similar.

Expt. 83.—*Preparation of Picric Acid.*—20 G. of phenol and 20 g. of sulphuric acid (conc.) are heated together in a porcelain basin till a drop gives no turbidity when mixed with a little water. The resulting solution of phenolsulphonic acid is diluted with 20 c.c. of water and transferred to a tap funnel. 55 c.c. of conc. nitric acid are placed in a 750 c.c. flask and the phenolsulphonic acid is slowly added with continuous shaking or stirring. The operation should be performed in the fume cupboard, as much nitrogen peroxide is evolved. 20 c.c. of fuming nitric acid are then added and the flask is heated on the water-bath for 2 hr. On cooling, picric acid separates. 150 c.c. of cold water are added and the crystals are filtered off. They are recrystallised by heating them with twenty-five times their weight of water (say 750 c.c.), containing a few drops of sulphuric acid, and allowing the solution to cool.

Picric acid crystallises from water, or solvents containing water, in yellow leaflets.

Pure dry picric acid, prepared by drying the ordinary product or crystallising it from petroleum ether, is colourless, as also is its solution in dry petroleum ether, ordinary ether, etc. The colour of the ordinary acid is probably due to ionisation induced by traces of water:

$$C_6H_2(NO_2)_3OH \rightleftharpoons C_6H_2(NO_2)_3O^- + H^+.$$

Picric acid dissolves in water to a strongly yellow solution which dyes the skin, silk, wool and animal material in general, a beautiful clear light yellow. The colour soon alters to a more orange shade Picric acid is not much used as a dye by itself, but is used as an ingredient in mixed dyes. Solutions of picric acid have an intensely bitter taste. The name picric acid is derived from the Greek πίκρος *pikros*, bitter. It is decidedly poisonous, acting in a manner similar to phenol, and like the latter is a good antiseptic. It has been used in surgery for sterilising the skin previous to operations, and till recently it has been considerably employed in the treatment of superficial burns. It relieves the pain of these by paralysing the nerve-endings, and also preserves the burnt parts from bacterial infection. It has, however, been largely superseded by tannic acid (§ 464).

Picric acid melts at 122·5° C. It sublimes when gently heated, and decomposes below its boiling-point, sometimes with explosion. It is sparingly soluble in cold water (1 : 86 at 15° C.), but somewhat more soluble in hot water (1 : 26 at 79° C.).

Chemical Properties.—When heated, picric acid usually decomposes without explosion, which may, however, occur when it is heated rapidly. When struck with a hammer it can occasionally be detonated. It burns, when ignited, with a bright, smoky flame.

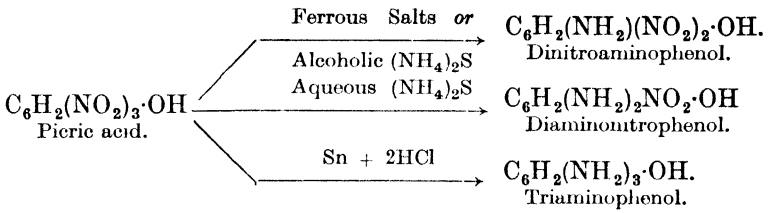
When subjected to the shock of a detonator of mercury fulminate (§ 149) or lead azide, it explodes with great violence. It has been much used as an explosive (lyddite, melinite) but has the disadvantage of forming salts, which are dangerously sensitive explosives. It has been largely replaced by the safer trinitrotoluene.

Picric acid is a much stronger acid than phenol, and forms well-defined salts with the metals. *Sodium picrate* is occasionally used as a reagent for testing for potassium, the nearly insoluble *potassium picrate* being precipitated in minute yellow crystals when solutions of sodium picrate and a potassium salt are mixed. Both the above salts explode rather feebly at about 310° C. The picrates of the

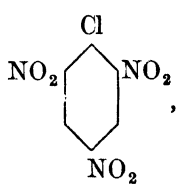
heavy metals (*e.g.*, copper, lead, manganese) explode with great violence when heated. Lead picrate is sensitive to shock or friction as well as to heat. Picric acid should therefore be kept away from lead compounds, vessels of lead, etc.

Picric acid forms esters such as ethyl picrate, $(NO_2)_3C_6H_2 \cdot O \cdot C_2H_5$, which forms almost colourless needles.

Picric acid, like other nitro-compounds, can be reduced. Mild reducing agents reduce only one nitro-group, but stronger ones reduce two or three.



Picric acid has a remarkable power of forming addition compounds with many aromatic hydrocarbons and phenols when the acid and the other component are mixed, usually in alcoholic solution. Thus when concentrated solutions of anthracene, $C_{14}H_{10}$, and picric acid are mixed, ruby-coloured crystals of anthracene picrate separate. The compound is not a true picrate, for it is a molecular compound and not a salt. Benzene, naphthalene, phenol, naphthol, etc., all form 'picrates' of this type, usually as yellow crystals.

Phosphorus pentachloride reacts with trinitrophenol in the same manner as with phenol, substituting chlorine for hydroxyl. The product picryl chloride, 

, is, however, quite unlike phenyl chloride, 

The three negative $-NO_2$ groups evidently make the attachment of the chlorine atom much less firm and the picryl chloride is highly reactive, resembling an acid chloride (§ 85) in its behaviour.

The action of bleaching powder on picric acid breaks up the ring and forms the interesting compound chloropicrin or trichloronitromethane, $CCl_3 \cdot NO_2$. It is a liquid boiling at 112° C. It has

been used in chemical warfare, its vapour being intensely lachrymatory, and in high concentrations lethal.

Picric acid is detected by the formation of the insoluble potassium salt. A much more sensitive test is the formation of *iso*-purpuric acid. To a hot solution of the substance add a few drops of potassium cyanide solution. A deep brown-red colour indicates picric acid. The colour is due to *iso*-purpuric acid, formerly used as a dye-stuff.

Expt. 84.—*Reactions of Picric Acid.*—(1) Dissolve a little in petroleum ether: shake the nearly colourless solution with water: note strongly yellow solution in water.

(2) Dissolve in water, warm with a piece of silk: wash the silk and note that it is dyed.

(3) Dissolve some picric acid in sodium hydroxide solution. Add potassium chloride solution and note slow precipitation of yellow crystalline potassium picrate.

(4) Mix a *small* portion ($\frac{1}{4}$ g.) with an equal amount of red lead and heat on an iron plate, standing well back. The mixture explodes with a deafening report.

(5) Add a solution of potassium cyanide to some picric acid. Note the purple colour produced.

378. Tetra- and Penta-nitrophenols.—Nitrophenols with four or five nitro-groups in the molecule are known, but are not of importance.

QUESTIONS

(1) How would you prepare (*a*) nitrobenzene, (*b*) dinitrobenzene? Would the latter be the *o*-, *m*-, or *p*-dinitrobenzene?

(2) What products can be made by the action of reducing agents on nitrobenzene under various conditions? Why do we regard nitrobenzene as such, and not as phenyl nitrite?

(3) How are *o*- and *p*-nitrophenol made? What is peculiar about their salts and esters?

(4) How is picric acid prepared? What effect have reducing agents upon it?

CHAPTER XXIV

ANILINE AND ITS DERIVATIVES

379. The Aromatic Amines.—The amino-compounds of benzene, notably aniline, $C_6H_5NH_2$, are reactive substances from which can be prepared a great variety of other compounds, many of which are of industrial importance.

The nuclear aromatic amines differ from the aliphatic amines in the following chief particulars:

(1) Aromatic amines are far weaker bases than aliphatic amines.

(2) The action of nitrous acid on aromatic amines gives the important *diazonium* salts, while from aliphatic amines nitrogen, alcohols and water are formed.

THE AROMATIC AMINES

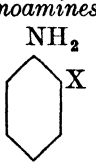
Primary Amines

Monoamines—



Aniline.

Substituted Monoamines—



ortho-

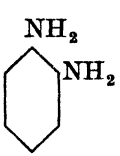


meta-

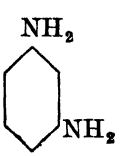


para-

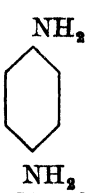
Diamines—



o-Phenylene-diamine.



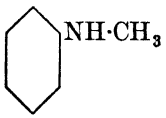
m-Phenylene-diamine.



p-Phenylene-diamine.

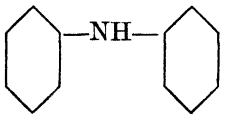
SECONDARY AMINES

Aromatic and Aliphatic—



Aromatic—

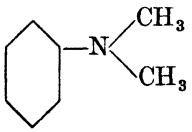
Methylaniline.



Diphenylamine.

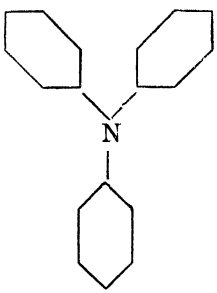
TERTIARY AMINES

Aromatic and Aliphatic—



Dimethylaniline.

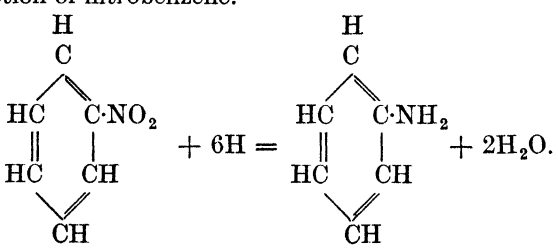
Aromatic—



Triphenylamine.

380. Aniline, Aminobenzene, $C_6H_5NH_2$.—Aniline was originally obtained by the action of heat on indigo. Its name is taken from the specific name of the indigo plant, *Indigofera anil.*

It is made, both in the laboratory and on the commercial scale, by the reduction of nitrobenzene:



On the commercial scale the reducing agent employed is iron and water, some hydrochloric acid being used to start the reaction. The nitrobenzene is introduced into a large iron vessel, provided with a stirrer, a pipe through which steam may be blown in, and a condenser which can either return the distillate to the vessel or direct it into a receiver. Some iron borings, water and hydrochloric acid are added and steam is blown in. When the reaction is under way more nitrobenzene and iron borings are added. The steam causes some of the liquid to distil and the distillate is returned to the reaction vessel as long as any nitrobenzene is left. When only aniline and water distil, the whole of the liquid is distilled over with steam. The aniline separates from the water and forms a lower layer:

$$C_6H_5NO_2 + 2Fe + H_2O = C_6H_5NH_2 + Fe_2O_3.$$

The laboratory preparation employs tin and hydrochloric acid as reducing agent. The aniline is present at the end as a double compound of the hydrochloride, $C_6H_5NH_3Cl$, with tin chloride. This is decomposed by caustic soda and the aniline separated by steam distillation (see Expt. 85 below):

$$2C_6H_5NO_2 + 3Sn + 14HCl = 2C_6H_5NH_3Cl + 3SnCl_4 + 4H_2O,$$
$$C_6H_5NH_3Cl + NaOH = C_6H_5NH_2 + NaCl + H_2O.$$

381. Steam Distillation.—If a mixture of water and a somewhat volatile liquid (partially miscible or immiscible with it) is heated, each will exert its own vapour pressure. The vapour pressure of water is 760 mm. at 100° C.; consequently the combined vapour pressure of the water and liquid reaches 760 mm. at a temperature of a few degrees below 100° C. Thus steam at 100° C. will cause the mixture to boil. When the vapour is condensed, the distillate will be a mixture of pure water and the substance, which often separates as an oil or as crystals.

Steam distillation is of value:—

(1) For distilling a liquid which decomposes below its boiling point.

(2) For separating a liquid with a boiling point higher than water from a large excess of water.

(3) For distilling a mixture which contains much solid and which would therefore bump badly and overheat locally if distilled by direct heat.

Steam distillation can only be used where the vapour pressure of the liquid just below 100° C. is appreciable. Liquids boiling below about 250° C. can, in general, be steam distilled. Liquids boiling below 100° C. are not steam distilled, as ordinary distillation on the water- or oil-bath is satisfactory.

The apparatus employed is shown in Fig. 53. Water is boiled in

a steam-can fitted with a safety tube to prevent excess of pressure or sucking back of the contents of the flask. The flask containing the mixture to be distilled is usually gently heated to prevent undue condensation of steam, but this is not essential. The steam is led into the mixture by means of a bent tube so inclined as to force the steam to the bottom of the flask. The flask is usually inclined so that splashes of liquid are caught on the top and not carried into the condenser. A rather wide delivery tube carries the steam and vapour to the condenser. The condensed liquid may separate into

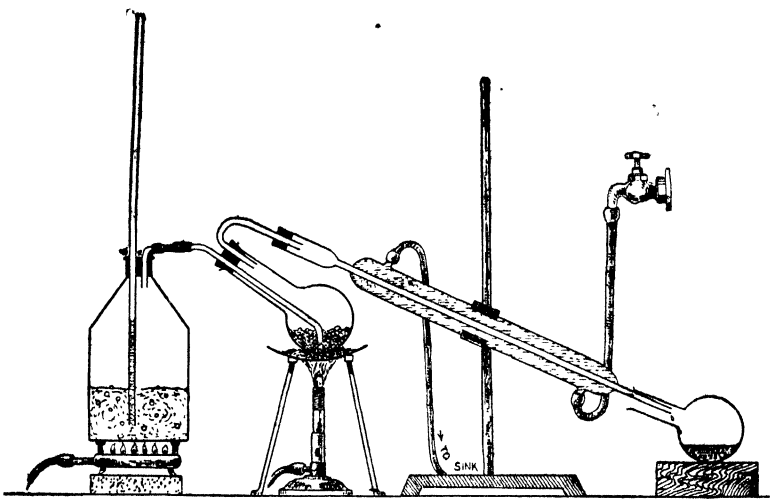


FIG. 53.—Distillation in Steam.

two layers spontaneously or on being saturated with salt. The liquid required may then be drawn off by means of a separating funnel. If the liquid is miscible with water, it is separated from it by extraction with a solvent (*e.g.*, ether), which is then distilled off.

Expt. 85.—*Preparation of Aniline.*—Weigh out 90 g. of granulated tin and place it with 50 g. (40 c.c.) of nitrobenzene in a round-bottomed flask (1,500 c.c.) fitted with a cork and an upright tube, 1·0–1·5 cm. wide, and 20–30 cm. long. Measure out 210 c.c. of concentrated hydrochloric acid. Add 20 c.c. of the acid and shake the contents of the flask. The mixture will become hot and boil. When the reaction has subsided add a second 20 c.c. and repeat the process. In this way add half the acid in portions of 20 c.c. The remaining acid may then be added in portions of 40 c.c. allowing the reaction to subside each time as before. When all the acid has been added, heat for an hour on the water-bath.

Set up a steam-distillation apparatus with cork and tubes to fit the flask used. Add to the contents of the flask first some water (100 c.c.), then, gradually, a solution of 150 g. of sodium hydroxide in 200 c.c. of water. The resulting solution is at once steam distilled until the distillate is no longer turbid. The liquid in the receiver is shaken with a quarter of its weight of salt and then extracted with ether. The ethereal solution of aniline is dried over solid caustic potash. The ether is distilled off on the water-bath and the aniline then distilled over by means of the naked flame, the water having been let out of the condenser. It should boil at 184° C.

382. Properties of Aniline.—*Physical Properties.*—Aniline is a colourless oily liquid, which, on exposure to air and light, soon becomes brownish and resinous. It has a slight characteristic odour. It is highly poisonous. Aniline boils at 184° C. It is slightly heavier than water at room temperature, but lighter than water at 100° C. It therefore floats on hot water but sinks in cold water. It is sparingly soluble in water, dissolving to the extent of about 3 per cent. It is miscible with most organic solvents.

Chemical Properties.—Aniline resembles the aliphatic amines, such as methylamine, $CH_3{\cdot}NH_2$, in many, but by no means all respects. Thus, its solutions are far less basic than those of methylamine. None the less, it forms well-defined salts such as aniline hydrochloride, $C_6H_5NH_3Cl$, and aniline sulphate, $C_6H_5NH_3{\cdot}HSO_4$. It is sufficiently basic to precipitate certain hydroxides, *e.g.*, those of aluminium, zinc, and iron, from their salts. Litmus is slightly affected by it, but is not turned fully blue.

The aniline salts of certain acids are readily converted into *anilides*. Just as ammonium acetate (§ 115) is readily converted into acetamide, so aniline (phenylammonium) acetate is easily converted into acetanilide. If we heat aniline and acetic acid together, acetanilide (§ 384) is readily obtained:

$$C_6H_5NH_2 + HO{\cdot}CO{\cdot}CH_3 = C_6H_5NH_3{\cdot}O{\cdot}CO{\cdot}CH_3$$
$$C_6H_5NH_3{\cdot}O{\cdot}CO{\cdot}CH_3 = C_6H_5{\cdot}NH{\cdot}CO{\cdot}CH_3 + H_2O.$$

Like aliphatic amines, aniline gives the carbylamine and the mustard oil reactions.

If a little aniline is warmed with chloroform and alcoholic potash the repulsive odour of phenyl *iso*cyanide is developed. The experiment is best performed out of doors, as the odour is very persistent and clinging. The smell can be removed from the test tube and contents by addition of concentrated hydrochloric acid which hydrolyses the *iso*cyanide.

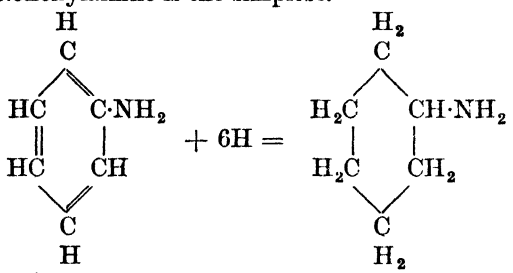
If some aniline is warmed with carbon disulphide in alcoholic solution and an excess of mercuric chloride then added, and the mixture again heated, the characteristic smell of phenyl mustard oil, $C_6H_5{\cdot}NCS$, is developed.

Aniline differs from the aliphatic amines chiefly in its reaction with nitrous acid. The aliphatic amines give an alcohol, water and nitrogen, $CH_3{\cdot}NH_2 + HNO_2 = CH_3OH + H_2O + N_2$. If, however, a well-cooled solution of an aniline salt is mixed with dilute acid and a solution of sodium nitrite is added, liberating nitrous acid, nitrogen is not evolved and a solution of a *benzenediazonium salt* is obtained:

$$C_6H_5NH_3Cl + HNO_2 = C_6H_5 - N_2 - Cl + 2H_2O.$$

This is capable of transformation into numerous other substances and is a most valuable means of preparing various phenyl compounds. The structure and reactions of the diazonium salts are discussed in § 399.

Liquid or dissolved aniline is not reduced by any reagent, but a mixture of hydrogen and the vapour of aniline, when passed over heated nickel at 190° C., is rapidly converted into various products of which *cyclo*hexylamine is the simplest:—

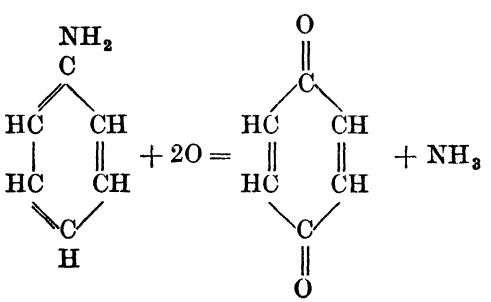


Aniline. *cyclo*Hexylamine.

Aniline gives a variety of products when oxidised. In alkaline solution the reddish azobenzene results:

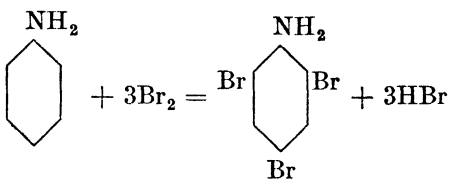
$$2C_6H_5NH_2 + 2O = C_6H_5{\cdot}N{=}N{\cdot}C_6H_5 + 2H_2O$$

Chromic acid oxidises aniline to quinone:



Several other products are obtainable by the use of other oxidising agents. The action of chlorates is important, as these, especially in presence of traces of vanadium salts, oxidise it to *aniline black*. This is produced directly on the cloth or yarn by impregnating it with an aniline salt, a chlorate and a trace of a vanadium salt. The moist material is heated by steam and a very permanent black dye is achieved. The composition of aniline black is not certain.

Chlorine and bromine react very vigorously with aniline. Bromine water instantly precipitates tribromoaniline from solutions of aniline and can be used to titrate it:



Nitric acid below 0° C. gives *o*-, *m*- and *p*-nitroaniline. At higher temperatures other nitroanilines together with tarry matter are produced.

Aniline undergoes many most important reactions which are treated in other portions of this book. Among these are the formation of the azo-dyes (§ 402), triphenylmethane dyes (§ 486), methyl- and dimethyl-aniline (§§ 390, 393), the synthesis of quinoline derivatives (§ 569).

Aniline is easily recognised by the purple coloration it gives with a solution of bleaching powder.

Expt. 86.—*Reactions of Aniline.*—(1) Note (*a*) slight solubility in water, (*b*) solubility in dilute acids forming aniline salts.

(2) Add bromine water to a solution of aniline. Note white precipitate of tribromoaniline (bromide).

(3) To a solution of aniline in water add bleaching powder: note violet coloration.

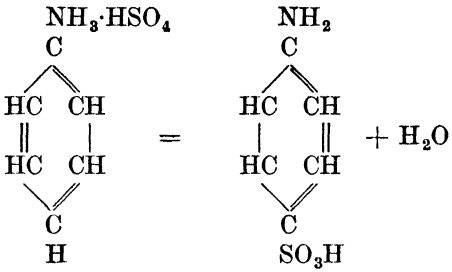
(4) To a solution of aniline in dilute sulphuric acid add a solution of potassium dichromate: note deep green oxidation products.

(5) To a cold solution of aniline in dilute hydrochloric acid add sodium nitrite solution. Heat; nitrogen is evolved and an odour of phenol is produced.

(6) Try the carbylamine and mustard-oil reactions.

383. Salts of Aniline.—*Aniline hydrochloride*, $C_6H_5 \cdot NH_3Cl$, is an article of commerce, being employed under the name of *aniline salt* in making aniline black (*v. supra*). It is easily made by mixing the calculated quantities of hydrochloric acid and aniline and allowing the salt to crystallise. As the salt of a weak base it is considerably hydrolysed in solution.

Aniline sulphate, $C_6H_5{\cdot}NH_3{\cdot}HSO_4$, is made by treating aniline with sulphuric acid. When heated to 200° C. it is transformed into sulphanilic acid or *p*-aminobenzenesulphonic acid, which is much used in the dyestuff industry.



384. Acetanilide, $C_6H_5{\cdot}NH{\cdot}CO{\cdot}CH_3$.—Acetanilide is analogous to acetamide (§ 115) and is similarly made. As acetamide is made by heating ammonium acetate or by treating acetyl chloride or acetic anhydride with ammonia, so acetanilide is made by heating aniline acetate, or by treating acetyl chloride or acetic anhydride with aniline.

Acetanilide is ordinarily prepared by heating glacial acetic acid with aniline:

$$C_6H_5{\cdot}NH_2 + HO{\cdot}OC{\cdot}CH_3 = C_6H_5{\cdot}NH_3{\cdot}O{\cdot}CO{\cdot}CH_3$$
$$C_6H_5NH_3{\cdot}O{\cdot}CO{\cdot}CH_3 = C_6H_5NH{\cdot}CO{\cdot}CH_3 + H_2O$$

Expt. 87.—*Preparation of Acetanilide.*—In a flask fitted with an upright air-condenser (Fig. 54) place a mixture of 20 g. of freshly-distilled aniline and 25 c.c. of glacial acetic acid. Boil gently for about 8 hr. Pour the hot product into 400 c.c. of cold water, stirring well. Filter off the solid acetanilide at the pump and wash well. Recrystallise by heating it with 800 c.c. of water in a large beaker, adding some alcohol if the substance will not dissolve completely. Filter, if necessary, through a hot-water funnel (Fig. 55) and let the product cool. The acetanilide crystallises out.

Acetanilide forms white crystals melting at 115–116° C. and boiling at 305° C. It is sparingly soluble in cold, but readily soluble in hot water. It dissolves in many organic solvents.

It is employed under the name of *antifebrin*, to relieve headache and reduce the temperature in feverish conditions.

Like acetamide, acetanilide is hydrolysed by dilute alkalis and acids, giving aniline and acetic acid or their salts:

$$C_6H_5{\cdot}NH{\cdot}CO{\cdot}CH_3 + H_2O = C_6H_5NH_2 + HO{\cdot}CO{\cdot}CH_3.$$

It can be chlorinated, brominated and nitrated and the resulting

chloro-, bromo- and nitro-acetanilides can be hydrolysed, giving chloroaniline, bromoaniline and nitroaniline. These latter products cannot readily be obtained by the action of the halogens or nitric acid on aniline, for the free base is so reactive that the halogens at once produce trichloroaniline and tribromoaniline, while nitric acid forms a variety of products unless the temperature is kept very low.

Phenacetin, acetylphenetidine, $CH_3 \cdot CO \cdot NH \cdot C_6H_4 \cdot OC_2H_5$, is similar to acetanilide and is used in medicine for lowering the temperature of the body and, in large doses, to relieve pain.

385. Chloro- and Bromo-anilines.—Three chloroanilines and three bromoanilines are known but are not of much importance. They are prepared as indicated in § 384.

386. Nitroanilines.—The nitroanilines are of some importance for the preparation of azo-dyestuff (§ 402).

They are not made by direct nitration of aniline. *o*-Nitroaniline and *p*-nitroaniline are made by nitrating acetanilide and hydrolysing the product. *m*-Nitroacetanilide cannot be made thus (*v.* § 347), but *m*-nitroaniline is readily made by the careful reduction of *m*-dinitrobenzene (§ 370).

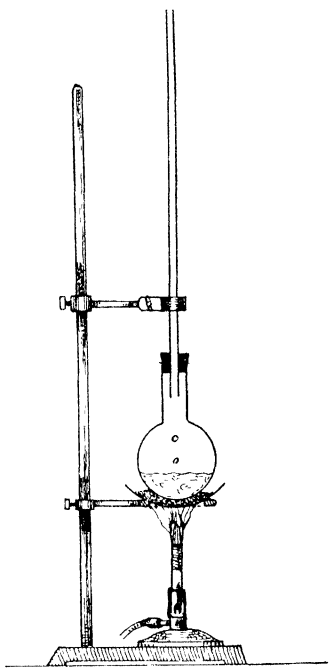


FIG. 54—Preparation of Acetanilide.

Expt. 88.—*Preparation of p-Nitroaniline.*—Have ready some ice in a basin. Set up the apparatus shown in Fig. 36, with the addition of a large jar containing a freezing mixture and surrounding the beaker. In the beaker place 20 g. of acetanilide, 20 g. of glacial acetic acid and 40 c.c. of concentrated sulphuric acid and set the stirrer going. In the tap funnel place 10 c.c. of fuming nitric acid (sp. gr. 1·5). Add the nitric acid drop by drop, keeping the temperature of the mixture below 20° C.

Continue to stir for an hour and then pour the product on to crushed ice contained in a basin. Add water and after half an hour, filter off the solid *p*-nitroacetanilide at the pump.

o-Nitroacetanilide remains dissolved. Wash the solid with water and dry by pressing on a porous plate or paper. The product is heated on the water-bath with three times its weight of concentrated hydrochloric acid until a few drops of the liquid give no turbidity with water. The *p*-nitroaniline hydrochloride is then decomposed by adding an excess of caustic soda. The liquid is cooled and the yellow crystalline *p*-nitroaniline is filtered off. It may be recrystallised from boiling water.

Expt. 89.—*Preparation of m-Nitroaniline.*—20 G. of *m*-dinitrobenzene and 100 c.c. of water are placed in a beaker and heated to 85° C. The mixture is agitated by a mechanical stirrer and 49 g. of hydrated sodium sulphide, dissolved in 40 c.c. water, are dropped in from a tap-funnel over a period of 10 minutes. When a drop of the reaction mixture placed on a piece of filter paper gives a black colour with copper sulphate which persists for 20 seconds the reduction is complete. The mixture is rapidly cooled to 20° C. preferably by addition of ice. Allow to stand for several hours: filter off the *m*-nitroaniline and recrystallise from boiling water.

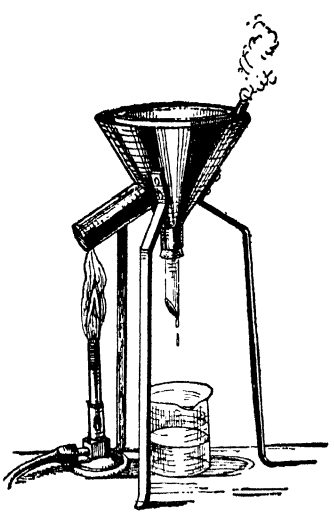


FIG. 55.—Hot Water Funnel.

Properties of the Nitroanilines.—The nitroanilines are yellow solids with physical properties as indicated below:—

	M.P.	Solubility.	
		Cold water.	Hot water.
o-Nitroaniline . .	71·5°	Sparingly soluble (*ca.* 0·1%)	Readily soluble.
m-Nitroaniline . .	114°		
p-Nitroaniline . .	148°		

In their chemical properties they have the functions both of nitro-compounds and of amines.

Thus they are reduced to diamines:

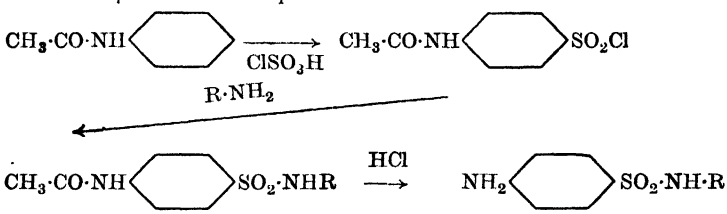
$$H_2N{\cdot}C_6H_4{\cdot}NO_2 + 6H = H_2N{\cdot}C_6H_4{\cdot}NH_2 + 2H_2O$$

Like aniline, they give salts with acids. They form diazonium compounds with nitrous acid, and from these azo-dyes can be prepared.

387. Sulphanilic Acid.—*p*-Aminobenzene sulphonic acid, $H_2N{\cdot}C_6H_4{\cdot}SO_3H$, is made by baking aniline sulphate at 200° C. (§ 383). It gives diazonium salts with nitrous acid, and from these numerous dyes have been prepared.

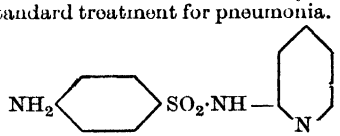
387a. *p*-Aminobenzenesulphonamide $NH_2{\cdot}C_6H_4{\cdot}SO_2{\cdot}NH_2$. — This substance has attained considerable importance as a chemotherapeutic remedy under the title of *sulphanilamide*, and with other drugs of similar constitution has revolutionised the treatment of puerperal fever, meningitis, gonorrhoea, etc.

Sulphanilamide is manufactured by more than one process. In the most usual, acetanilide is treated with chlorsulphonic acid, giving *N*-acetyl-*p*-aminobenzenesulphonchloride. This when treated with ammonia or an amino-compound gives sulphonamide or a derivative thereof.



The radical R may be hydrogen as in sulphanilamide or a great variety of other organic radicles.

It is a white sparingly soluble substance melting at 163° C. The pyridyl derivative, sulphapyridine or M & B 693, is extremely effective against pneumococci and is now the standard treatment for pneumonia.



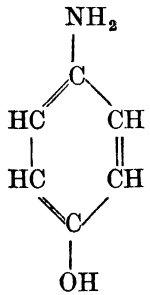
2(p-aminobenzenesulphonamido) pyridine
(M & B 693)

388. The Aminophenols, $HO{\cdot}C_6H_4{\cdot}NH_2$.—The aminophenols cannot be prepared directly from aniline, but are made by reduction of the nitrophenols (§375), etc.

They have the general properties of amines, giving salts with acids, diazo-compounds with nitrous acid, etc. They have also most of the properties of phenols but differ from them in that they are not acidic. The nitrophenols are stronger acids than phenol on account of the presence of the electronegative $-NO_2$ group; the aminophenols, which contain the basic $-NH_2$ group have, on the other hand, no acidic properties at all, and form salts with hydrochloric acid, etc.

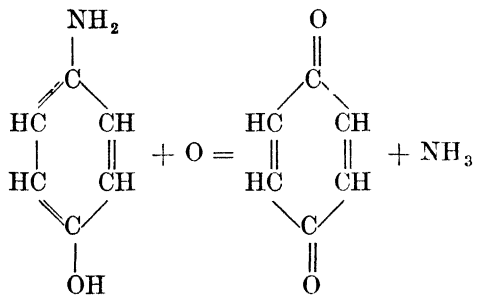
The most important of the aminophenols is *p*-aminophenol.

p-*Aminophenol*,

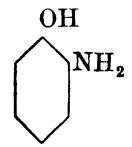


is prepared by reducing *p*-nitrophenol, or better, by reduction of nitrobenzene to phenylhydroxylamine and treatment of this substance with acids (*v.* table p. 366).

It forms colourless crystals melting at 184° C. Besides the general properties of aminophenols, as described above, it has strong reducing powers, being readily oxidised to quinone:



It is used as a photographic developer under the name of *rodinal*. Diaminophenols with the $-OH$ and $-NH_2$ groups in the 1 : 4 position also have reducing power. Amidol, a salt of 2 : 4-diamino-



phenol, , and metol, a salt of *N*-methyl-*p*-aminophenol [1]

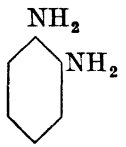


are favourite developers of this type.

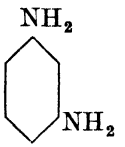
[1] The *N*-signifies that the methyl group is attached to the nitrogen atom, so distinguishing the compound from $CH_3 \cdot O \cdot C_6H_4 \cdot NH_2$ and other isomerides.

THE DIAMINES

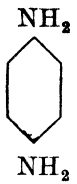
389. The Phenylenediamines.—Three diaminobenzenes are known. They are usually called phenylenediamines, and comprise:



o-Phenylenediamine.



m-Phenylenediamine.

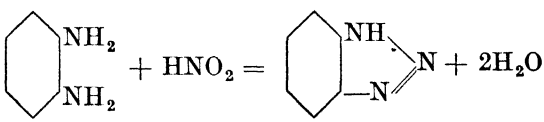


p-Phenylenediamine.

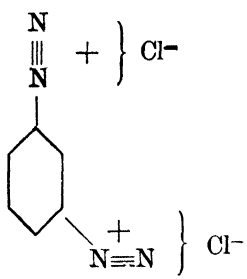
Ortho- and *para*-phenylenediamine are made by reducing *o-* and *p*-nitroaniline (§ 386): *m*-phenylenediamine by reducing *m*-dinitrobenzene (§370).

They are all solids, soluble in hot water. They are colourless when pure, but soon oxidise to brownish compounds.

They have the general properties of primary aromatic amines (as exemplified by aniline, § 382), but differ somewhat from the monoamines in their behaviour with nitrous acid. Aniline forms a diazonium salt, *e.g.*, $C_6H_5—N_2—Cl$ with nitrous acid. *o*-Phenylenediamine, on the other hand, forms azimido-benzene:

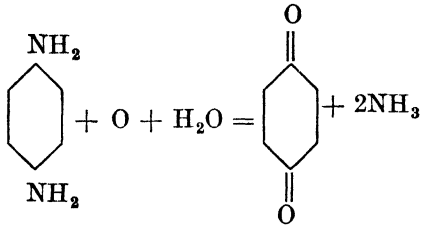


m-Phenylenediamine with nitrous acid gives intensely coloured yellow-brown dyes. It therefore affords a sensitive test for nitrous acid or nitrites. The reaction is a complex one. In presence of much acid it reacts like aniline, giving a bis-diazonium salt.



p-Phenylenediamine also forms a bis-diazonium salt.

p-Phenylenediamine, like *p*-aminophenol and hydroquinone (*p*-dihydroxybenzene), is readily oxidised to quinone:

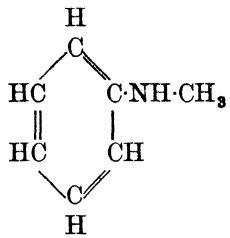


Triamino- and tetramino-benzenes are known but are not of importance.

SECONDARY AROMATIC AMINES

Secondary aromatic amines, containing the group =NH, may contain a phenyl and an alkyl group, or two phenyl groups.

As representatives we may take methylaniline, $C_6H_5{\cdot}NH{\cdot}CH_3$, and diphenylamine, $C_6H_5{\cdot}NH{\cdot}C_6H_5$.

390. Methylaniline,  , can be made by

heating aniline with methyl iodide,

$$C_6H_5{\cdot}NH_2 + ICH_3 = C_6H_5{\cdot}NH{\cdot}CH_3 + HI.$$

On the commercial scale, aniline and methyl alcohol are sometimes heated under pressure, together with some sulphuric acid,

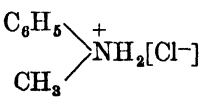
$$C_6H_5NH_2 + HO{\cdot}CH_3 = C_6H_5{\cdot}NH{\cdot}CH_3 + H_2O,$$

but some dimethylaniline (§ 393) is also formed, and is only separated with difficulty from it. The method now in general use is to condense aniline with formaldehyde and reduce the product with zinc and caustic soda:

$$C_6H_5{\cdot}NH_2 + OCH_2 = C_6H_5{\cdot}N = CH_2 + H_2O$$
$$C_6H_5{\cdot}N = CH_2 + 2H = C_6H_5{\cdot}NH{\cdot}CH_3$$

Methylaniline is a colourless liquid which boils at 194° C.

It is a stronger base than aniline, and forms salts such as



It differs from aniline in that it does not give the carbylamine or mustard-oil reactions, and also in its behaviour with nitrous acid, with which, like other secondary amines, it gives a nitrosoamine:

$$\begin{matrix} C_6H_5 \\ CH_3 \end{matrix}\!\!>\!NH + HO{\cdot}NO = \begin{matrix} C_6H_5 \\ CH_3 \end{matrix}\!\!>\!N{-}N = O + H_2O.$$

Primary aromatic amines give diazonium salts in these circumstances. When treated with methyl iodide, it gives dimethylaniline (*q.v.* below).

Methylaniline is much used in the manufacture of dyes.

391. Ethylaniline and other alkylanilines are prepared in an analogous manner and have similar properties.

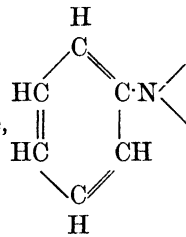
392. Diphenylamine, $(C_6H_5)_2NH$, is made by heating aniline hydrochloride with aniline:

$$C_6H_5{\cdot}NH_3Cl + H_2N{\cdot}C_6H_5 = C_6H_5{\cdot}NH{\cdot}C_6H_5 + NH_4Cl.$$

It is a solid melting at 54° C. and boiling at 302° C. It is a very feeble base. Its nitro-derivative, $C_6H_2(NO_2)_3{-}NH{-}C_6H_2(NO_2)_3$, is acidic in character (cf. § 314). Its ammonium salt is used as an orange dye under the name *aurantia*.

TERTIARY AROMATIC AMINES

The most important of these is dimethylaniline.

393. Dimethylaniline,  .—Dimethylaniline is made by heating excess of methyl alcohol with aniline in presence of sulphuric acid at 230° C. The use of excess of methyl alcohol prevents the formation of much monomethylaniline.

It is one of the most important materials used in the manufacture of dyes (§ 484 ff.).

Dimethylaniline is a colourless liquid which boils at 193° C. It has basic properties and forms salts with acids. Being a tertiary amine, it does not give the carbylamine or mustard-oil reaction.

It differs from a tertiary aliphatic amine, such as trimethylamine (§ 127), in forming a nitroso-compound with nitrous acid. The —N=O group is attached to the benzene nucleus in the para-position, not, as in the nitrosoamines, to the nitrogen atom:

$$ON{\cdot}OH + C_6H_5{\cdot}N(CH_3)_2 \rightarrow O = N{-}C_6H_4{\cdot}N(CH_3)_2 + H_2O.$$

Dimethylaniline reacts very readily with methyl iodide, giving phenyltrimethylammonium iodide, $[C_6H_5 \cdot N(CH_3)_3]I$.

394. Triphenylamine, $(C_6H_5)_3N$, has no basic properties, the three somewhat electronegative phenyl groups neutralising the basic effect of the $\equiv N$ group.

QUATERNARY AMMONIUM SALTS

These strongly resemble the quaternary ammonium salts of the aliphatic series (§ 128). Phenyltrimethylammonium iodide, mentioned above, is an example of one of these. By treating this with moist silver oxide, phenyltrimethylammonium hydroxide is formed, which is a strong base.

Both salts and bases break up when heated, giving a tertiary amine and an alkyl compound:

$$[C_6H_5 \cdot N(CH_3)_3]I = C_6H_5 \cdot N(CH_3)_2 + CH_3I$$

$$C_6H_5 \cdot N(CH_3)_3OH = C_6H_5 \cdot N(CH_3)_2 + CH_3OH.$$

QUESTIONS

(1) What are the chief differences between aromatic and aliphatic amines? Illustrate your answer by comparing aniline and methylamine.

(2) What are primary, secondary and tertiary amines? To which of these classes belong aniline, *m*-phenylenediamine, dimethylaniline, diphenylamine, monomethylaniline, *m*-nitroaniline?

(3) Describe the laboratory preparation of aniline, starting from benzene.

(4) How is the process of steam-distillation carried out, and for what types of separation is it suitable?

(5) What is an anilide? Describe the preparation of acetanilide. How can it be converted into one of the nitroanilines?

(6) Discuss the reaction of nitrous acid with the various classes of aliphatic and aromatic amines.

CHAPTER XXV

DIAZO-COMPOUNDS AND OTHER AROMATIC NITROGEN COMPOUNDS

WHEN a well-cooled solution of a salt of aniline or other primary aromatic amine is treated with nitrous acid, no gas is evolved.

From the resulting solution unstable salts of the formula $C_6H_5—N_2—\bar{A}$, where $\bar{A}$ is an acid radical, can be isolated. These are called benzenediazonium salts. The constitution of the $-N_2-$ group is discussed in § 398.

They undergo a most remarkable series of transformations, and are of the greatest use both in the laboratory and on the commercial scale.

395. Preparation of Diazonium Salts.—As an example we may take the preparation of a solution of benzenediazonium chloride from aniline.

The aniline is dissolved in an excess of hydrochloric acid (at least 3 mols.), and the resulting solution of aniline hydrochloride cooled to near 0° C. A cold, concentrated solution of sodium nitrite is then slowly added until a very slight excess of nitrous acid is present, the temperature being kept below 5° C.

$$C_6H_5—NH_3Cl + HO·NO = C_6H_5—N_2—Cl + 2H_2O$$

The benzenediazonium chloride remains in solution.

Expt. 90.—*To Prepare a Solution of Benzenediazonium Chloride.*—This experiment should be performed when the student can follow it up immediately by Expts.—92–94 or 96. The solution will not keep for even an hour or so at room temperature. 8 G. of aniline are dissolved in a mixture of 40 c.c. of hydrochloric acid and 100 c.c. water. The solution, contained in a beaker, is cooled in a freezing mixture to 0°—5° C. Meanwhile 8 g. of sodium nitrite are dissolved in 50 c.c. of cold water and added, a little at a time, with good stirring to the mixture, the temperature of which must not rise above 5° C. About 1 minute after each addition of sodium nitrite a drop of the solution is taken out and spotted on to starch-iodide paper. When a slight excess of nitrous acid is indicated by this being turned blue, the diazotisation is complete. The solution should be kept cold till required (*v.* Expts. 92, 93, 94, 96).

The benzenediazonium salts are very soluble in water, but not very soluble in alcohol or ether. The solid salts are made by a modification of the above process, amyl nitrite being used in place of sodium nitrite and alcohol being used as solvent:

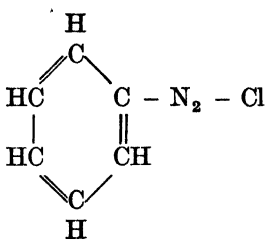
$$(C_6H_5NH_3)_2SO_4 + 2ON\cdot O\cdot C_5H_{11} = (C_6H_5{-}N_2)_2SO_4 + 2C_5H_{11}OH + 2H_2O$$

Expt. 91.—*Preparation of Benzenediazonium Sulphate.*—To 15 g. of aniline in a beaker add 140 c.c. of absolute alcohol and then add 16 c.c. of concentrated sulphuric acid, stirring vigorously till the aniline sulphate has redissolved. Cool to 30° C. and add from a tap-funnel 20 c.c. of amyl nitrite, stirring steadily and not allowing the temperature to exceed 35° C. Cool the beaker by surrounding it with crushed ice. Crystals of benzenediazonium sulphate separate and are filtered off at the pump and washed with a little alcohol. It should be nearly, but not quite dried by pressing on filter-paper, and *at once* used for Expts. 92, 93, 94, 96. Any residue left over should be washed down the sink.

396. Benzenediazonium Chloride, $C_6H_5{-}N_2{-}Cl$, and **Nitrate,** $C_6H_5{-}N_2{-}NO_3$, can be precipitated from their solutions, prepared by the method of Expt. 90, by addition of alcohol and ether. The chloride and nitrate are more unstable than the sulphate. All the benzenediazonium salts are explosive when dry.

397. Benzenediazonium Hydroxide, $C_6H_5{-}N_2{-}OH$, is obtained by the action of moist silver oxide on a solution of benzenediazonium chloride. Its solutions are strongly alkaline. It is very unstable and cannot be isolated in the solid state.

398. Constitution of the Diazonium Compounds.—The empirical formula, $C_6H_5N_2Cl$, and the numerous reactions in which free nitrogen is evolved show that benzene diazonium chloride has the structural formula,



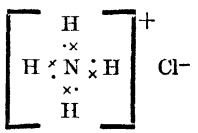
The constitution of the $-N_2-$ group has given rise to much discussion.

The chief alternatives are the Kekulé formula, $C_6H_5—N{=}N—Cl$, and the Blomstrand formula, $C_6H_5—\underset{\underset{N}{\|}}{N}—Cl$. The first formula explains their reduction to hydrazines,

$$C_6H_5—N = N—Cl + 3H \rightarrow C_6H_5—NH—NH_2,$$

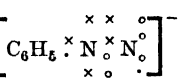
and their formation of azo-dyes, which certainly contain the $-N=N-$ group. The objection to it is that in other salts where the acid radical is attached to nitrogen (ammonium salts, salts of amines, hydrazines, etc.) the nitrogen atom is apparently quinquevalent. Apart from their instability the diazonium salts show a decided resemblance to the ammonium salts, and so presumably have an analogous structure.

The nitrogen atom in the ammonium salts and in all the cases mentioned above has four electronic valencies (§ 19), and the group NR_4 as a whole has a single positive charge and therefore one ionic valency. Ammonium chloride may be represented as

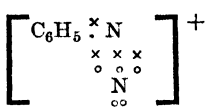


where dots represent electrons derived from the hydrogen atom, crosses those derived from the nitrogen atom. The fact that four hydrogen atoms have four valency electrons and a nitrogen atom five, while the group, as shown above, has only eight, explains its positive charge.

The group $C_6H_5-N=N-$ could not form a positive ion, but if it formed an ion would give a negative one,

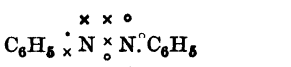


one *additional* electron (·) being taken into the group. The group $C_6H_5-\underset{\underset{N}{\|}}{N}-$ would, however, give a positive ion.



It will be noted that one electron from the five (×) originally present in the upper nitrogen atom, has disappeared, thus accounting for the positive charge. The above considerations are strong evidence for the Blomstrand formula.

The azo-compounds, which are not ionised, evidently have the $-N=N-$ structure. Thus azobenzene is $C_6H_5-N=N-C_6H_5$, or



and a formula, $C_6H_5-N-C_6H_5$ (with a triple bond between the two N atoms), would not correspond to any possible electronic structure.

It should be noted that the linkage between the chlorine and nitrogen atoms in the diazonium salts is electrovalent, while the remaining linkages are covalent. This distinction has not been made in writing the formulæ on pp. 394 ff.

The Blomstrand formula, $C_6H_5—N—Cl$ (with a triple bond between the two N atoms), explains the trans-

formations of the diazonium compounds satisfactorily, while representing the group to which the acid radical is attached as having a similar structure to the ammonium group.

399. Chemical Properties of the Benzenediazonium Salts.—Solutions of benzenediazonium salts at temperatures (near 0° C.) at which they are stable, closely resemble those of the ammonium salts. Thus they form sparingly soluble platinichlorides [*e.g.*, $(C_6H_5—N_2)_2PtCl_6$, cf. $(NH_4)_2\ PtCl_6$] and aurichlorides, give the free base with moist silver oxide; etc.

Their characteristic reaction is the loss of nitrogen and the simultaneous entry of a substituent univalent group into the benzene nucleus.

Thus, when heated with water, benzenediazonium chloride gives phenol and hydrochloric acid, nitrogen being copiously evolved:

$$C_6H_5—N—Cl + H\cdot OH = C_6H_5—OH + N_2 + HCl$$

(N—N triple bond)

When it is boiled with alcohol, the latter is oxidised to aldehyde while the diazonium salt is reduced to the hydrocarbon:—

$$C_6H_5—N—Cl + C_2H_6O = C_6H_6 + N_2 + HCl + C_2H_4O.$$

(N—N triple bond)

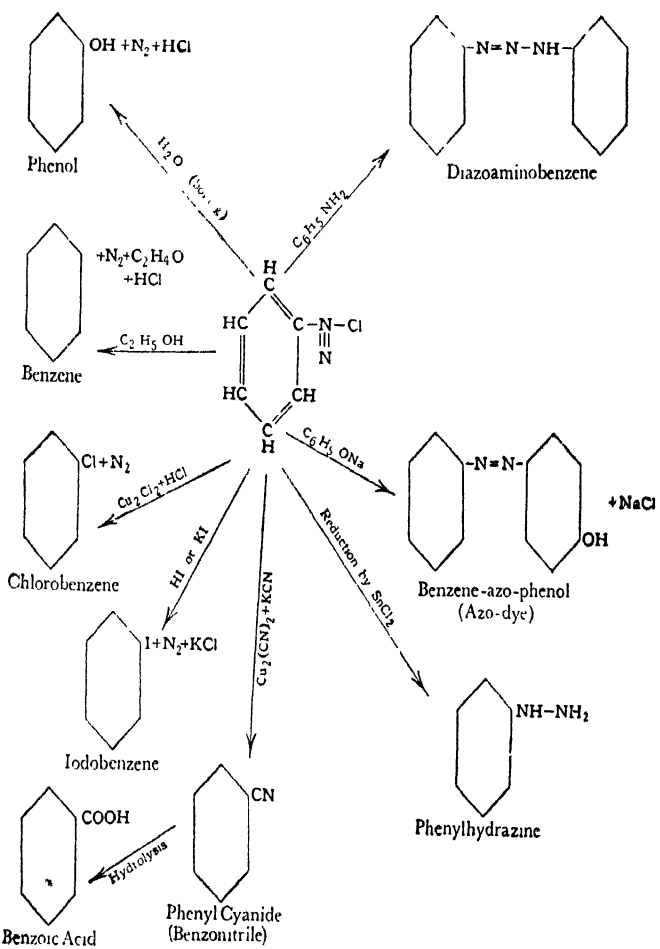
The *Sandmeyer* reaction consists of treating the diazonium salt with a cuprous compound. In this way the diazonium group may be replaced by chlorine, bromine, or the cyanide radical.

Thus, if benzenediazonium chloride is warmed with a concentrated solution of cuprous chloride in hydrochloric acid, chlorobenzene is formed and nitrogen is evolved:

$$C_6H_5{-}\underset{\underset{N}{\|}}{N}{-}Cl = C_6H_5Cl + N_2$$

Bromobenzene can be prepared by a similar reaction. Iodobenzene

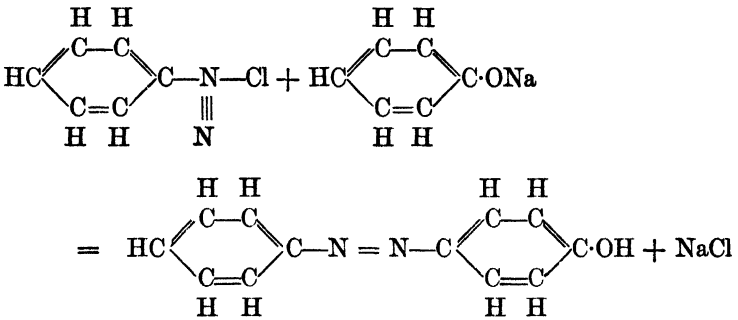
REACTIONS OF A DIAZONIUM SALT



can be made simply by treating the diazonium salt with hydriodic acid or potassium iodide:

$$C_6H_5—N—Cl + KI = C_6H_5I + N_2 + KCl.$$
$$\quad\quad\quad

of the diazonium compounds is their reaction with the phenols. If, for example, benzenediazonium chloride solution is added to a solution of phenol in alkali, the *azo-dye*, benzeneazophenol, is produced:



Since any primary aromatic amine or substitution product of a primary amine may replace aniline, and any aromatic hydroxy-compound may replace phenol, an enormous number of azo-dyes may be prepared (§ 402).

Expt. 92.—*Reactions of Solutions of Diazonium Salts.*—(1) Add an excess of ethyl alcohol and warm. Nitrogen is evolved. Dilute the solution with water, benzene floats to the surface (some phenetole is also formed).

(2) To a portion add an excess of potassium iodide solution. Nitrogen is evolved and iodobenzene separates out.

(3) Warm a portion of the solution. A dark oil (which is phenol containing some water) separates and is easily recognised by its smell.

(4) To a portion add a solution of phenol in caustic soda. A brilliant orange precipitate of benzene-azophenol is produced (cf. Expt. 93).

(5) Add a few drops of aniline. On shaking, diazoaminobenzene (§ 405) separates as a yellow ppt.

THE AZO-DYES

400. Dyes.—A dye is a substance capable of imparting to a textile fibre a coloration which is not removed by washing with water.

Many coloured substances, *e.g.*, a solution of copper sulphate, are not dyes and if a piece of fabric is coloured by such a substance, washing with water will wholly remove the colour. A piece of silk coloured by a dye, say, picric acid or fuchsine (§486), may be soaked in running water for an unlimited period without removing the colouring substance.

We can then distinguish

(1) Colourless organic substances,

(2) Coloured organic substances which are not dyes,

(3) Dyes.

401. Colour and Structure.—The great majority of organic substances are colourless. The possession of colour is associated with the presence of certain groups.

In the first place all dyes[1] are cyclic compounds. They do not necessarily contain a benzene nucleus, for many contain heterocyclic rings in which one of the members is a nitrogen, oxygen, or sulphur atom.

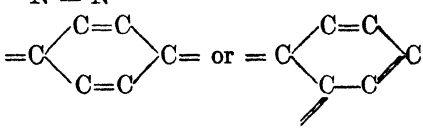
Benzene itself is colourless in the sense of having no absorption bands in the visible region of the spectrum. It is, however, 'invisibly coloured' and has seven absorption bands in the ultra-violet region of the spectrum. It is thought that certain groups, 'chromophores,' shift these bands to the region of the visible spectrum.

The groups which, when present in or attached to a benzene ring, induce colour are numerous.

The most important chromophores are the following:

Nitro-group —NO_2

Azo-group —N = N—

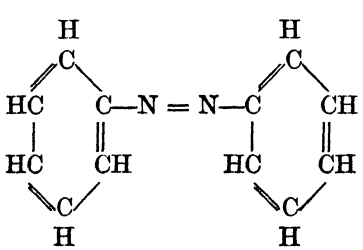
Quinonoid structure 

Carbonyl group —CO—

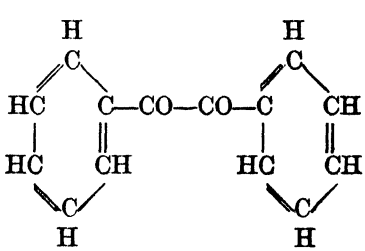
Nitroso-group —N = O

Ethylenic linkages —C = C—

The presence of these groups or structures in a benzene or other cyclic compound may give a coloured substance. The quinonoid structure and the azo-group are most effective, the nitro-group less so, while the carbonyl groups and unsaturated linkages must be repeated several times in the molecule to bring about colour. As examples of coloured substances which are not dyes we may take:

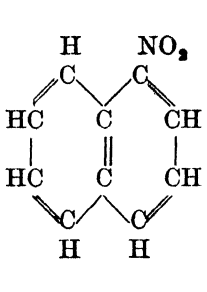


Azobenzene; *orange red.*

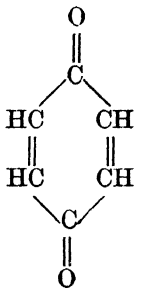


Benzil; *yellow.*

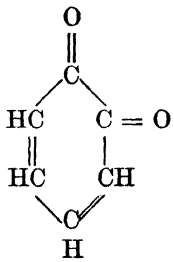
[1] But not all coloured organic compounds.



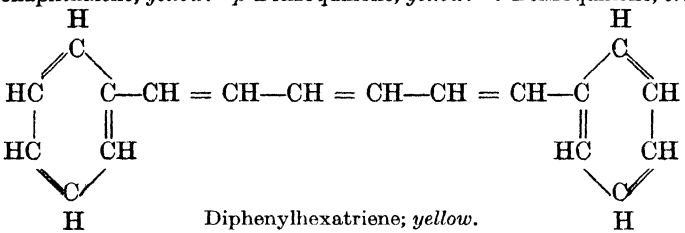
Nitronaphthalene; *yellow*.



p-Benzoquinone; *yellow*.

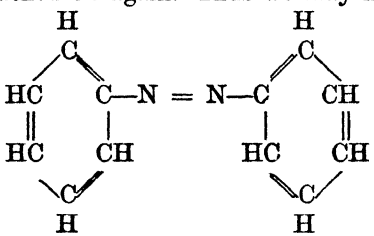


o-Benzoquinone; *orange*.

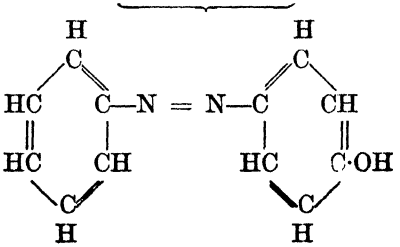


Diphenylhexatriene; *yellow*.

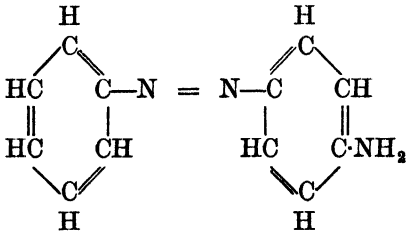
If in addition the groups —NH_2 or —OH, which have been called ***auxochromes***, are present the colour is much intensified, though these groups will not give colour by themselves. The compounds containing a *chromophore* and an *auxochrome* are also usually dyestuffs, that is, they can be attached to textile fibres in such a way that they cannot be washed off again. Thus we may have:



Azobenzene; orange, but not a dye.
Chromophore only



Benzeneazophenol (§ 399); *yellow* DYE.
Chromophore + auxochrome.



Aminoazobenzene : yellow DYE.
Chromophore + auxochrome.

The question of the relation between the colour and structure of an organic compound is one which has been argued very fully and is still a matter of dispute. The influence of auxochromes and chromophores as set out above is, however, soundly established.

The actual colour produced by a given structure cannot yet be predicted. The simplest coloured compounds are as a rule yellow or orange. Blue and green compounds are usually of high molecular weight.

402. The Preparation of Azo-dyes.—The actual preparation of an azo-dyestuff is very simple. An aromatic compound containing an amino-group is diazotised by a modification of the method described in Expt. 90.

$$R{-}NH_3Cl + HNO_2 = R{-}\overset{\overset{\|}{N}}{N}{-}Cl + 2H_2O.$$

The diazonium salt is mixed with a solution of a phenol in alkali and the azo-dye is at once produced:

$$R{-}\overset{\overset{\|}{N}}{N}{-}Cl + NaO{\cdot}R'(H) = R{-}N{=}N{-}R'{\cdot}OH + NaCl.$$

The azo-dye is often precipitated and has only to be filtered off. If it is not precipitated, it may be salted out.

Expt. 93.—*Preparation of Resorcin Yellow and Dyeing of Silk.*—This dye is known as 'Sudan G.' Prepare a solution of benzenediazonium chloride as described in Expt. 90. Dissolve resorcinol (4 g. for every 3 g. of aniline diazotised) in water and add a third of its weight of caustic soda and about as much sodium carbonate. When dissolved, cool to 10—15° C. and add gradually with good stirring to the diazo-solution. If the dye-stuff is not wholly precipitated, saturate the solution with salt. Filter off the dye-stuff at the pump, wash with a little water and dry.

Boil about 0·5 g. of the dye with 250 c.c. of water and a few drops of acetic acid. Filter off any undissolved dye through wet filter-paper, let the temperature fall to 60° C., and drop in a few square centimetres of silk. After a few minutes remove and wash well. It will be dyed a fine yellow colour.

403. Dyeing.—Dyes are applied to materials in several different ways. They are applied as:

(1) Direct dyes.
(2) Mordant dyes.
(3) Ingrain dyes.
(4) Vat dyes.

Protein fibres, *e.g.*, wool and silk, are much more readily dyed than are cellulose fibres, cotton, linen, etc.

(1) *Direct Dyeing.*—The majority of dye-stuffs will dye wool and silk permanently when the latter are merely heated with a solution of the dye-stuff. The addition of salt or dilute acid may improve the process, but is not necessary to it.

Cotton, linen, etc., are not dyed when merely boiled with most dyestuffs, and the colour imparted is merely temporary. Mordant, ingrain or vat dyeing is largely adopted for these materials. A class of dyes which are capable of directly dyeing cotton and linen and artificial silk have recently come to the fore. These are the sulphide dyes. They contain heterocyclic rings composed of carbon and sulphur atoms. They give greens, blues, browns and blacks, but no good orange or red shades.

A dyestuff which will dye fabrics directly is often called a *substantive* dye, as distinguished from the *adjective* dyes attached by mordanting.

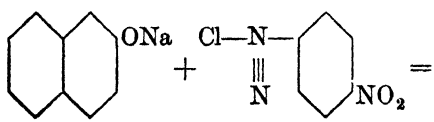
(2) *Mordant Dyeing.*—Numerous dyes form insoluble compounds with various metallic salts. These are used for dyeing cotton and linen, and to a smaller extent for wool. The process as applied to cotton may be as follows: The material is impregnated with a solution of a metallic salt, usually the acetate, and this is hydrolysed by the action of steam. The material is thus impregnated with the hydroxide of the metal. It is then dyed. The metallic compound is permanently attached to the fibre and the dye attaches itself to the metallic compound in an insoluble form. The chief mordants employed are aluminium, iron, chromium, and tin compounds. Different mordants often give different colours with the same dye. Acidic dyes are best mordanted with metallic compounds, but basic dyes are mordanted on cotton by the use of tannic acid, which acts in the same manner as the metallic mordants.

The most important mordant dyes are those of the alizarin series (§ 542).

(3) *Ingrain dyeing* is confined to aniline black (already mentioned, § 382), and to the insoluble azo-dyes.

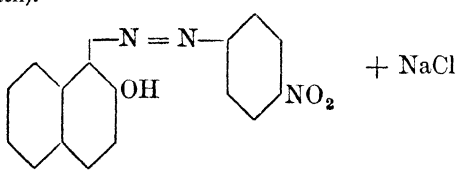
Many of the most brilliant azo-colours are insoluble in water, and so cannot be dyed by methods (1) and (2) above. The process employed for these is to moisten (or *pad*) the material with an alkaline solution of a phenol and then immerse it in a solution of a diazonium salt. The dye is produced within the fibre itself, and is not to be removed by any amount of washing.

The chief dye of this type is *paranitraniline red*, which is the usual red dye applied to cotton. The cotton is damped with an alkaline solution of β-naphthol and passed into a solution of paranitrobenzenediazonium chloride, obtained by diazotising (Expt. 90) paranitroaniline:



Sodium salt of β-naphthol (on cloth).

Paranitrobenzenediazonium chloride (in bath).



Naphtholazonitrobenzene (Paranitraniline red).

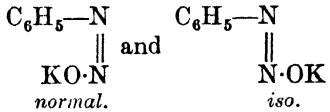
Numerous other colours may be obtained if other phenols and amines are employed.

Expt. 94.—*Ingrain Dyeing.*—Soak a piece of cloth in a strong solution of β-naphthol in caustic soda. Dry the cloth first with blotting paper, then on a warm radiator. Dip it into a solution of benzenediazonium chloride as prepared in Expt. 90. It is instantly dyed orange.

(4) *Vat Dyes.*—Vat dyes are insoluble coloured compounds which are brought into solution by some chemical reagent, usually an alkaline reducing agent. The fibre is 'dyed' with this solution (which may be colourless) and the colouring matter in the fibre regenerated by oxidation. The process is discussed under indigo (§ 565). Indigo is the most important vat dye, but many others have been synthesised. They are, as a rule, very permanent.

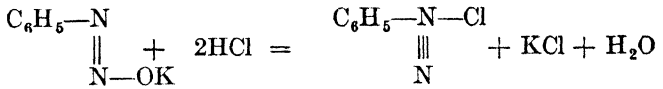
404. The Diazotates.—When a solution of a benzenediazonium salt is treated with excess of caustic potash a salt is precipitated with the formula $C_6H_5—N_2—OK$. This is called potassium benzenediazotate or potassium diazobenzene oxide. By heating this with

caustic soda to 130°—135° C. it is converted into potassium *iso*-diazobenzene oxide, of the same formula. These compounds are probably stereoisomerides with the formulæ[1]



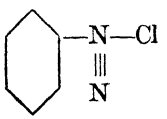
They differ in stability, the *iso*-compounds being much more stable.

When acidified, they regenerate benzenediazonium salts. Since they are much more stable than these it has proved possible to manufacture the *iso*-diazotates commercially for use in dye-works. The diazonium salts are too unstable to be stored, but the *iso*-diazotates keep well and have only to be acidified to yield the diazonium salts:

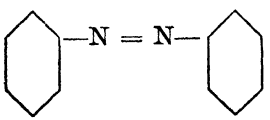


AZO- AND RELATED COMPOUNDS

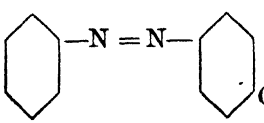
Diazonium Salt



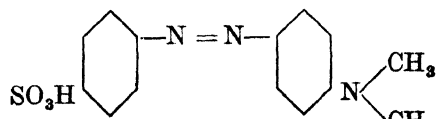
Azo-Compounds



Azobenzene.



Benzeneazophenol.

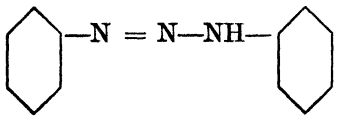


p-Sulphobenzeneazodimethylaniline (methyl orange).

Azo-dyes.

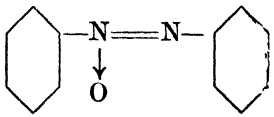
[1] There has been controversy about these formulæ. It appears that the *iso*-diazotates can also react as if they were salts of phenyl nitrosoamine and had the formula $C_6H_5 \cdot NK—N=O$. They are probably tautomeric.

Diazoamino-Compound



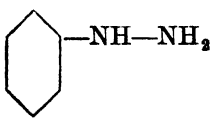
Diazoaminobenzene.

Azoxy-Compound



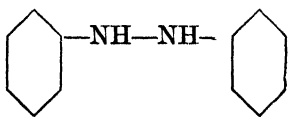
Azoxybenzene.

Hydrazine



Phenylhydrazine.

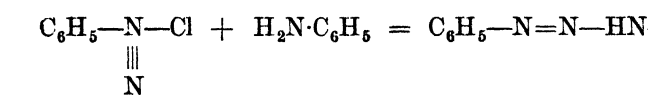
Hydrazo-Compound



Hydrazobenzene.

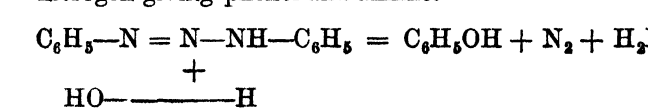
405. Diazoaminobenzene.—When a primary or secondary amine reacts with a diazonium salt a diazoamino-compound results.

Thus aniline and benzenediazonium chloride give diazoaminobenzene, which separates as a yellow precipitate:



Expt. 95.—*Preparation of Diazoaminobenzene.*—3 G. of concentrated sulphuric acid are mixed with 300 c.c of water into which are stirred 10 g. of aniline, about half of which will not dissolve. The liquid containing aniline and aniline sulphate is heated to 27° C. on the water-bath and 3·75 g. of sodium nitrite dissolved in 10 c.c. of water are slowly added, the whole being vigorously stirred. The benzenediazonium sulphate, so formed, reacts with the aniline, as described above. After a quarter of an hour, the liquid is allowed to cool and is left to stand for half an hour. The diazoaminobenzene crystallises out and is filtered off and dried by pressing on absorbent paper. If required pure, it may be recrystallised by finely powdering it and stirring it into three times its weight of boiling alcohol, which is at once left to cool. It is decomposed when heated for long.

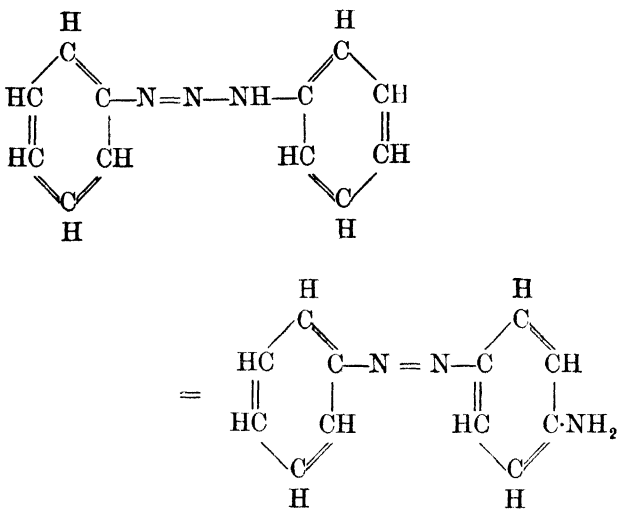
Diazoaminobenzene forms golden yellow crystals melting at 98° C. It is not basic. When boiled with water for a long period it loses nitrogen giving phenol and aniline:



Nitrous acid converts it into benzenediazonium chloride:

$$C_6H_5{\cdot}N = N{\cdot}NH{\cdot}C_6H_5 + HNO_2 + 2HCl = 2C_6H_5{-}\underset{\underset{N}{\|}}{N}{-}Cl + 2H_2O$$

When heated, especially in presence of aniline hydrochloride, it forms the basic dye aminoazobenzene by an intramolecular rearrangement:



406. Azoxybenzene.—When nitrobenzene is reduced by means of alcoholic potash azoxybenzene is obtained.

The formula for azoxybenzene is

$$C_6H_5{-}\underset{\underset{O}{\downarrow}}{N} = N{-}C_6H_5,$$

a view supported by the fact that two different *p*-mono-substitution products of azoxybenzenes can be prepared.

It is best prepared by dissolving 10 g. of sodium in 250 g. of methyl alcohol and adding 30 g. of nitrobenzene. The mixture is heated under reflux (Fig. 26) for several hours. The alcohol is distilled off on the water-bath and the residue shaken with water. The azoxybenzene forms a yellow or dark-coloured oil which solidifies and may be recrystallised from petroleum ether,

$$2C_6H_5\cdot NO_2+2O_2N\cdot C_6H_5+3NaO\cdot CH_3=2C_6H_5-\underset{\underset{O}{\downarrow}}{N}=N-C_6H_5$$
$$+3NaO\cdot OC\cdot H+3H_2O$$

It forms yellow crystals insoluble in water, melting at 36° C. When heated with iron filings it is readily decomposed into azobenzene and aniline. It can be reduced first to hydrazobenzene and finally to aniline:

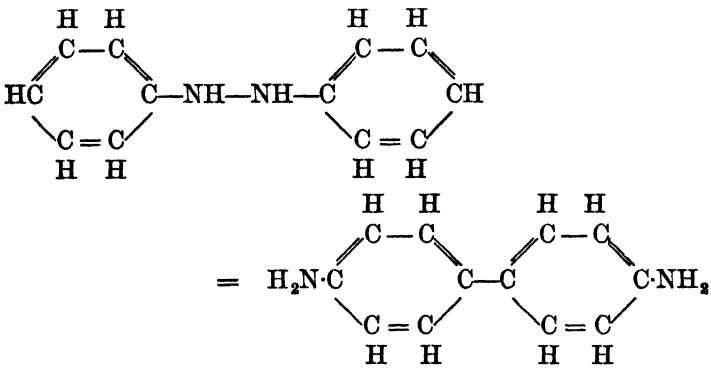
$$C_6H_5-\underset{\underset{O}{\downarrow}}{N}=\!=N-C_6H_5+4H=C_6H_5-NH-NH-C_6H_5+H_2O.$$

407. Hydrazobenzene, $C_6H_5-NH-NH-C_6H_5$, is prepared by reducing azoxybenzene or azobenzene with sodium amalgam. It forms colourless crystals melting at 131° C.

It is decomposed into azobenzene and aniline when heated:

$$2C_6H_5\cdot NH-NH\cdot C_6H_5 = C_6H_5\cdot N=N\cdot C_6H_5+2C_6H_5NH_2.$$

It is readily oxidised to azobenzene and can be reduced to aniline. The most interesting reaction of hydrazobenzene is the *benzidine transformation.* If hydrazobenzene is treated with hydrochloric acid even in the cold, it is converted into benzidine:



The reaction is used commercially for making benzidine, which is used in preparing certain dyes. The shifting of groups from the 1 to the 4 position is not uncommon in aromatic compounds, but in the benzidine transformation it should be noted that both rings must turn round completely.

408. Azobenzene, $C_6H_5-N=N-C_6H_5$.—Azobenzene is made on the large scale by reducing nitrobenzene with zinc dust and caustic soda:

$$C_6H_5\cdot NO_2+O_2N\cdot C_6H_5+8H = C_6H_5-N=N-C_6H_5+4H_2O.$$

In the laboratory it may be made by heating azoxybenzene with

iron filings, which serve to diminish the vigour of the reaction. A mixture of 5 g. of azoxybenzene and 15 g. of iron filings may be cautiously distilled from a small retort, the product being recrystallised from petroleum ether:

$$C_6H_5—N{=}{=}N—C_6H_5 + Fe = C_6H_5—N=N—C_6H_5 + FeO.$$
$$\downarrow$$
$$O$$

Azobenzene forms large orange-red crystals. It melts at 68° C. and boils at 293° C. It is insoluble in water, but dissolves in most organic solvents. In comparison to the diazo-compounds it is a very stable substance. It does not lose nitrogen in any of its ordinary reactions. Thus it is stable up to 300° C. Oxidising agents convert it into azoxybenzene and reducing agents into hydrazobenzene.

HYDRAZINES

409. Phenylhydrazine, $C_6H_5{\cdot}NH{\cdot}NH_2$, is the most important of the hydrazines. It is prepared by reducing diazonium compounds, best with stannous chloride and hydrochloric acid:—

$$C_6H_5—N—Cl \quad + 4H = \quad C_6H_5—NH$$
$$\|\!| \qquad\qquad\qquad\qquad |$$
$$N \qquad\qquad\qquad\qquad NH_2Cl$$

Benzenediazonium chloride. — Phenylhydrazine hydrochloride.

It should be noted that phenylhydrazine is very poisonous and causes severe irritation of the skin: it must therefore be handled with care.

Expt. 96.—*Preparation of Phenylhydrazine.*—Dissolve 10 g. of aniline in 85 c.c. of conc. HCl and cool to 0° C. by a freezing mixture. Dissolve 10 g. of sodium nitrite in 100 c.c. of water and add it to the former solution, keeping the temperature below 10° C. When a drop of the mixture turns potassium iodide-starch paper blue, the process is complete (*v.* Expt. 90). Meanwhile 120 g. of stannous chloride are dissolved in about 100 c.c. of concentrated hydrochloric acid and the cold solution is added to the well-cooled benzenediazonium chloride. After standing for half an hour, the phenylhydrazine hydrochloride is filtered off at the pump and sucked as dry as possible. The product is shaken with excess of caustic soda. Phenylhydrazine separates as an oil. The solution is extracted with ether, the ethereal solution dried over solid potassium carbonate, decanted and distilled on the water-bath. The oily liquid remaining after distilling off the ether is phenylhydrazine. It can be purified by distillation *in vacuo*.

Phenylhydrazine forms colourless crystals which melt at 23° C. It readily oxidises in air to indefinite brownish compounds. It boils at 240° C. with slight decomposition. Phenylhydrazine does not dissolve easily in water, but forms a hydrate $(C_6H_5{\cdot}NH{\cdot}NH_2)_2H_2O$.

Phenylhydrazine is basic in character and readily forms salts such as phenylhydrazine hydrochloride, $C_6H_5NH{\cdot}NH_3Cl$. It is a powerful reducing agent, forming benzenediazonium salts when gently oxidised, aniline and ammonia by stronger oxidation.

Its most important reaction is the formation of phenylhydrazones and osazones with compounds containing (or capable of forming) a carbonyl group $>CO$. The formation of a phenylhydrazone may be represented thus:

$$\begin{matrix} R \\ \\ R' \end{matrix}\!\!>\!C{=}O + H_2N{\cdot}NH{\cdot}C_6H_5 = \begin{matrix} R \\ \\ R' \end{matrix}\!\!>\!C{=}N{-}NH{\cdot}C_6H_5 + H_2O.$$

Its reaction with sugars to form osazones is discussed in § 272 (*v.* also Expt. 62).

The hydrazones and osazones are crystalline substances, which have definite melting points. They are therefore most useful for identifying the substances (*e.g.*, sugars) from which they have been made, many of which are difficult to purify and do not easily give exact and reproducible physical constants.

It is not always easy to recover a ketone or aldehyde from its hydrazone or osazone, and the semicarbazones (§ 313), which are easily hydrolysed to the original substance and semicarbazide, are now preferred to the phenylhydrazones. The phenylhydrazine may be removed from osazones by treatment with benzaldehyde, as exemplified in the synthesis of glucose (§ 272).

AROMATIC CYANOGEN COMPOUNDS

The cyanide group $-CN$ and the *iso*cyanide group $-NC$ can be substituted in the benzene ring.

410. Phenyl Cyanide, Cyanobenzene, Benzonitrile, C_6H_5CN.—Cyanobenzene can be prepared by the Sandmeyer reaction from aniline.

A solution of benzenediazonium chloride is prepared and added a little at a time to a solution of potassium cuprocyanide, obtained by the reaction of copper sulphate solution with potassium cyanide solution (§ 399):

$$C_6H_5{\cdot}N_2{\cdot}Cl + KCN = C_6H_5{\cdot}CN + N_2 + KCl.$$

The product is steam distilled (§ 381), when the phenyl cyanide separates from the distillate as an oil. Some phenol is often formed

at the same time and must be separated by careful fractional distillation.

Phenyl cyanide is a colourless oil with an almond-like odour. It boils at 190·7° C.

Its chemical properties closely resemble those of the aliphatic nitriles (§ 144). Thus it can be hydrolysed with some difficulty by caustic potash solution to potassium benzoate (§ 454) and ammonia:

$$C_6H_5{\cdot}CN + KOH + H_2O = C_6H_5{\cdot}CO{\cdot}OK + NH_3.$$

It can be reduced to benzylamine (§ 447):

$$C_6H_5{\cdot}CN + 4H = C_6H_5{\cdot}CH_2{\cdot}NH_2.$$

411. Phenyl *iso*cyanide, $C_6H_5{\cdot}NC$.—This resembles the aliphatic *iso*cyanides. It is made by the reaction of aniline, chloroform and caustic potash in alcoholic solution (compare § 146):

$$C_6H_5{\cdot}NH_2 + CHCl_3 + 3KOH = C_6H_5NC + 3KCl + 3H_2O.$$

It is a liquid of an intolerable and nauseating odour. It is readily hydrolysed when boiled with dilute acids, aniline and formic acid being produced:

$$C_6H_5{\cdot}NC + 2H_2O = C_6H_5{\cdot}NH_2 + H{\cdot}CO{\cdot}OH.$$

When reduced it forms methylaniline:

$$C_6H_5NC + 4H = C_6H_5{-}NH{-}CH_3.$$

412. Phenyl. *iso*thiocyanate, $C_6H_5N = C = S$.—This substance is also known as phenyl mustard oil. Its formation is mentioned under aniline (§ 382).

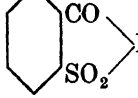
SULPHUR AND PHOSPHORUS COMPOUNDS OF BENZENE

Phenyl compounds analogous to those mentioned in § 153 are known.

413. Thiophenol, Phenyl Mercaptan, $C_6H_5{\cdot}SH$, is made by the action of phosphorus pentasulphide on phenol. In this respect and in its general properties it closely resembles mercaptan (§ 154)

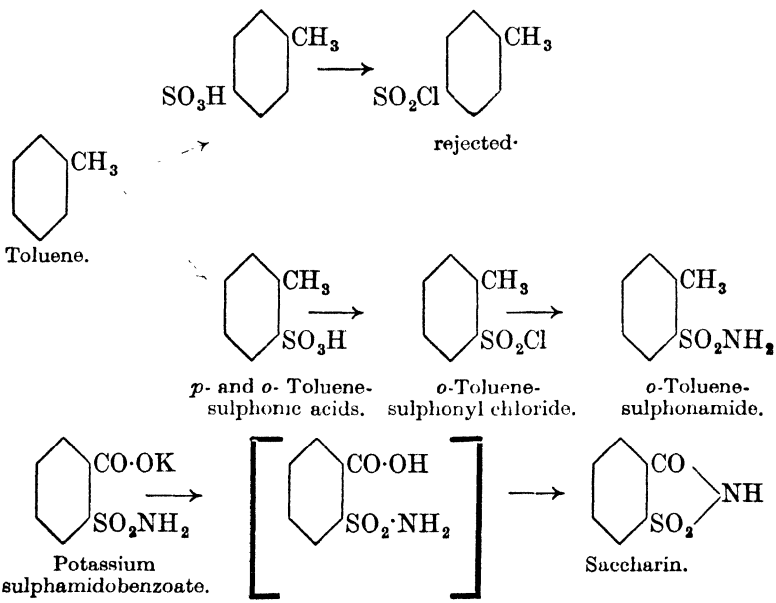
414. Diphenyl Sulphide, $(C_6H_5)_2S$, is a liquid smelling of leeks. It is readily oxidised to a sulphone $(C_6H_5)_2SO_2$.

415. Saccharin.—*o*-Anhydro-sulphamido-benzoic acid,



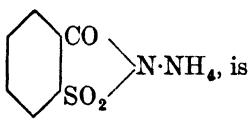
, may be mentioned here. It is prepared by sulphonating toluene to *o*- and *p*-toluenesulphonic acids, and converting

these into the respective toluenesulphonyl chlorides. The *p*-compound crystallises, and the residual *o*-compound is converted by ammonia under pressure into the *o*-toluene-sulphonamide. By oxidising this with alkaline permanganate a salt of *o*-sulphamidobenzoic acid is obtained. By treatment with mineral acid, the free acid is liberated and changes into its anhydride, saccharin.



Saccharin is a white crystalline substance melting at 227·5° C. It is 550 times as sweet as cane sugar. Saccharin is employed for sweetening purposes where cane sugar is contra-indicated, in cases of diabetes, undue corpulence, etc.

It has acidic properties, and its ammonium salt (*sucramine*),



, is even sweeter than saccharin itself.

416. Phenyl Phosphines, such as $C_6H_5 \cdot PH_2$, are known. They are inflammable liquids with a powerful and offensive phosphine-like odour.

416a. Triphenyl Phosphate, $(C_6H_5)_3PO_4$, is made by the action of phosphorus oxychloride on phenol

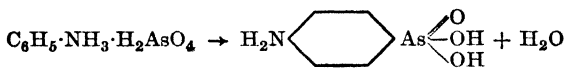
$$3C_6H_5 \cdot OH + POCl_3 = (C_6H_5)_3PO_4 + 3HCl.$$

It forms slightly deliquescent crystals. It is added to cellulose acetate to make it plastic and flexible like celluloid. Such mixtures are employed as 'dope' for aeroplane wings, cellulose varnishes, non-inflammable film, etc.

ARSENIC COMPOUNDS OF BENZENE

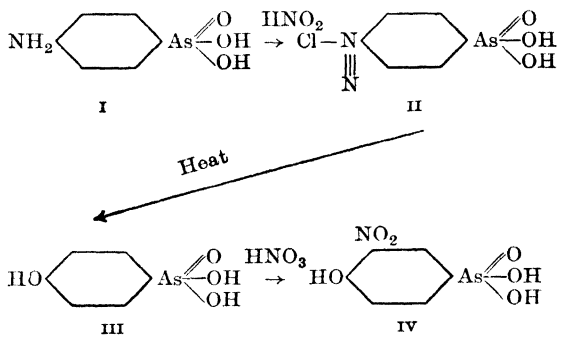
417. Phenylarsine Chlorides are obtained by the action of aluminium chloride on benzene and arsenic trichloride (cf. § 342). Of these, diphenylchloroarsine, $(C_6H_5)_2AsCl$, was used in chemical warfare on account of its intense irritant action on the eyes, nose and throat.

418. Arseno-benzene, $C_6H_5—As = As—C_6H_5$, is analogous to azobenzene (§ 408). Though not of importance itself several of its derivatives are most valuable drugs. The most important of these are salvarsan and neosalvarsan, the use of which has revolutionised the treatment of syphilis. The first stage in the preparation of salvarsan is the action of heat on aniline arsenate.



I

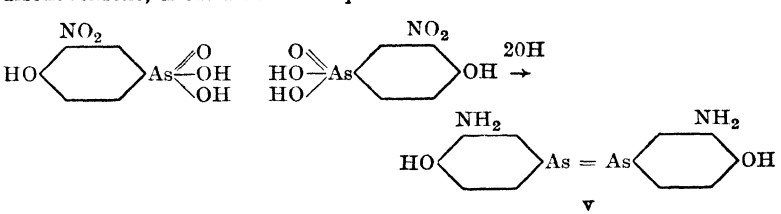
A reaction analogous to the formation of sulphanilic acid (§ 387) takes place, and *p*-aminophenylarsonic acid (I) is produced. The acid I is then diazotised (II) and heated (III). The hydroxy-acid (III) is then nitrated (IV).



I II III IV

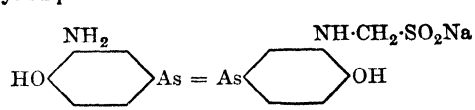
It is then strongly reduced by sodium hydrosulphite.

The hydrochloride of the product (V), 3 : 3′ - diamino-4: 4′ -dihydroxyarsenobenzene, is *salvarsan* or *arsphenamine.*



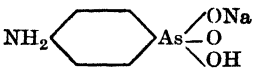
V

Salvarsan has been largely replaced by *neo-salvarsan,* which is sodium salvarsan-methyl-sulphinate

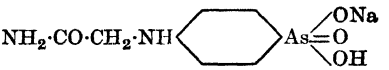


Sulpharsphenamine is of similar constitution.

419. Atoxyl and Tryparsamide are drugs found of much use in treating sleeping sickness and other protozoal diseases. *Atoxyl* is the sodium salt of *p*-aminophenyl-arsonic acid, and tryparsamide is the sodium salt of a derivative of this acid.



Atoxyl.



Tryparsamide.

Atoxyl is rarely used owing to its cumulative poisonous action leading to blindness and kidney complications, but tryparsamide is a valuable drug.

420. Phenyl Derivatives of the Metals.—Phenylmagnesium bromide, $C_6H_5{\cdot}Mg{\cdot}Br$, can be made by methods analogous to those set out for methylmagnesium iodide (§ 162, Expt. 45). It is a useful synthetic reagent, and numerous phenyl compounds may be prepared from it by the methods indicated in § 163.

Phenyl derivatives of antimony mercury, lead, tin, etc., are known. Tetraphenyl lead, $Pb(C_6H_5)_4$, may serve as an example of these.

QUESTIONS

(1) How is a solution of benzenediazonium chloride prepared? Discuss the formula of the diazonium salts and of the diazotates.

(2) How can aniline be converted by means of the diazo-reactions into (*a*) chlorobenzene, (*b*) phenyl cyanide, (*c*) phenol, (*d*) benzene, (*e*) iodobenzene?

(3) What is a dye, and with what types of structure are dyeing properties particularly associated? Describe the preparation of an azo-dye.

(4) Write the formulæ of diazoaminobenzene, azobenzene, azoxybenzene, hydrazobenzene, benzidine, and indicate briefly how they could be prepared starting from nitrobenzene.

(5) How is phenylhydrazine prepared? What are hydrazones and osazones? If a compound forms a hydrazone, what group does it contain?

CHAPTER XXVI

TOLUENE AND THE ALKYLBENZENES

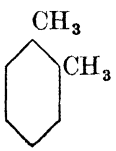
421. Alkylbenzenes.—Any number of alkyl groups up to six can be inserted in the benzene ring, and a very great number of hydrocarbons of this type can be prepared. Of these the methylbenzenes are the most important. They include:

Monomethylbenzenes

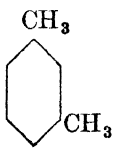


Toluene.

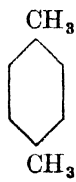
Dimethylbenzenes



o-Xylene.

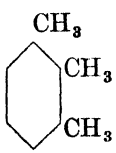


m-Xylene.

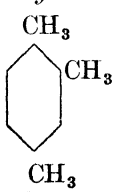


p-Xylene.

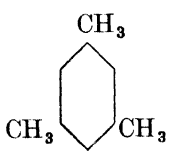
Trimethylbenzenes



(Hemimellitene).

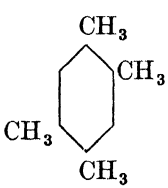


(Pseudocumene).

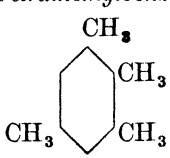


Mesitylene.

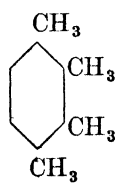
Tetramethylbenzenes



Durene.

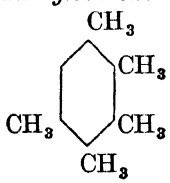


Isodurene.

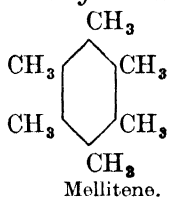


Prehnitene.

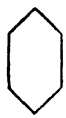
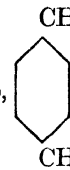
Pentamethylbenzene



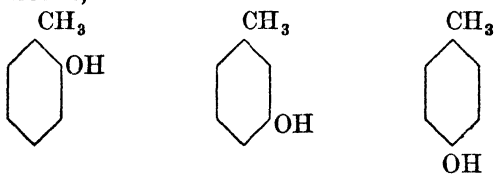
Hexamethylbenzene



Mellitene.

Among other alkylbenzenes may be mentioned ethylbenzene,  , and cymene, methyl-*p*-*iso*propylbenzene,  , which is of interest owing to its relation to the terpenes (Chapter XXIX). Numerous less important compounds of this kind are also known.

The alkylbenzenes are of particular interest as forming two series of substitution products. A substituent group, *e.g.*, chlorine or hydroxyl, may be introduced into the benzene ring, producing compounds closely resembling the derivatives of benzene which have been studied in Chapters XXI to XXV. Alternatively, a substituent may be introduced into the alkyl group, or side chain, producing a derivative much more nearly resembling an aliphatic compound. Thus from toluene we can make two types of hydroxy- derivatives. The first, the cresols,



very closely resemble phenol (§ 354); the other derivative, benzyl alcohol,  , on the other hand, in its chemical behaviour much resembles methyl or ethyl alcohol (§ 42).

Where it is necessary to indicate that a group is present in the side-chain and not in the nucleus Greek letters are employed. The prefix ω- indicates that the group is at the end of the side-chain. Thus ω-chloroacetophenone is $C_6H_5 \cdot CO \cdot CH_2Cl$ and not $Cl \cdot C_6H_4 \cdot CO \cdot CH_3$.

422. Toluene, $C_6H_5 \cdot CH_3$.—Toluene was originally made by the dry distillation of certain resins. It is now always prepared from

coal-tar. It is separated therefrom with the benzene (§ 337), and is purified by fractional distillation.

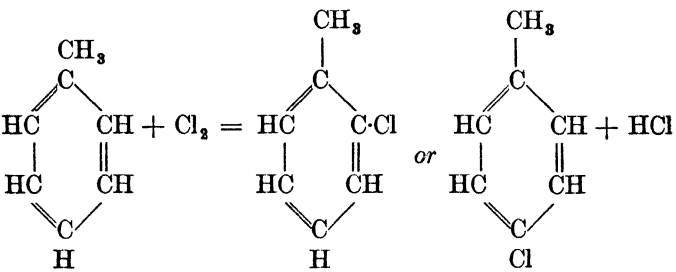
Its manufacture is of importance for the production of the toluidines, $CH_3 \cdot C_6H_4 \cdot NH_2$ (required for the dye industry), and of benzaldehyde (§ 450).

It can be made by the Friedel-Crafts reaction. Methyl chloride is caused to react with benzene in presence of aluminium chloride, and the addition product formed is decomposed by water. The Friedel-Crafts reaction may be employed to insert any alkyl or acyl group into the benzene ring.

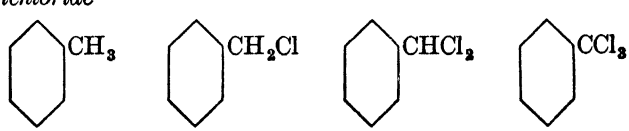
$$CH_3Cl + C_6H_6 = C_6H_5 \cdot CH_3 + HCl.$$

Physical Properties.—Toluene is a colourless liquid which boils at 111° C. It is lighter than water (sp. gr. 0·8723 15°/15°). It is insoluble in water and is a good solvent for many organic substances.

Chemical Properties.—Toluene can react with the halogens in two different ways. If chlorine be passed into toluene in presence of a halogen-carrier, *e.g.*, iodine, *o*- and *p*-chlorotoluene are produced:



If toluene, particularly when heated to boiling and exposed to sunlight, is treated with chlorine alone, benzyl chloride is formed, which in direct sunlight can be further chlorinated to *benzal chloride* and *benzotrichloride*



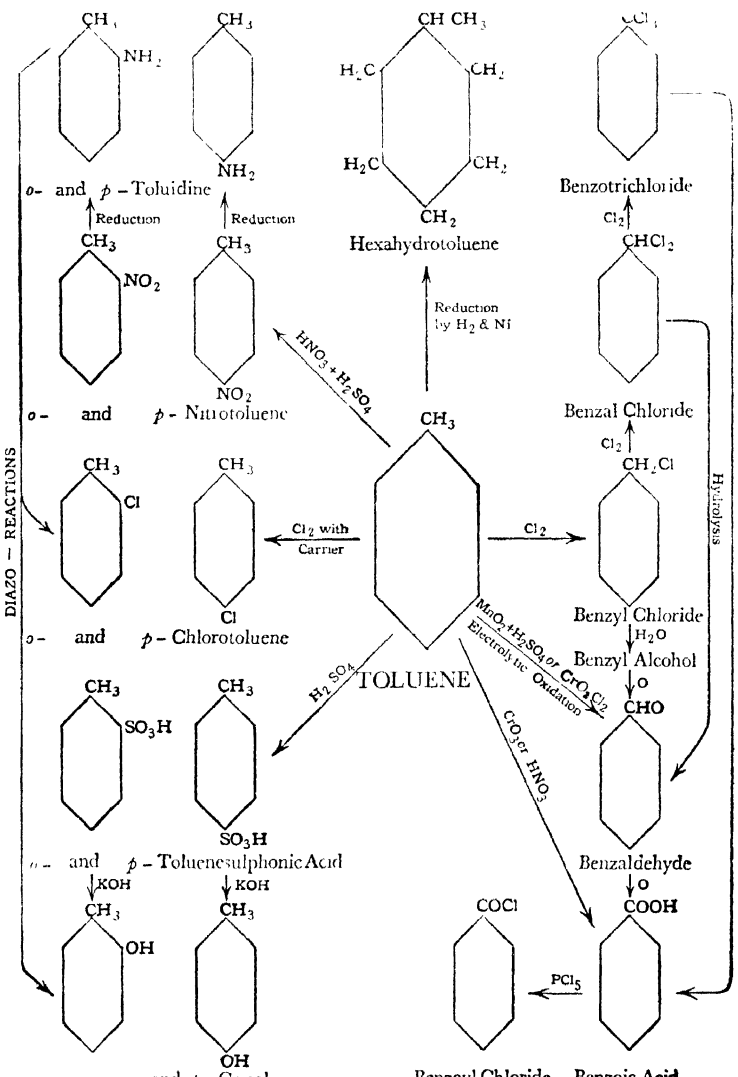
Toluene. Benzyl chloride. Benzal chloride. Benzotrichloride.

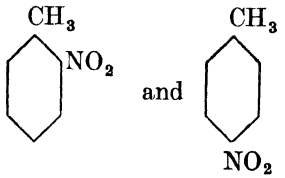
all of which are commercially important substances (§§ 443–445).

Sulphuric acid reacts with toluene as with benzene (§ 342) forming ortho- and para-toluenesulphonic acids. It does not attack the side chain. The toluenesulphonic acids are used in the manufacture of saccharin (§ 415).

A mixture of nitric acid and sulphuric acid nitrates toluene forming chiefly *o*- and *p*-nitrotoluene:

REACTIONS OF TOLUENE





The process of nitration is the same as that employed for nitrobenzene (*Expt.* 79, § 368).

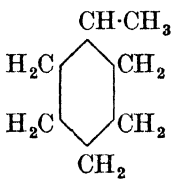
Most oxidising agents, such as potassium permanganate, or better a solution of chromium trioxide in acetic acid, which do not affect benzene appreciably, oxidise toluene to *benzoic acid*:

$$C_6H_5{\cdot}CH_3 + 3O = C_6H_5{\cdot}CO{\cdot}OH + H_2O.$$

It is possible, however, to oxidise toluene to benzaldehyde by the use of manganese dioxide and sulphuric acid or by electrolytic oxidation under certain conditions:

$$C_6H_5{\cdot}CH_3 + 2O = C_6H_5{\cdot}CHO + H_2O.$$

Toluene may be reduced by hydrogen in presence of heated nickel to a methylhexamethylene, hexahydrotoluene:



423. The Xylenes.—The three dimethylbenzenes are known as ortho-, meta- and para-xylene. They are found in coal-tar and, like benzene and toluene, are separated from the light-oil fraction by distillation. The product boiling at about 140° C. contains all three xylenes. Their boiling points lie very close together and they are separated by treatment with concentrated sulphuric acid, which does not attack *p*-xylene but converts *o*- and *m*-xylene into xylene-sulphonic acids. Fractional crystallisation separates sodium *o*-xylene-sulphonate from the more soluble *m*-xylene-sulphonate. The hydrocarbons may be made from the sulphonates by distillation with ammonium chloride; the ammonium xylene-sulphonate is formed and then decomposes:

$$(CH_3)_2C_6H_3{\cdot}SO_3NH_4 + H_2O = (CH_3)_2C_6H_4 + NH_3 + H_2SO_4.$$

They can also be made synthetically by the reaction of sodium with mixtures of methyl iodide and the three bromo-toluenes (*o*-, *p*- and *m*-):

$$CH_3{\cdot}C_6H_4Br + 2Na + ICH_3 = CH_3{\cdot}C_6H_4{\cdot}CH_3 + NaBr + NaI.$$

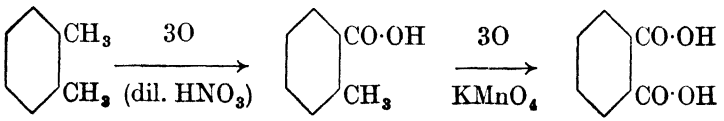
The xylenes are all colourless liquids resembling toluene. Their boiling points are:

o-Xylene	144° C.
m-Xylene	139° C.
p-Xylene	138·5° C.

They find uses as solvents, but their chief importance is in the preparation of the amines, xylidine $(CH_3)_2C_6H_3{\cdot}NH_2$ (§ 441), much used for producing brilliant scarlet azo-dyes.

The xylenes form substitution products in much the same way as toluene. Nitro- and bromo-xylenes are prepared in a manner analogous to nitro- and bromo-toluene.

They are oxidised by dilute nitric acid, chromic acid, etc., first to toluic acids then to the phthalic acids (§§ 468, 471):



o-Xylene. *o*-Toluic acid. *o*-Phthalic acid.

424. Trimethylbenzenes, $C_6H_3(CH_3)_3$.—Mesitylene is symmetrical 1 : 3 : 5-trimethylbenzene. Its synthesis from acetone is mentioned in § 112. It resembles the xylenes in most particulars, as do its isomerides pseudocumene and hemimellitene.

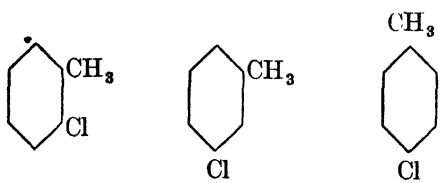
425. Hexamethylbenzene (Mellitene), $C_6(CH_3)_6$, is remarkably unreactive. Having no hydrogen atom attached to the benzene ring it cannot be nitrated or sulphonated. It can be oxidised to mellitic acid, $C_6(CO{\cdot}OH)_6$ (§ 473).

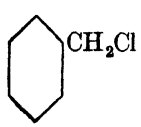
425a. Ethylbenzene, $C_6H_5{\cdot}C_2H_5$, much resembles toluene. When oxidised it yields benzoic acid.

Cymene, methyl-*p-iso*propylbenzene, $CH_3{\cdot}C_6H_4{\cdot}CH(CH_3)_2$, is found in eucalyptus oil. It may be regarded as the parent sustance of the monocyclic terpenes (Chapter XXIX).

CHLORO- AND BROMO-TOLUENES

The name chlorotoluene is applied to the three compounds of formulæ:



The compound 

is not called chlorotoluene, but benzyl chloride (§ 443).

426. The Chlorotoluenes.—The chlorotoluenes are made by the methods applicable to the preparation of chlorobenzene (*q.v.*) including:—

(1) Chlorination of toluene *in presence of a halogen-carrier, e.g.*, iodine. Ortho- and para-chlorotoluene are the chief products. Their boiling points are too close to allow of their separation by fractional distillation:

$$C_6H_5{\cdot}CH_3 + Cl_2 = Cl{\cdot}C_6H_4{\cdot}CH_3 + HCl.$$

(2) The pure *o*-, *m*-, and *p*- compounds are best prepared by the Sandmeyer reaction. The appropriate toluidine (§§ 438–440) is diazotised and the toluenediazonium chloride warmed with a solution of cuprous chloride in hydrochloric acid:

$$CH_3{\cdot}C_6H_4{\cdot}N_2{\cdot}Cl = CH_3{\cdot}C_6H_4{\cdot}Cl + N_2.$$

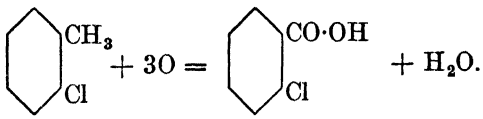
The chlorotoluene is recovered from the reaction mixture by steam distillation.

The Gattermann process, employing copper powder in place of cuprous chloride, can also be used.

Physical Properties.—The three chlorotoluenes are liquids much resembling bromobenzene. Their boiling points are:

o-Chlorotoluene	159° C.
m-Chlorotoluene	162° C.
p-Chlorotoluene	162° C.

Chemical Properties.—The chlorotoluenes closely resemble chlorobenzene. The halogen atoms are removed only with difficulty, *e.g.*, by sodium, and they do not react with KOH, KCN, NH_3, etc., as do both the aliphatic halides and the benzyl halides (§§ 443–445). They form Grignard reagents with magnesium, *e.g.*, $CH_3{\cdot}C_6H_4{\cdot}Mg{\cdot}Cl$, and from these many toluene derivatives can be made (§ 162). When oxidised by nitric acid or permanganates they form chlorobenzoic acids:



427. Bromotoluenes.—The bromotoluenes are in all respects analogous to the chlorotoluenes.

428. Iodotoluenes.—Iodotoluenes are prepared by the action of potassium iodide on diazotised toluidine (cf. § 399).

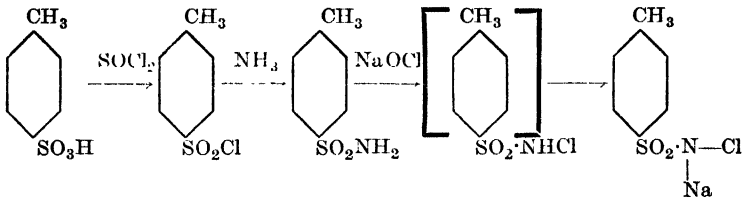
TOLUENESULPHONIC ACIDS, $CH_3{\cdot}C_6H_4{\cdot}SO_3H$

429. Toluenesulphonic Acids.—*o*-, *m*- and *p*-Toluenesulphonic acids can be made by sulphonating toluene exactly as described for

benzene (Expt. 76). The para-compound is formed in largest quantity.

Their reactions closely resemble those of benzenesulphonic acid. When their potassium salts are fused with caustic potash the hydroxytoluenes or *cresols* are formed. *o*-Toluenesulphonic acid is an intermediate product in the manufacture of saccharin (§ 415).

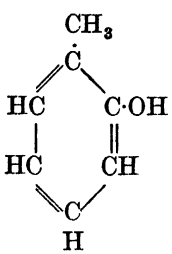
'*Chloramine*-T' is the name given to sodium *p*-toluenesulphonchloroamide. It is obtained by the action of sodium hypochlorite on *p*-toluenesulphonamide.



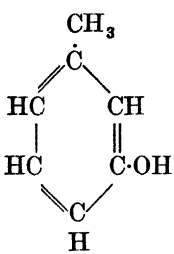
Like the true chloramine, NH_2Cl, of which it is a derivative, it is a powerful oxidising agent and disinfectant. It is used in the treatment of wounds, etc.

THE CRESOLS

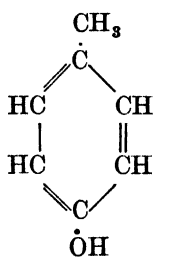
430. Manufacture and Industrial Uses of the Cresols.—The three cresols are all found in coal-tar, and they are separated by the



o-Cresol.



m-Cresol.



p-Cresol.

process described in § 354. The chief importance of the cresols is their use as disinfectants. The residue obtained by the above process, containing all three cresols and some phenol, is brought into a form readily soluble in water. This may be done by heating it with resin and caustic soda, thus forming a solution of the sodium derivatives of phenol and cresol together with resin-soap. On dilution the sodium salts are hydrolysed, forming a solution or a milky suspension of phenol and cresols, which are powerful disinfectants.

431. Preparation of the Pure Cresols.—The chief source of the cresols in the laboratory is toluidine (§§ 438–440).

The appropriate toluidine (*o*-, *m*- or *p*-) is diazotised and the diazo-solution warmed. The cresol is removed by steam distillation:

$$CH_3{\cdot}C_6H_4{\cdot}NH_3Cl + HNO_2 = CH_3{\cdot}C_6H_4{\cdot}N_2{\cdot}Cl + 2H_2O,$$

$$CH_3{\cdot}C_6H_4{\cdot}N_2{\cdot}Cl + H_2O = CH_3{\cdot}C_6H_4{\cdot}OH + N_2 + HCl.$$

Expt. 97.—*Preparation of* p-*Cresol.* Dissolve 20 g. of *p*-toluidine in 20 c.c. of concentrated sulphuric acid. Dilute to 650 c.c and stir in 13 g. of sodium nitrite previously dissolved in 50 c.c. of water. Heat the solution slowly to boiling on the water-bath. When the evolution of nitrogen has ceased, distil the product in steam till a specimen of the distillate no longer becomes cloudy when saturated with salt.

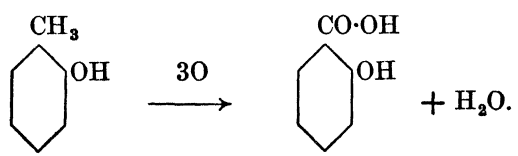
Dissolve 25 g. of salt in every 100 c.c. of distillate and shake with 50 c.c. of ether. Separate the ethereal layer: dry over calcium chloride and distil off the ether on the water-bath; then replace the water-condenser by an air-condenser and distil over the *p*-cresol, collecting the fraction boiling near 202° C. The liquid should solidify to colourless crystals.

432. Properties of the Cresols.—The cresols are oily liquids or solids with a characteristic disinfectant odour. They are poisonous. They melt and boil at the following temperatures:

	M.P.	B.P.
o-Cresol . .	30° C.	191° C.
m-Cresol . .	4° C.	203° C.
p-Cresol . .	36° C.	202° C.

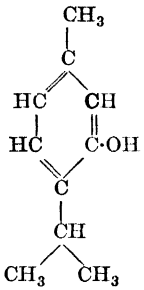
The cresols have almost all the characteristic properties of the phenols. They form cresylates with alkalis, *e.g.*, $CH_3{\cdot}C_6H_4{\cdot}OK$. Like phenol, they are very readily substituted. A mixture of dinitrocresols, obtained by nitrating them by the same method as is described in § 377 for preparing picric acid, is used as a dye, "Victoria yellow."

The cresols are much less easily oxidised than most toluene derivatives, but oxidation with peroxides at high temperatures converts them into hydroxybenzoic acids:



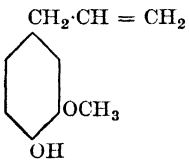
o-Cresol. *o*-Hydroxybenzoic acid.

433. Thymol,



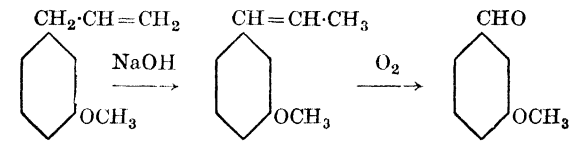
is 3-hydroxy-1-methyl-4-*iso*propyl-benzene. It is found with other products in oil of thyme, from which it is extracted by shaking with alkali and acidifying the aqueous solution. It has an odour of thyme. It is a powerful antiseptic and is used in mouth-washes, etc. Its small solubility is a disadvantage. In its chemical properties it resembles the cresols.

434. Eugenol.—1-Allyl-3-methoxy-4-hydroxybenzene



is the active principle of oil of cloves. It has strong antiseptic properties.

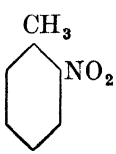
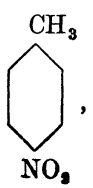
Eugenol can be converted by oxidation into *vanillin*, the flavouring matter of vanilla.



Eugenol. *iso*Eugenol. Vanillin.

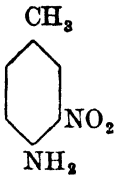
NITROTOLUENES

Dilute nitric acid attacks the methyl group in toluene and oxidises it to benzoic acid (§ 454). A mixture of nitric and sulphuric acid, however, converts it into nitrotoluenes. *o*- and *p*-Nitrotoluene are first formed by direct nitration, but *m*-nitrotoluene has to be prepared indirectly. Further nitration gives di- and tri-nitrotoluenes.

435. *o*- and *p*-Nitrotoluene,  and  , are made in

exactly the same way as nitrobenzene (§ 368, Expt. 79). The two isomerides are separated by fractional distillation under reduced pressure. The lower-boiling fraction is mainly *o*-nitrotoluene (B.P. 222° C.) while the higher-boiling fraction on cooling deposits crystals of *p*-nitrotoluene, which is a solid melting at 51·6° C.

m-*Nitrotoluene* is prepared by converting *p*-toluidine into *p*-acetotoluidide (cf. § 438) and nitrating this. The nitroacetotoluidide is hydrolysed (cf. Expt. 88), so obtaining the compound



This is diazotised and heated with alcohol, when the NH_2 group is replaced by hydrogen (§ 399).

The nitrotoluenes closely resemble nitrobenzene in most of their physical and chemical properties. Their melting points and boiling points are:

	M.P.	B.P.
o-Nitrotoluene . . .	—4°	222°
m-Nitrotoluene . .	16·1°	230–231°
p-Nitrotoluene . .	51·6°	238°

They are readily reduced by means of tin and hydrochloric acid to the aminotoluenes or toluidines:

$$CH_3{\cdot}C_6H_4{\cdot}NO_2 + 6H = CH_3{\cdot}C_6H_4{\cdot}NH_2 + 2H_2O$$

and this is their chief industrial value.

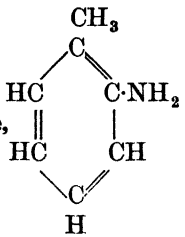
436. The Dinitrotoluenes, $CH_3.C_6H_3(NO_2)_2$, are also of importance as being readily reduced to amines which are employed in the dye industry.

437. Symmetrical Trinitrotoluene, "T.N.T.," $CH_3{\cdot}C_6H_2(NO_2)_3$, is a most important explosive for shell-filling and military purposes in general. It is made by running toluene into a well-stirred mixture of nitric acid and sulphuric acid containing some SO_3. The product is run into water and the solid is washed with sodium sulphite solution which dissolves out any isomerides and leaves pure symmetrical trinitrotoluene.

As an explosive for military purposes it is employed without admixture of other substances. A mixture of 1 part of trinitrotoluene with 4 parts of ammonium nitrate has been widely used for blasting purposes under the name of *amatol*.

THE TOLUIDINES

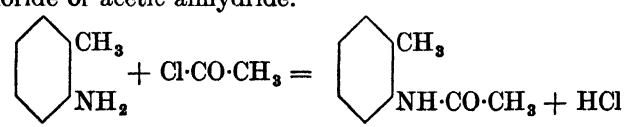
The three aminotoluenes, $CH_3 \cdot C_6H_4 \cdot NH_2$, are known as the toluidines. *o*- and *p*-Toluidine are of great importance in the dye industry.

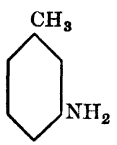
438. *o*-Toluidine,  , is prepared by reducing *o*-nitrotoluene (§ 435) by precisely the same method as is used for making aniline from nitrobenzene (§ 381, Expt. 85).

It is a colourless oily liquid, slightly heavier than water and nearly insoluble in it. It boils at 199·7° C.

Its reactions are similar to those of aniline. Thus it forms salts, and can be diazotised by the methods of Expts. 90, 91. The resulting solution of *o*-toluenediazonium chloride yields azo-dyes, and from it most of the *o*-derivatives of toluene can be prepared. The student may with advantage work out the methods by which toluene, *o*-cresol, *o*-bromotoluene, *o*-cyanotoluene, *o*-tolylhydrazine could be prepared from it.

Just as aniline forms anilides, so *o*-toluidine forms *o*-toluidides. Thus acet-*o*-toluidide can be made by treating *o*-toluidine with acetyl chloride or acetic anhydride:



439. *m*-Toluidine,  , is of much less use than the other toluidines in the dye industry on account of the difficulty of preparing *m*-nitrotoluene (§ 435) from which it is made.

440. *p*-Toluidine,  , is prepared by reducing *p*-nitrotoluene

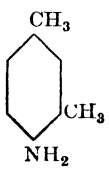
by the same methods as are used for the manufacture and preparation of aniline.

p-Toluidine forms white crystals with a peculiar odour, recalling both aniline and mice. It is poisonous. It melts at 45° C., boils at 200·4° C., and can be distilled in steam. It is almost insoluble in water, but is soluble in most organic solvents.

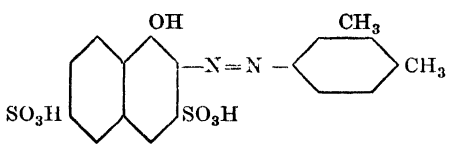
The chemical properties of *p*-toluidine much resemble those of aniline. It forms salts with acids resembling the salts of aniline. It can be diazotised (§ 395), and from the *p*-toluenediazonium salt so obtained many *p*-toluene derivatives can be made. The azo-dyes (§ 402), made from the *p*-toluenediazonium salts, include many brilliant and valuable colours.

Both *o*- and *p*-toluidine find uses in preparing the important triphenylmethane dyes (Chapter XXVIII).

441. Xylidines.—By nitrating the xylenes, $C_6H_4(CH_3)_2$, and reducing the nitroxylenes so produced, the xylidines, $C_6H_3(CH_3)_2NH_2$, are formed. There are eight possible isomerides with this formula. Commercial xylidine contains five of these, the chief one being 1 : 3-dimethyl-4-aminobenzene (*m*-4-xylidine):



They are employed in the manufacture of the azo-dye xylidine scarlet, made by diazotising commercial xylidine and combining it with α-naphthol-3 : 6-disulphonic acid:



Xylidine scarlet.

THE BENZYL COMPOUNDS

442. Substitution in the Side-chain.—When substituent groups enter the side-chain of an alkyl-benzene such as toluene, a set of compounds is formed which resembles the aliphatic compounds much more nearly than the aromatic compounds.

Thus toluene can be converted into a series of compounds of the type $C_6H_5{\cdot}CH_2R$, known as benzyl compounds, which are widely different in properties from their isomerides, $R{\cdot}C_6H_4{\cdot}CH_3$, with the substituent in the benzene ring. The sources of all these compounds are the products obtained by chlorinating boiling toluene in a good light, without a halogen-carrier being present.

The result of this process is the successive formation of the three substances, benzyl chloride, $C_6H_5 \cdot CH_2Cl$, benzal chloride, $C_6H_5 \cdot CHCl_2$, and benzotrichloride, $C_6H_5 \cdot CCl_3$.

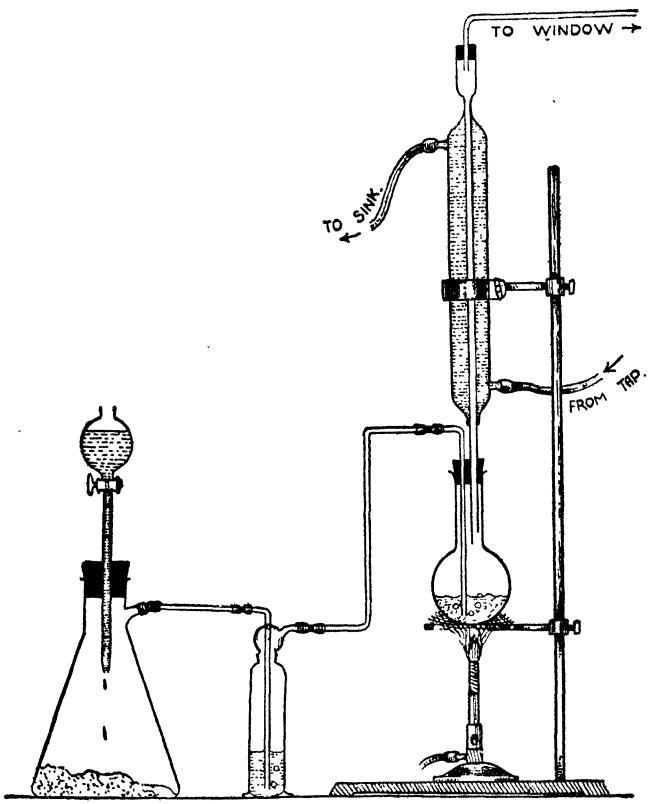
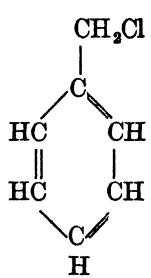


FIG. 56.—Preparation of Benzyl Chloride.

443. Benzyl chloride,  , is obtained both in the laboratory and on the commercial scale by passing chlorine into boiling toluene,

$$C_6H_5 \cdot CH_3 + Cl_2 = C_6H_5 \cdot CH_2Cl + HCl,$$

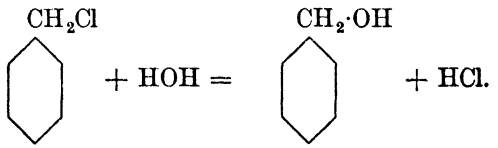
until it has increased in weight by the theoretical amount as indicated by the above equation.

Expt. 98.—*Preparation of Benzyl Chloride.*—Set up the apparatus shown in Fig. 56 in the lightest position in the laboratory. Do not attempt the preparation on a cloudy day. In the flask A place 50 g. of bleaching powder, and in the tap-funnel conc. hydrochloric acid. Weigh the other flask and place in it 50 g. of toluene, and heat to boiling. Pass a steady stream of chlorine through the flask until the toluene has gained in weight by 20 g. The bleaching powder may need replenishing more than once. When the necessary increase of weight has taken place, shake the product with dilute sodium carbonate, dry over calcium chloride and distil. Benzyl chloride comes over between 175° and 180° C.

Benzyl chloride can also be made by the action of HCl or PCl_3 on benzyl alcohol (*q.v.*).

Properties.—Benzyl chloride is a colourless liquid, the vapour of which has a pungent smell and irritates the eyes. It boils at 176—179° C. It is insoluble in water.

Benzyl chloride behaves in almost all respects like a paraffin halide (§ 58). Thus it gives benzyl alcohol when boiled with water for a long period or with weak alkali (*e.g.*, potassium carbonate) for a shorter time:

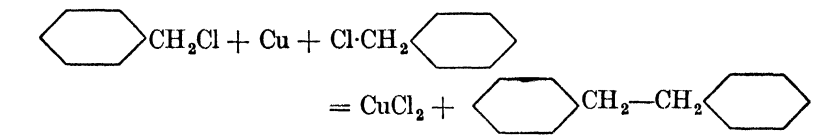


It gives benzylamine with ammonia

$$C_6H_5{\cdot}CH_2Cl + 2NH_3 = C_6H_5{\cdot}CH_2{\cdot}NH_2 + NH_4Cl,$$

and benzyl cyanide with potassium cyanide. In all the above respects it resembles, say, ethyl chloride (§ 58) and differs from phenyl chloride (chlorobenzene) (§ 346).

When heated with copper powder it gives dibenzyl:



The action of chlorine converts it into benzal chloride.

Benzyl chloride is sometimes converted commercially into benzaldehyde by heating it with lead nitrate solution which oxidises it:

$$C_6H_5{\cdot}CH_2Cl + O = C_6H_5{\cdot}CHO + HCl.$$

444. Benzal chloride, $C_6H_5{\cdot}CHCl_2$, is made by chlorinating boiling toluene in sunlight until the theoretical increase of weight has occurred.

It is a colourless liquid, insoluble in water. It boils at 206° C.

When hydrolysed it behaves like ethylidene chloride, $CH_3{\cdot}CHCl_2$, (§ 60) and gives an aldehyde. Benzaldehyde is prepared commercially by heating it with milk of lime.

The reaction probably takes place in two stages as below:

$$C_6H_5{\cdot}CHCl_2 + Ca(OH)_2 = C_6H_5{\cdot}CH(OH)_2 + CaCl_2$$

$$C_6H_5{\cdot}CH\begin{matrix}\diagup OH\\ \\ \diagdown OH\end{matrix} = C_6H_5{\cdot}CHO + H_2O.$$

It is also used in preparing cinnamic acid (β-phenylacrylic acid), for which purpose it is heated with dry sodium acetate:

$$C_6H_5{\cdot}CHCl_2 + H_3C{\cdot}CO{\cdot}ONa + H_3C{\cdot}CO{\cdot}ONa = C_6H_5{\cdot}CH=CH{\cdot}CO{\cdot}OH + 2NaCl + CH_3{\cdot}CO{\cdot}OH.$$

445. Benzotrichloride, $C_6H_5{\cdot}CCl_3$, is made by carrying on the chlorination of boiling toluene in sunlight until no further increase in weight occurs.

Benzotrichloride is a colourless liquid which boils at 213° C.

In its chemical properties it shows analogies to chloroform, $H{\cdot}CCl_3$, but is much more reactive. Thus it gives benzoic acid on hydrolysis, just as chloroform gives formic acid. The reaction is brought about by heating it with water to 150° C. or with alkalis to a lower temperature:—

$$C_6H_5{\cdot}CCl_3 + 3HOH = C_6H_5{\cdot}C(OH)_3 + 3HCl$$

$$C_6H_5C\begin{matrix}\diagup OH\\ —OH\\ \diagdown OH\end{matrix} = C_6H_5{\cdot}CO{\cdot}OH + H_2O.$$

Benzoic acid is commercially prepared (§ 454) by this reaction.

446. Benzyl alcohol, $C_6H_5{\cdot}CH_2{\cdot}OH$, can be made by boiling benzyl chloride under reflux with dilute potassium carbonate solution:

$$C_6H_5{\cdot}CH_2Cl + H_2O = C_6H_5{\cdot}CH_2{\cdot}OH + HCl.$$

The most convenient method is the action of concentrated caustic potash on benzaldehyde (Cannizzaro's reaction). One molecule of benzaldehyde is oxidised to benzoic acid and the other reduced to benzyl alcohol:

$$\begin{matrix}C_6H_5{\cdot}CHO + KOH = C_6H_5{\cdot}COOK\\ + \qquad\qquad\quad +\\ C_6H_5{\cdot}CHO \qquad\quad C_6H_5{\cdot}CH_2{\cdot}OH.\end{matrix}$$

Expt. 99.—*Preparation of Benzyl Alcohol.*—Place 20 g. of

benzaldehyde in a small stoppered bottle and add a solution of 18 g. caustic potash in 12 c.c. of water. Shake vigorously till an emulsion is formed which does not settle out, and leave for a day. Shake the mass with the least quantity of water which will dissolve the potassium benzoate, and extract the liquid with ether. Distil off the ether on the water-bath and then distil over the benzyl alcohol (b.p. 204° C.), having replaced the water-condenser by an air-condenser.

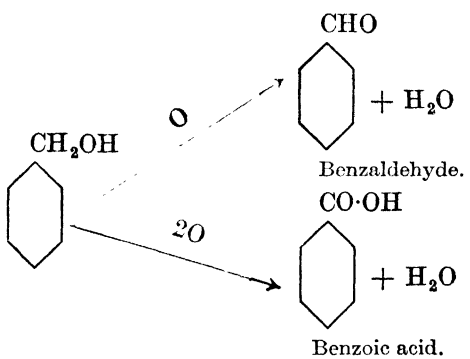
Benzyl alcohol is a colourless liquid with a faint pleasant odour and boils at 204° C. It is slightly soluble in water.

Its chemical properties are closely analogous to those of ethyl alcohol.

Thus with acids or acid chlorides it forms esters. Benzyl acetate, readily made by the usual methods employed for making esters, has a pleasant odour of jasmine and is used in perfumery. Hydrochloric acid or phosphorus trichloride converts benzyl alcohol into benzyl chloride:

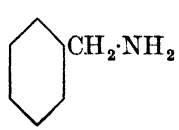
$$C_6H_5{\cdot}CH_2OH + HCl = C_6H_5{\cdot}CH_2Cl + H_2O.$$

Like an aliphatic alcohol, it is readily oxidised to an aldehyde. Dilute nitric acid oxidises it to benzaldehyde, while chromic acid oxidises it to benzoic acid:



Very energetic reduction (phosphorus and hydriodic acid) will convert it into toluene.

The student may with advantage compare the reactions of the hydroxyl group in phenol and benzyl alcohol respectively.

447. Benzylamine,  , is made by the action of ammonia on benzyl chloride :

$$C_6H_5{\cdot}CH_2{\cdot}Cl + NH_3 = C_6H_5{\cdot}CH_2NH_2{\cdot}HCl,$$

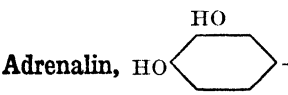
or by reducing benzaldehyde phenylhydrazone:

$$C_6H_5{-}CH = N{-}NH{\cdot}C_6H_5 + 4H = C_6H_5{\cdot}CH_2NH_2 + H_2N{\cdot}C_6H_5.$$

It is a liquid with an ammoniacal odour. It boils at 183° C. In its chemical properties it resembles an aliphatic amine. It is strongly alkaline and forms stable salts. With nitrous acid it gives benzyl alcohol, water and nitrogen,

$$C_6H_5{\cdot}CH_2{\cdot}NH_2 + HNO_2 = C_6H_5{\cdot}CH_2OH + N_2 + H_2O,$$

and not a diazonium salt.

448. Adrenalin, 

may be considered here. It is a substance of great physiological activity, secreted by the medulla of the suprarenal glands possessed by all vertebrates. Adrenalin has a most powerful vaso-constrictor action, and by causing the capillaries to contract effectively stops bleeding. It is administered hypodermically with cocaine (or other local anæsthetic) in minor dental operations. By its constriction of the capillaries it hinders the removal of the local anæsthetic by the blood stream, and also prevents bleeding. It is also useful in combating shock, as it causes a rise in blood pressure.

Adrenalin, as will be seen from its formula, is a phenol with secondary alcoholic and amino-groups in the side chain.

449. Other Physiologically Active Amines.—*p*-Hydroxyphenylethylamine, $HO{\cdot}C_6H_4{\cdot}CH_2{\cdot}CH_2\,NH_2$, is found in the drug ergot, derived from a fungus growing on rye. The dimethyl derivative of this substance is known as *hordenine*, and is found in barley.

It seems that all the *p*-hydroxyphenylalkylamines are physiologically active.

Ephedrine, a base obtained from the Chinese plant *Ephedra sinica*, has the formula $C_6H_5{\cdot}CH(OH){\cdot}CH(NH{\cdot}CH_3){\cdot}CH_3$. It has somewhat similar properties to adrenalin and has been used in the treatment of asthma.

These substances are often classified as alkaloids (Chapter XXXII), but the term is best confined to heterocyclic compounds.

AROMATIC ALDEHYDES

450. Benzaldehyde, $C_6H_5{\cdot}CHO$.—Benzaldehyde occurs in bitter almonds, peach kernels, etc., as a glucoside *amygdalin*, complete hydrolysis of which yields two molecules of glucose, one of hydrocyanic acid and one of benzaldehyde. The structure and decomposition of this substance have already been discussed in § 273 (*q.v.*).

It may be prepared from bitter almonds or peach kernels by grinding them, squeezing out the fatty oil and mixing the meal with water. After twenty-four hours the mixture is steam-distilled,

when benzaldehyde passes over. Some HCN also comes ov may be removed by distillation.

This method is now but little used and benzaldehyde is always made commercially from toluene. Three processes are in commercial use.

(1) Toluene is chlorinated to benzyl chloride (§ 443), $C_6H_5{\cdot}CH_2Cl$, and this is at once hydrolysed and oxidised by boiling it with lead nitrate solution:

$$C_6H_5{\cdot}CH_2Cl + Pb(NO_3)_2 = C_6H_5{\cdot}CHO + 2NO_2 + PbCl(OH).$$

(2) Toluene is chlorinated to benzal chloride (§ 444), which is boiled with milk of lime:

$$C_6H_5{\cdot}CHCl_2 + Ca(OH)_2 = C_6H_5{\cdot}CHO + H_2O + CaCl_2.$$

These processes furnish benzaldehyde contaminated with chlorine compounds which are objectionable for some purposes. The following process produces chlorine-free benzaldehyde.

(3) Toluene is oxidised with sulphuric acid and manganese dioxide or other higher metallic oxides (or electrolytically oxidised):

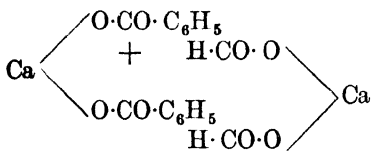
$$C_6H_5{\cdot}CH_3 + 2O = C_6H_5{\cdot}CHO + H_2O.$$

Benzaldehyde may also be made by the usual methods applicable to the preparation of aldehydes, *e.g.*,

(4) Oxidation of benzyl alcohol by dilute nitric acid:

$$C_6H_5{\cdot}CH_2OH + O = C_6H_5{\cdot}CHO + H_2O.$$

(5) Heating a mixture of calcium formate and benzoate:



$$= 2CaCO_3 + 2C_6H_5{\cdot}CHO.$$

(6) The action of chromyl chloride, CrO_2Cl_2, on toluene forms an additive compound, $C_6H_5{-}CH_3{\cdot}(CrO_2Cl_2)_2$, which on addition of water yields the aldehyde.

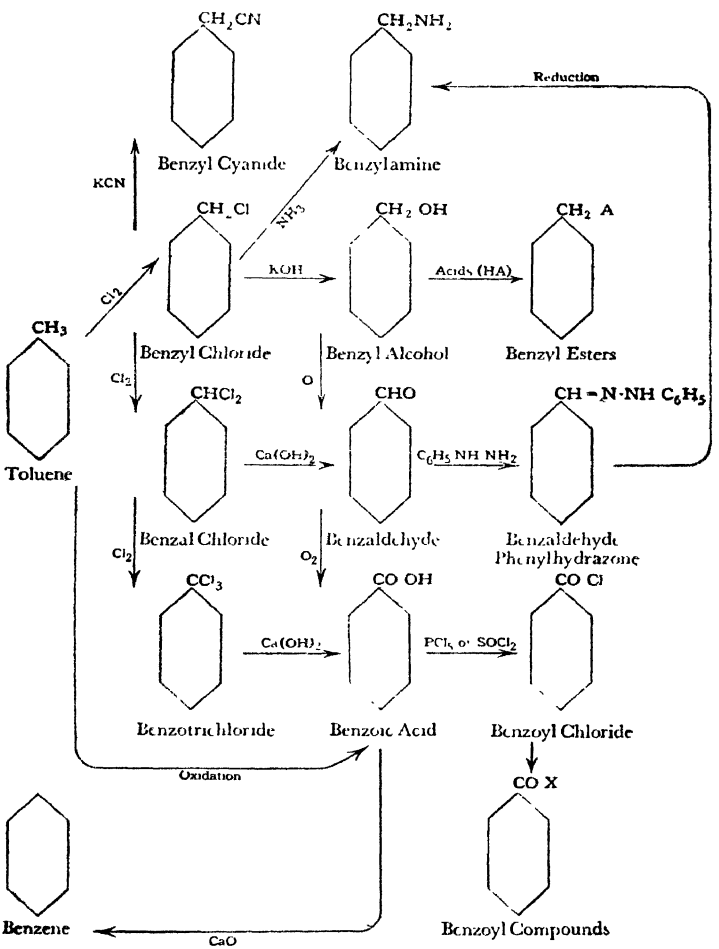
Properties.—Benzaldehyde is a colourless liquid which becomes yellowish on keeping. It has a strong odour of almonds and is not poisonous. It boils at 179–180° C. It is slightly heavier than water, in which it is almost insoluble.

Benzaldehyde displays almost all the reactions of an aliphatic aldehyde (§ 70). It is very readily oxidised to benzoic acid:

$$C_6H_5{\cdot}CHO + O = C_6H_5{\cdot}CO{\cdot}OH.$$

The oxidation is brought about by atmospheric air and takes place

BENZYL AND RELATED COMPOUNDS



in two stages. A peroxide is first formed and then oxidises more of the aldehyde:

$$C_6H_5{\cdot}CHO + O_2 = C_6H_5{\cdot}CO{\cdot}O{\cdot}OH$$
$$C_6H_5{\cdot}CO{\cdot}O{\cdot}OH + C_6H_5{\cdot}CHO = 2C_6H_5{\cdot}CO{\cdot}OH.$$

Thus the aldehyde, if kept in a bottle with an ill-fitting stopper, soon deposits crystals of benzoic acid together with some of the peroxide. It reduces ammoniacal silver nitrate.

Reducing agents convert it into benzyl alcohol:

$$C_6H_5{\cdot}CHO + 2H = C_6H_5{\cdot}CH_2{\cdot}OH.$$

It forms compounds with sodium bisulphite, hydrocyanic acid, hydroxylamine and phenylhydrazine analogous to those formed by acetaldehyde (§ 70).

Like other aldehydes it reacts with phosphorus pentachloride. Benzal chloride is formed:

$$C_6H_5{\cdot}CHO + PCl_5 = C_6H_5{\cdot}CHCl_2 + POCl_3.$$

The chief differences between benzaldehyde and, say, acetaldehyde are to be found in its reactions with ammonia, with potassium cyanide and with caustic potash.

Benzaldehyde does not form an aldehyde-ammonia (§ 70), but gives hydrobenzamide $(C_6H_5{\cdot}CH)_3N_2$.

When heated with alcoholic potassium cyanide it forms *benzoin* (§ 481):

$$C_6H_5{\cdot}CHO + OHC{\cdot}C_6H_5 = C_6H_5{-}CH(OH){-}CO{-}C_6H_5.$$

With caustic potash it does not form resinous products as does acetaldehyde, but gives benzyl alcohol and potassium benzoate (Expt. 99):

$$2C_6H_5{\cdot}CHO + KOH = C_6H_5{\cdot}COOK + C_6H_5{\cdot}CH_2OH.$$

Benzaldehyde condenses with numerous compounds. The most important of such reactions are the formation of certain triphenylmethane dyes (malachite green, § 485), and the formation of unsaturated acids by Perkin's synthesis (§ 466).

Benzaldehyde can be nitrated, sulphonated, etc. *o*-Nitrobenzaldehyde is important as a means of synthesising indigo. It is usually made by oxidising *o*-nitrotoluene. When treated with acetone and caustic soda it yields indigo (*v.* § 563).

Expt. 100.—*Reactions of Benzaldehyde.*—(1) Shake with potassium permanganate solution; note oxidation.

(2) Heat ½ c.c. of benzaldehyde with 1 c.c. of dimethylaniline and a little anhydrous zinc chloride. Note green coloration due to malachite green (§ 485).

(3) Warm with phosphorus pentachloride. Vigorous evolution of HCl. Shake product with excess of water. Benzal chloride remains.

451. Salicylaldehyde, *o*-Hydroxybenzaldehyde, 

—Salicylaldehyde is contained in oil of meadowsweet, *Spiræa Ulmaria*. It and other hydroxyaldehydes are made by the Reimer-Tiemann reaction. One part of phenol and two parts of caustic soda are dissolved in four or five parts of water. The solution is heated to 50–60° C. in a flask fitted with a reflux condenser, and two parts of chloroform are slowly added with good shaking. After half an hour's boiling the excess of chloroform is distilled off. The liquid is acidified and steam-distilled. The *p*-hydroxybenzaldehyde formed at the same time is not volatile in steam and remains behind. The distillate contains phenol and salicylaldehyde. The latter is converted into its bisulphite compound, which is decomposed by sodium carbonate:

$$C_6H_5{\cdot}OH + CHCl_3 + 4NaOH = C_6H_4(ONa)CHO + 3NaCl + 3H_2O.$$

Salicylaldehyde is a colourless liquid with a pleasant odour. It boils at 196·5° C. It is both a phenol and an aldehyde, and has the properties of both classes. Its oxime is used as a means of testing for acetone. If a liquid containing acetone is mixed with a drop of caustic potash solution and 8–10 drops of an alcoholic solution of salicylaldoxime and warmed to 70° C., a purple or carmine colour appears and gradually deepens. Its oxime is used in the estimation of copper.

AROMATIC KETONES

Numerous aromatic ketones are known. These may be entirely aromatic like benzophenone, $C_6H_5{\cdot}CO{\cdot}C_6H_5$, considered in § 477, or aromatic and aliphatic like acetophenone, $C_6H_5{\cdot}CO{\cdot}CH_3$, discussed below.

452. Acetophenone, Phenyl Methyl Ketone, $C_6H_5{\cdot}CO{\cdot}CH_3$.—Acetophenone can be made by distilling a mixture of calcium acetate and benzoate (cf. §§ 109, 113). It is usually made by the Friedel-Crafts reaction. Benzene and acetyl chloride in solution in carbon disulphide are boiled with anhydrous aluminium chloride,

$$C_6H_6 + Cl{\cdot}CO{\cdot}CH_3 = C_6H_5{\cdot}CO{\cdot}CH_3 + HCl,$$

the product being decomposed by water.

Acetophenone is a solid which melts at 20·5° C. and boils at 202° C. It has an odour resembling that of almonds. It is a hypnotic, small doses inducing a natural type of sleep: it is used for this purpose under the name of *hypnone*.

Acetophenone has many of the usual properties of a ketone, but does not form a bisulphite compound.

QUESTIONS

(1) What names are given to monomethylbenzene, three dimethylbenzenes, *s*-trimethylbenzene? How may these compounds be distinguished by chemical methods from benzene?

(2) How are four different compounds of the formula C_7H_7Cl prepared from toluene? What are they called, and how do they differ?

(3) How can toluene be made from benzene? What effect have (*a*) nitric acid, (*b*) chlorine, (*c*) permanganates, on toluene?

(4) What are the cresols? How could pure *p*-cresol be made from toluene? Compare its properties with those of benzyl alcohol.

(5) How is *o*-toluidine made? How could it be converted into *o*-bromotoluene?

(6) What names are given to the compounds, $C_6H_5{\cdot}CH_2Cl$, $C_6H_5{\cdot}CHCl_2$, and $C_6H_5{\cdot}CCl_3$? What products can be obtained by hydrolysing them?

(7) How is benzyl alcohol made? How does it react with acids, alkalis, oxidising agents? Contrast it with *o*-cresol.

(8) How is benzaldehyde made? How does it resemble and differ from acetaldehyde?

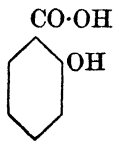
CHAPTER XXVII

AROMATIC ACIDS

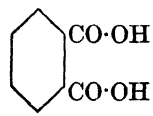
453. Characteristics of Aromatic Acids.—The chief aromatic acids are those which have the carboxyl groups – CO·OH attached directly to the nucleus. The most important of these are:



Benzoic acid.



Salicylic acid.



o-Phthalic acid.

The aromatic acids differ from the aliphatic in only a few particulars other than the differences which exist between all classes of aliphatic and aromatic compounds.

Chief of these is their comparatively easy detachment of the – CO·OH group. Thus benzoic acid gives benzene when heated with lime,

$$C_6H_5{\cdot}CO{\cdot}OH + CaO = C_6H_6 + CaCO_3,$$

and gallic acid forms pyrogallol when merely heated,

$$C_6H_2(OH)_3{\cdot}CO{\cdot}OH = C_6H_3(OH)_3 + CO_2.$$

Analogous behaviour is uncommon among monobasic aliphatic acids.

454. Benzoic Acid, $C_6H_5{\cdot}CO{\cdot}OH$.—*Preparation.*—(1) Benzoic acid is found in gum benzoin and some other balsams and resins. It can be prepared from the gum by sublimation.

Benzoic acid is now almost exclusively manufactured from toluene.

(2) The toluene is converted into benzotrichloride (§ 445) and this is boiled with milk of lime or with water under pressure:

$$2C_6H_5{\cdot}CCl_3 + 4Ca(OH)_2 = (C_6H_5CO{\cdot}O)_2Ca + 3CaCl_2 + 4H_2O.$$

The calcium benzoate is decomposed by a dilute mineral acid.

(3) Benzoic acid can be made by boiling benzonitrile, phenyl cyanide, with dilute acid:

$$C_6H_5{\cdot}CN + 2H_2O = C_6H_5{\cdot}CO{\cdot}O{\cdot}NH_4.$$

(4) Hippuric acid, benzoylglycocoll, is found in the urine of

herbivorous animals. When boiled with hydrochloric acid it forms benzoic acid and glycocoll:

$$C_6H_5{\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}OH = C_6H_5{\cdot}CO{\cdot}OH + NH_2{\cdot}CH_2{\cdot}CO{\cdot}OH.$$
$$+ HO{\cdot}H$$

Properties.—Benzoic acid crystallises from water in white leaflets, and can be sublimed, when it forms fine snow-like needles. It has a somewhat pleasant incense-like odour; in larger quantities its vapour excites coughing. Benzoic acid melts at 121·4° C. It sublimes readily and boils at 249° C. It is very sparingly soluble in cold water (0·3 per cent) but moderately soluble in boiling water (5·9 per cent).

Benzoic acid forms stable benzoates with the metals, some of which are used in medicine. It forms pleasant-smelling esters, such as ethyl benzoate (b.p. 211·8° C.), which can be prepared by the usual methods.

When benzoic acid is heated with lime it gives benzene (§ 453). Oxidising agents do not readily affect it, but it can be reduced with some difficulty to benzaldehyde and benzyl alcohol.

When benzoic acid is treated with phosphorus pentachloride, or, better, thionyl chloride, $SOCl_2$, the important acid chloride, benzoyl chloride, is formed:

$$C_6H_5{\cdot}CO{\cdot}OH + PCl_5 = C_6H_5{\cdot}CO{\cdot}Cl + POCl_3 + HCl.$$

Benzoic acid can be chlorinated and nitrated. The meta-compound is usually obtained (cf. § 347).

The most important substitution products of benzoic acid are *o*-hydroxybenzoic acid or salicylic acid and *o*-aminobenzoic acid or anthranilic acid. These are discussed in §§ 459, 470, below.

The chief uses of benzoic acid are in medicine. When administered by mouth, usually as ammonium benzoate, it is excreted in the urine as hippuric acid, benzoylglycocoll. This tends to stimulate and disinfect the urinary system.

Benzoic acid is the chief constituent of friar's balsam, which is used by mixing a small quantity with very hot water and inhaling the vapour. This contains some benzoic acid which tends to disinfect and stimulate the bronchial mucous membrane.

It has been employed as a preservative for foodstuffs, but its use is not to be commended.

Expt. 101.—*Reactions of Benzoic Acid.*—(1) Heat in a test-tube: note sublimation and incense-like odour.

(2) Grind a little with excess of lime and heat. Inflammable vapours of benzene.

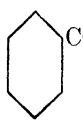
(3) Add PCl_5 and warm. HCl is evolved. Cool product,

dilute with water. Benzoyl chloride comes out as an oil of very irritating odour, and slowly redissolves on boiling.

(4) Add ammonia to ferric chloride solution until it is red, but no actual ppt. is formed. Add this solution to a solution of benzoic acid *just* neutralised with sodium hydroxide. Flesh-coloured ppt. of basic ferric benzoate.

BENZOYL COMPOUNDS

Just as acetyl compounds, $CH_3{\cdot}CO{\cdot}R$ (§ 84), are derived from acetic acid, $CH_3{\cdot}CO{\cdot}OH$, so benzoyl compounds, $C_6H_5{\cdot}CO{\cdot}R$, are derived from benzoic acid, $C_6H_5{\cdot}CO{\cdot}OH$.

455. Benzoyl Chloride, 

.—Benzoyl chloride is made by heating benzoic acid with a slight excess of phosphorus pentachloride, or, better, thionyl chloride,

$$C_6H_5{\cdot}CO{\cdot}OH + SOCl_2 = C_6H_5{\cdot}CO{\cdot}Cl + SO_2 + HCl.$$

The product is distilled: benzoyl chloride comes over at 197° C.

Physical Properties.—Benzoyl chloride is a colourless liquid with a pungent odour which irritates the eyes. It boils at 197·2° C. It is heavier than water.

Benzoyl chloride is insoluble in water, but reacts with it.

Chemical Properties.—Benzoyl chloride closely resembles acetyl chloride in its chemical reactions (*v.* § 85). It reacts slowly with cold water, but rapidly with hot, forming benzoic and hydrochloric acids:

$$C_6H_5{\cdot}CO{\cdot}Cl + H_2O = C_6H_5{\cdot}CO{\cdot}OH + HCl.$$

With ammonia it forms benzamide (*q.v.*).

$$C_6H_5{\cdot}CO{\cdot}Cl + NH_3 = C_6H_5{\cdot}CO{\cdot}NH_2 + HCl.$$

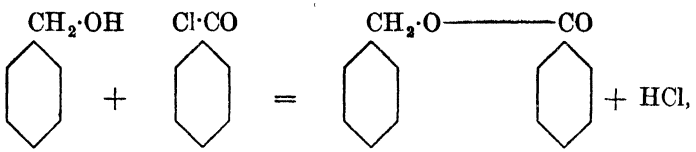
Like acetyl chloride, it reacts with compounds containing hydroxyl, amino- or imino-groups, and forms benzoyl compounds. Thus with ethyl alcohol it gives ethyl benzoate:

$$C_2H_5OH + Cl{\cdot}CO{\cdot}C_6H_5 = C_2H_5{\cdot}O{\cdot}CO{\cdot}C_6H_5 + HCl.$$

With glycocoll it gives hippuric acid:

$$C_6H_5{\cdot}CO{\cdot}Cl + H_2N{\cdot}CH_2{\cdot}CO{\cdot}OH = C_6H_5{\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}OH + HCl.$$

Its action on the hydroxyl and amino-groups makes it a useful means of testing for their presence. Thus benzyl alcohol would give a benzoyl derivative (benzyl benzoate):



thus proving that it contains a hydroxyl group, while the isomeric anisole, $C_6H_5{\cdot}O{\cdot}CH_3$, would not give any benzoyl compound. Benzoic anhydride, $(C_6H_5{\cdot}CO)_2O$, is used in the same way.

456. Benzoic Anhydride, $C_6H_5{\cdot}CO{-}O{-}CO{\cdot}C_6H_5$.—Benzoic anhydride can be made by the action of benzoyl chloride on sodium benzoate (cf. § 86):

$$C_6H_5{\cdot}CO{\cdot}Cl + Na{\cdot}O{\cdot}CO{\cdot}C_6H_5 = C_6H_5{\cdot}CO{\cdot}O{\cdot}CO{\cdot}C_6H_5 + NaCl,$$

but is best made by refluxing a mixture of sodium benzoate with phosphorus oxychloride at 150° C. The sodium salts are removed by washing with dilute sodium carbonate solution. The residual anhydride is dried and distilled, when it passes over at 360° C.:

$$4C_6H_5{\cdot}CO{\cdot}ONa + POCl_3 = 2(C_6H_5{\cdot}CO)_2O + NaPO_3 + 3NaCl.$$

Physical Properties.—Benzoic anhydride forms white crystals which melt at 42° C. to a liquid which boils at 360° C. It is insoluble in water.

Chemical Properties.—Benzoic anhydride resembles acetic anhydride (*q.v.*), but is much less reactive. Cold water hardly affects it, but on boiling with water it gives benzoic acid:

$$\begin{matrix} C_6H_5 - CO \\ C_6H_5 - CO \end{matrix}\!\!>\!O + \begin{matrix} H \\ OH \end{matrix} = C_6H_5{\cdot}CO{\cdot}OH + C_6H_5{\cdot}CO{\cdot}OH.$$

Its other reactions resemble those of acetic anhydride (§ 86). It substitutes benzoyl, $C_6H_5{\cdot}CO{-}$, in hydroxy- and amino-compounds.

456a. Benzamide, $C_6H_5{\cdot}CO{\cdot}NH_2$, is formed by the action of ammonia on benzoyl chloride. It is a white solid, soluble in hot water, melting at 130° C. and boiling at 288° C.

457. Hippuric Acid, Benzoylglycocoll, $C_6H_5{\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}OH$, is found in the urine of herbivora but not in that of carnivora. It can be prepared from the urine of horses or cows but is commonly made by heating benzoic anhydride with glycocoll:

$$(C_6H_5{\cdot}CO)_2O + 2NH_2{\cdot}CH_2{\cdot}CO{\cdot}OH = 2C_6H_5{\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}OH + H_2O$$

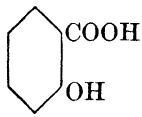
It is a solid melting at 187·5° C. and is soluble in water. It is easily hydrolysed to benzoic acid and amino-acetic acid (glycocoll):

$$C_6H_5{\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}OH + HO{\cdot}H = C_6H_5{\cdot}CO{\cdot}OH + NH_2{\cdot}CH_2{\cdot}CO{\cdot}OH.$$

457a. Aminobenzoic Acids.—*o*-Aminobenzoic acid is known as anthranilic acid. It is prepared from phthalimide (§ 470) and used in the synthesis of indigo (§ 563). Ethyl *p*-aminobenzoate is used as a local anæsthetic, *benzocaine*.

458. The Toluic Acids, $CH_3 \cdot C_6H_4 \cdot CO \cdot OH$, are obtained by gently oxidising the three xylenes (§ 423). They closely resemble benzoic acid.

HYDROXY-BENZOIC ACIDS

459. Salicylic Acid, *o*-Hydroxybenzoic Acid, 

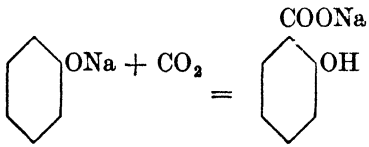
.—Three hydroxybenzoic acids are known, but only the ortho-compound, salicylic acid, is of importance.

It is used in medicine, in the manufacture of aspirin and in the dye industry.

Occurrence and Preparation.—Salicylaldehyde (§ 451) and methyl salicylate (§ 460) are found in certain plants.

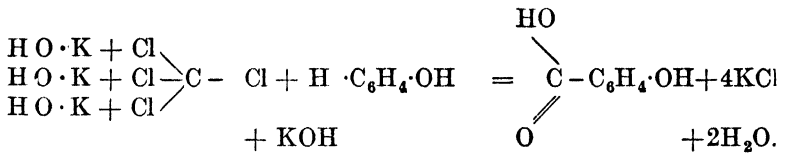
Salicylic acid is prepared industrially by the reaction of carbon dioxide with sodium phenoxide (Kolbe's reaction).

Pure phenol is treated with caustic soda solution and the resulting phenoxide evaporated to dryness. The dry powder is heated to 120—140° C. in an atmosphere of carbon dioxide at 100 lb./sq. in. pressure, as long as any gas is absorbed.



The sodium salicylate is acidified and the sparingly soluble salicylic acid separates. It may be purified by recrystallisation from hot water or alcohol.

Salicylic acid can be made by the Reimer-Tiemann process using phenol, carbon tetrachloride, and alcoholic potash:



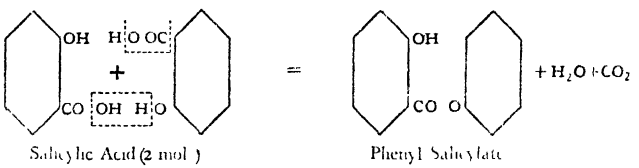
p-Hydroxybenzoic acid is formed at the same time.

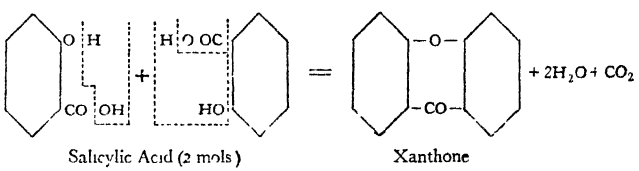
Properties.—Salicylic acid forms white needle-shaped crystals which melt at 156·7° C. When slowly heated it sublimes, but when

quickly heated decomposes (*v. infra*). It is somewhat poisonous but finds numerous uses in medicine. Its alcoholic solution is applied to warts, corns, etc., as it has a disintegrating effect on the hardened skin. Internally, it is given as sodium salicylate and is useful in rheumatic conditions. Acetylsalicylic acid, aspirin (*q.v.*), has similar effects to salicylic acid, but is much less poisonous.

Salicylic acid can be used as a preservative since it has a strong antiseptic action. It should not be used as a preservative for food.

Chemical Properties.—Salicylic acid decomposes when heated. At about 195—220° C. it forms first salol, *phenyl salicylate*, and then *xanthone*.





When rapidly heated it is converted into phenol and carbon dioxide:

$$HO{\cdot}C_6H_4{\cdot}CO{\cdot}OH = HO{\cdot}C_6H_5 + CO_2.$$

Salicylic acid has the reactions of a phenol and an aromatic acid. Thus, like phenol, it gives a violet colour with ferric chloride and forms an acetyl compound. It also forms azo-dyes with diazonium salts and this is its chief commercial use.

It readily undergoes substitution to chloro-, bromo- and nitro-salicylic acids. Reacting as an acid it forms stable salts and esters which are discussed below.

Salicylic acid can be reduced to pimelic acid (§ 204) if sodium and boiling amyl alcohol are used as reducing agent.

460. Methyl Salicylate, $CH_3{\cdot}O{\cdot}CO{\cdot}C_6H_4{\cdot}OH$.—Methyl salicylate, known as oil of wintergreen, is found in the plant *Gaultheria procumbens*. It is prepared by boiling salicylic acid and methyl alcohol with sulphuric acid and separating the ester by shaking with dilute alkali.

It is a colourless liquid with a strong and not unpleasant odour. It boils at 222·2° C. It is used in medicine. It has the usual properties of esters (§ 92).

461. Phenyl Salicylate, Salol, $HO{\cdot}C_6H_4{\cdot}CO{\cdot}O{\cdot}C_6H_5$.—Salol can be made by heating salicylic acid alone (*v. supra*), but is better prepared by heating a mixture of sodium salicylate and phenoxide with carbonyl (or phosphoryl) chloride:

$$\begin{matrix} HO{\cdot}C_6H_4{\cdot}CO{\cdot}O{\cdot}Na \\ + \\ C_6H_5{\cdot}O{\cdot}Na \end{matrix} + COCl_2 = \begin{matrix} HO{\cdot}C_6H_4{\cdot}CO \\ \\ C_6H_5 \end{matrix}\!\!>\!O + 2NaCl + CO_2.$$

It forms white crystals melting at 43° C. It is used as an intestinal antiseptic. It passes through the stomach unchanged but breaks up into phenol and salicylic acid when it meets the secretion of the pancreas in the duodenum.

462. Acetylsalicylic Acid, Aspirin, $CH_3{\cdot}CO{\cdot}O{\cdot}C_6H_4{\cdot}CO{\cdot}OH$.—Aspirin is made by treating salicylic acid with acetyl chloride:

$$CH_3{\cdot}CO{\cdot}Cl + HO{\cdot}C_6H_4{\cdot}CO{\cdot}OH = CH_3{\cdot}CO{\cdot}O{\cdot}C_6H_4{\cdot}CO{\cdot}OH + HCl.$$

It is a white solid, sparingly soluble in water. It is of great value in acute rheumatic conditions. It finds an enormous sale as an analgesic, relieving, but not curing, neuralgia, toothache, headaches, etc. In large doses it is poisonous.

463. Protocatechuic Acid, 3 : 4-Dihydroxybenzoic Acid, $C_6H_3(OH)_2{\cdot}CO{\cdot}OH$, is obtained from various resins. It has reducing properties like pyro-catechol (§ 356).

464. Tannins.—The name 'tannin' is given to a group of vegetable products which have the property of coagulating proteins and forming insoluble compounds with them, and which are therefore capable of converting raw skins into leather. Tannins are found in many different plants, notably the bark and galls of the oak, the sumach tree, etc.

The tannins are of various compositions. Some are glucosides (§ 273) of gallic acid or of protocatechuic acid (§ 463). Common tannin or tannic acid forms some 50 per cent. of gall-nuts. It is digallic acid, $(HO)_2C_6H_2(CO_2H){\cdot}O{\cdot}(CO_2H)C_6H_2(OH)_2$.

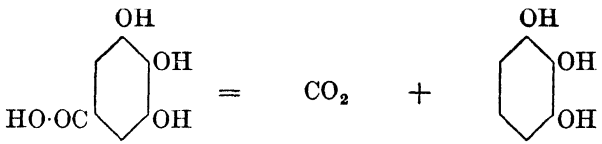
When boiled with water it forms gallic acid. Besides the use of tannin in tanning hides, it finds uses in medicine as an astringent and a styptic. A recent use is in the treatment of severe burns. A tannic acid spray applied to the part coagulates and so immobilises the poisonous products of the effect of heat on the proteins of the flesh, thus preventing the often fatal effects which follow their absorption into the system.

465. Gallic Acid, 3:4:5-Trihydroxybenzoic Acid, $C_6H_2(OH)_3{\cdot}COOH$, is of some technical importance. It occurs in galls in the form of tanuin (§ 464), from which it is prepared by boiling with water:

$$[HO{\cdot}OC{\cdot}C_6H_2{\cdot}(OH)_2]_2O + H_2O = 2(HO)_3C_6H_2{\cdot}CO{\cdot}OH.$$

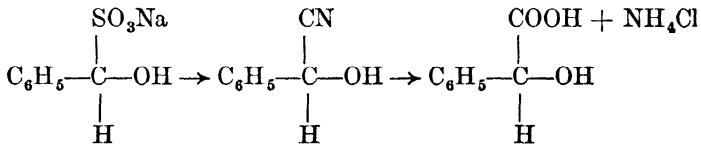
Gallic acid forms white needles readily soluble in water.

When heated it breaks up, giving pyrogallol (1 : 2 : 3-trihydroxybenzene):—



It is a strong reducing agent. An important use of gallic acid is in the manufacture of ink, which at its simplest is a mixture of a ferrous salt with gallic acid. With ferrous sulphate it gives a pale-brown ferrous gallate. This is not oxidised in air in presence of traces of acid, but when it dries on paper the acid is neutralised and the ferrous gallate oxidises to a black substance. The ink is coloured with indigo-sulphonic acid, for it would otherwise be very pale in colour before it dried.

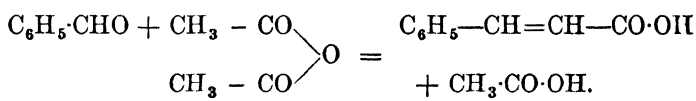
465a. Mandelic acid, Phenylglycollic acid, $C_6H_5{\cdot}CH(OH){\cdot}CO{\cdot}OH$ occurs in the products obtained when bitter almonds are crushed with water (§ 273). It is prepared by treating the bisulphite compound of benzaldehyde with potassium cyanide solution. Mandelonitrile separates as an oil and is hydrolysed by boiling with hydrochloric acid:



Mandelic acid forms colourless crystals which melt at 118° C. It is optically active. Its importance lies in its power of combating certain bacterial infections of the urinary system.

466. Cinnamic Acid, Phenylacrylic Acid, $C_6H_5{\cdot}CH{:}CH{\cdot}CO{\cdot}OH$, occurs in certain balsams and resins, such as balsam of Peru and storax.

It is made by Perkin's reaction in which benzaldehyde, acetic anhydride and sodium acetate are heated together:



Alternatively, benzal chloride may be heated with sodium acetate (§ 444).

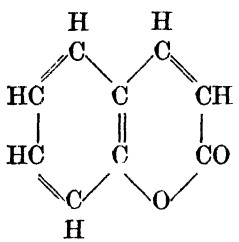
Cinnamic acid resembles benzoic acid in most of its physical properties. It melts at 133° C. and boils at 300° C.

Cinnamic acid is a typical unsaturated acid. Like acrylic acid (*q.v.*, § 178), it reacts with hydrogen, with bromine and with hydrogen halides, forming addition products. Oxidation converts it first

into benzaldehyde, then into benzoic acid. It was at one time used in the manufacture of indigo, but the process is obsolete.

Cinnamaldehyde, $C_6H_5—CH=CH—CHO$, is *phenylacrolein*. It is contained in oil of cinnamon, to which it gives its aromatic odour. It has the reactions of an aldehyde and of an unsaturated compound.

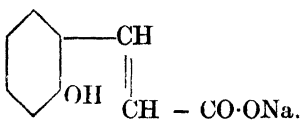
467. Coumarin,



is the odoriferous principle of new-mown hay, woodruff, Tonka beans, etc., and finds much use in perfumery. It is the lactone of *o*-hydroxy-cinnamic acid.

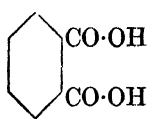
It is synthesised by Perkin's synthesis from salicylaldehyde (cf. §§ 466, 451).

Coumarin forms pleasant-smelling crystals which melt at 67° C. It boils at 290° C. Alkalis convert it into the sodium salt of coumarinic acid:

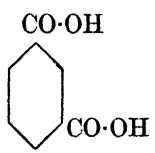


THE PHTHALIC ACIDS

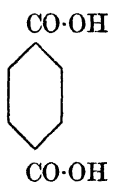
The phthalic acids have the formula $C_6H_4(CO·OH)_2$. Three isomerides are known:



Phthalic acid.



*iso*Phthalic acid.



Terephthalic acid.

but of these only the first, *o*-phthalic acid, is of technical importance.

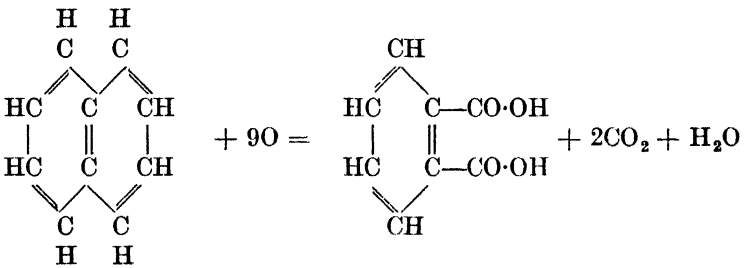
The three isomerides can be made by oxidising the respective xylenes with nitric acid or potassium permanganate:

$$C_6H_4(CH_3)_2 + 6O = C_6H_4(CO·OH)_2 + 2H_2O,$$

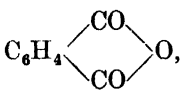
but *o*-phthalic acid is usually made by oxidising naphthalene.

468. Phthalic Acid, Benzene-*o*-dicarboxylic Acid. $C_6H_4(CO·OH)_2$. Phthalic acid can be made by oxidising ortho-xylene (as mentioned ove). It may be manufactured by oxidising naphthalene, $C_{10}H_8$,

with concentrated sulphuric acid at 270—300° C., a little mercuric sulphate being added as a catalyst.



This method is being superseded by direct oxidation of naphthalene vapour by air in presence of vanadium pentoxide at 300—350° C. The anhydride,

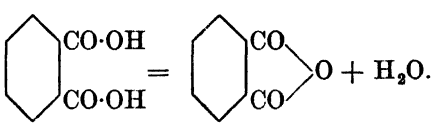


is thus produced, and may, if required, be converted into the acid by boiling with water.

A method more convenient for a laboratory preparation is to oxidise the naphthalene by heating it gently with two parts of potassium chlorate and ten parts of concentrated hydrochloric acid. This chlorinates it to tetrachloro-naphthalene, which is then oxidised by concentrated nitric acid.

Phthalic acid forms white crystals which melt above 200° C. with some decomposition into the anhydride. It is sparingly soluble in cold water (0·5 per cent.) and readily soluble in hot (18 per cent.). It is not readily soluble in ether, and is insoluble in chloroform.

o-Phthalic acid, when heated, very readily forms phthalic anhydride,

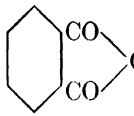


The other phthalic acids (§ 471) do not form anhydrides when heated.

Like benzoic acid, it yields benzene when heated with lime,

$$C_6H_4(CO{\cdot}OH)_2 + 2CaO = 2CaCO_3 + C_6H_6.$$

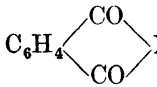
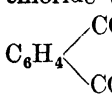
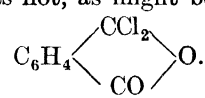
The chief importance of phthalic acid is in the manufacture of phthalic anhydride, which is used in manufacturing numerous important dye-stuffs.

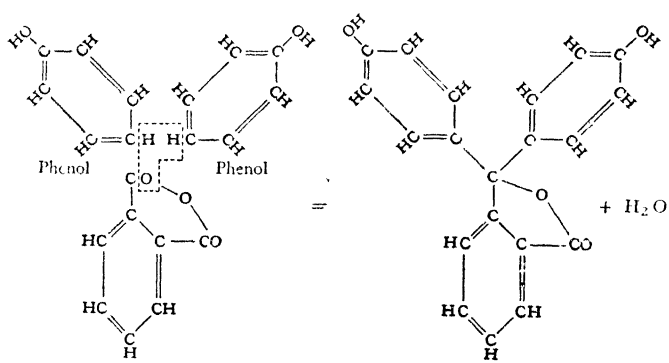
469. Phthalic Anhydride,  .—Phthalic anhydride is made by the action of heat upon phthalic acid, as described above. It is prepared commercially by heating fuming sulphuric acid and naphthalene. Phthalic acid is first formed as described in § 468 above, then decomposes, and phthalic anhydride sublimes together with some sulphuric acid. It is purified by centrifuging and re-subliming.

The preparation by direct oxidation of naphthalene by air is now much used, and is described in § 468 above.

Phthalic anhydride forms tough white needles which melt at 128° C. and boil at 284° C. It is almost insoluble in cold water.

Phthalic anhydride reacts only very slowly with water, forming phthalic acid.

It reacts with ammonia, giving phthalimide (*q.v.* below),  . With phosphorus pentachloride it gives phthalyl chloride which has not, as might be expected, the formula  , but  . Phthalic anhydride may be nitrated and chlorinated like other benzene derivatives. Its chief importance is its reaction with phenols giving the phthaleins, an important class of triphenylmethane dyes. These are discussed in Chapter XXVIII., but an example of the process may be given here. Phenol, when heated with phthalic anhydride, gives the familiar indicator, phenolphthalein.

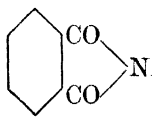


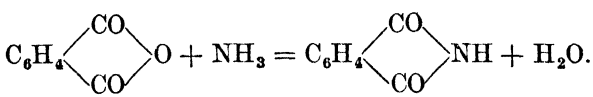
Phthalic Anhydride — Phenolphthalein

A condensation of this type can be carried out with any internal anhydride containing the group  and any phenol with the *p*-position free.

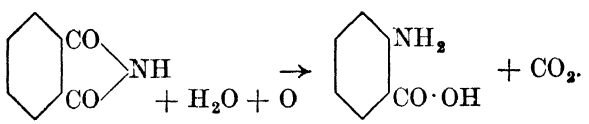
The formation of the dye fluorescein (§ 491) is so readily brought about that it affords an excellent test for phthalic anhydride.

The phthalic anhydride (1 g.) is fused with 2 g. of resorcinol and a drop of concentrated sulphuric acid. The product, containing fluorescein, is dissolved in dilute caustic soda and poured into a large volume of water. Even small traces of fluorescein give a fine yellow-green fluorescent solution.

470. Phthalimide,  , is made by passing dry ammonia gas into molten phthalic anhydride for a long period:

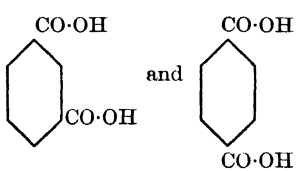


It is of interest as being readily converted by treatment with potassium hypobromite into *anthranilic acid*, which can be further transformed into indigo (§ 563):



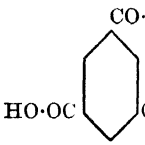
The reaction is analogous to the conversion of acetamide into methylamine (*v.* § 120).

471. ***iso*Phthalic Acid and Terephthalic Acid** are the respective names given to the acids of formulæ



As might be expected from their formulæ they differ from phthalic acid in not forming an internal anhydride or imide, and consequently in not giving rise to phthaleins. They are, therefore, of small practical importance.

472. Trimesic Acid, $C_6H_3(CO\cdot OH)_3$,

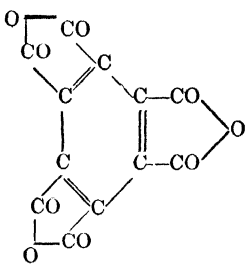


is made by oxidising mesitylene, $C_6H_3(CH_3)_3$. The other two benzene-tricarboxylic acids (1 : 2 : 3 and 1 : 2 : 4) are known, as also are the three tetracarboxylic acids, $C_6H_2(CO\cdot OH)_4$.

473. Mellitic Acid, $C_6(CO\cdot OH)_6$, is of interest as occurring in peat beds in the form of aluminium mellitate and as being formed by the direct oxidation of graphite with potassium permanganate. Its formation is evidence for the existence of a hexagonal structure in elementary carbon: this is confirmed by the results of the X-ray analysis of graphite crystals.

Mellitic acid is very stable. It cannot be substituted but may be reduced to hydromellitic acid, $C_6H_6(CO_2H)_6$.

It forms an anhydride,



which is of interest as being an oxide of carbon, $C_{12}O_9$.

QUESTIONS

(1) How is benzoic acid made? In what respects does it differ from acetic acid? How can it be converted into (*a*) benzene, (*b*) benzoic anhydride?

(2) How are salicylaldehyde, salicylic acid, methyl salicylate, aspirin, prepared synthetically? What substances are formed by the action of heat upon salicylic acid? Is anything similar found among aliphatic hydroxy-acids?

(3) Write the formulæ of the three phthalic acids. How is *o*-phthalic acid made, and how does it differ from the other two acids?

(4) How is phthalic anhydride made? How can it be converted into phthalic acid, phenolphthalein, phthalimide?

CHAPTER XXVIII

COMPOUNDS CONTAINING MORE THAN ONE BENZENE RING

THE most important hydrocarbons containing two or more benzene rings are:

Diphenyl	$C_6H_5 \cdot C_6H_5$
Diphenylmethane	$C_6H_5 \cdot CH_2 \cdot C_6H_5$
Dibenzyl	$C_6H_5 \cdot CH_2 \cdot CH_2 \cdot C_6H_5$
Stilbene	$C_6H_5 \cdot CH = CH \cdot C_6H_5$
Triphenylmethane	$(C_6H_5)_3CH$.

The chief derivatives of these which should be noticed are,

pp'-Diaminodiphenyl or Benzidine, $NH_2 \cdot C_6H_4 \cdot C_6H_4 \cdot NH_2$

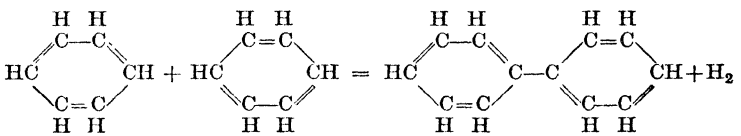
Benzoin	$C_6H_5 \cdot CO \cdot CH(OH) \cdot C_6H_5$
Benzil	$C_6H_5 \cdot CO \cdot CO \cdot C_6H_5$.

The triphenylmethane dyes.

474. Diphenyl, $C_6H_5 \cdot C_6H_5$, may be prepared by Fittig's reaction, *i.e.*, by the action of sodium on a solution of bromobenzene in ether:

$$C_6H_5Br + 2Na + BrC_6H_5 = C_6H_5 \cdot C_6H_5 + 2NaBr.$$

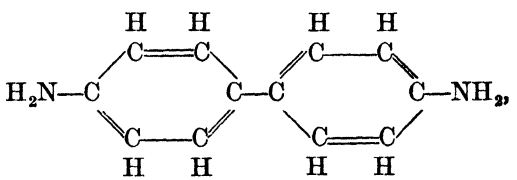
The reaction is slow, and a more convenient method is to pass the vapour of benzene through a red-hot iron tube packed with pumice, or through molten lead. The issuing vapours are condensed and the product fractionally distilled. Diphenyl passes over at 250–260° C. and is recrystallised from alcohol.



Diphenyl forms white crystals. It melts at 70·5° C. and boils at 254° C.

Its chemical properties on the whole resemble those of benzene. It forms numerous substitution products, *e.g.*, chloro- and nitro-diphenyls. Substituent groups usually, but not always, enter the para-position.

475. Benzidine, *pp'*-Diaminodiphenyl,



is a substance of commercial importance.

Benzidine is made technically from nitrobenzene. This is reduced with zinc dust and caustic soda, thus forming hydrazobenzene (§ 407):

$$C_6H_5{\cdot}NO_2 + 10H + O_2N{\cdot}C_6H_5 = C_6H_5{-}NH{-}NH{-}C_6H_5 + 4H_2O.$$

The liquid is now acidified, care being taken to keep it cool. Hydrazobenzene separates out, and is filtered off and then boiled with dilute hydrochloric acid. It undergoes transformation to the isomeric benzidine, which remains in solution as the hydrochloride:

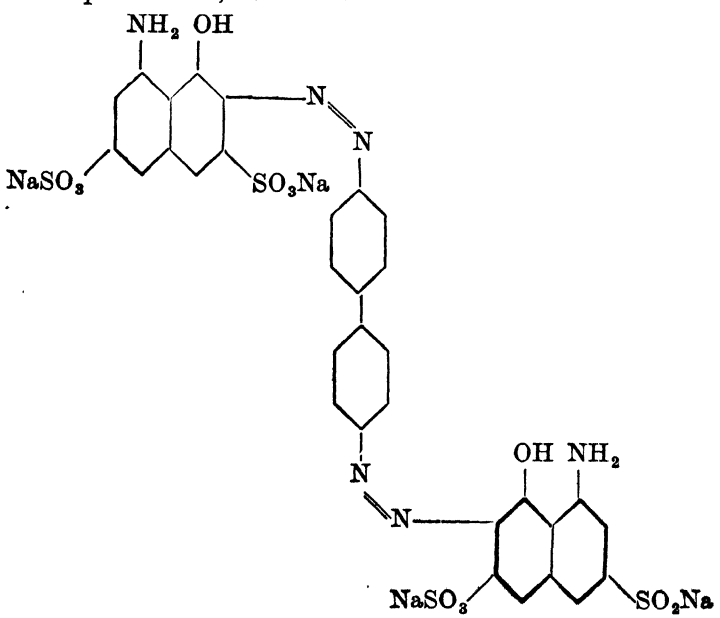
$$C_6H_5{\cdot}NH{\cdot}NH{\cdot}C_6H_5 = NH_2{\cdot}C_6H_4{\cdot}C_6H_4{\cdot}NH_2.$$

Dilute sulphuric is added and precipitates benzidine sulphate, which is sparingly soluble, and benzidine is prepared from this by boiling it with caustic soda.

Properties.—Benzidine forms colourless crystals melting at 122° C. It boils at 400° C. Its importance lies in the fact that its salts, when treated with nitrous acid, give diphenylbisdiazonium salts,

$$\begin{array}{llll} ClH_3N{\cdot}C_6H_4{\cdot}C_6H_4{\cdot}NH_3Cl & & Cl{-}N{-}C_6H_4{-}C_6H_4{-}N{-}Cl & +4H_2O \\ + & + = & \| \qquad\qquad \| & \\ HNO_2 & HNO_2 & N \qquad\qquad N & \end{array}$$

and these couple with various phenols, giving azo-dyes which have the valuable property of dyeing cotton and linen without a mordant. An example is Direct Blue 2B or Chlorazol-Blue RB, made by coupling diphenylbisdiazonium chloride with 8-amino-*a*-naphthol-3 : 6-disulphonic acid, in alkaline solution.



Direct Blue 2B

Tolidine (dimethylbenzidine) and other substituted benzidines give similar valuable dyes.

Benzidine is employed as a means of testing for blood. Sodium perborate and acetic acid will not oxidise a solution of benzidine in pyridine, but on addition of a little blood, a blue colour is produced owing to the catalytic action of the *peroxidase* contained therein.

476. Diphenylmethane, $C_6H_5 \cdot CH_2 \cdot C_6H_5$.—Diphenylmethane can be made by the Friedel-Crafts reaction (§ 342) from benzene, methylene chloride (CH_2Cl_2) and aluminium chloride. It is, however, usually made by heating benzyl alcohol, benzene and concentrated sulphuric acid:

$$C_6H_5 \cdot CH_2OH + H \cdot C_6H_5 = C_6H_5 \cdot CH_2 \cdot C_6H_5 + H_2O.$$

Diphenylmethane forms colourless, pleasant-smelling needles. It melts at 26–27° C. and boils at 261–262° C.

It resembles benzene in being readily nitrated. When oxidised by chromic acid it gives benzophenone, $C_6H_5 \cdot CO \cdot C_6H_5$.

477. Benzophenone, $C_6H_5 \cdot CO \cdot C_6H_5$.—Benzophenone is formed as mentioned above, but is better made by the Friedel-Crafts reaction from benzene, benzoyl chloride and aluminium chloride (cf. § 342):

$$C_6H_6 + Cl \cdot CO \cdot C_6H_5 = C_6H_5 \cdot CO \cdot C_6H_5 + HCl.$$

It can also be obtained in rather poor yield by distilling calcium benzoate (cf. § 109).

It forms colourless crystals melting at 48—49° C. It boils at 306° C. Like other ketones, it gives an oxime and phenylhydrazone. On reduction it gives the secondary alcohol benzhydrol, $C_6H_5 \cdot CH(OH) \cdot C_6H_5$. Benzophenone is itself not of much importance, but its methylamino-derivatives, such as 'Michler's ketone,' $(CH_3)_2N \cdot C_6H_4 \cdot CO \cdot C_6H_4 \cdot N(CH_3)_2$, are used in the dye industry.

478. Trihydroxybenzophenone, $C_6H_5 \cdot CO \cdot C_6H_2(OH)_3$, is a dye-stuff known as Alizarin Yellow. It is made by heating equal parts of pyrogallol and benzoic acid to 145° C. and adding three parts of zinc chloride, stirring well. The latter acts as a dehydrating and condensing agent:

$$C_6H_5 \cdot CO \cdot OH + H \cdot C_6H_2(OH)_3 = C_6H_5 \cdot CO \cdot C_6H_2(OH)_3 + H_2O.$$

Note the effect of the auxochrome —OH in converting the colourless benzophenone, which, however, contains the chromophore —CO—, into a yellow dye-stuff.

479. Diphenylethane, Dibenzyl, $C_6H_5 \cdot CH_2 \cdot CH_2 \cdot C_6H_5$.—Diphenylethane can be made by treating benzyl chloride with sodium,

$$C_6H_5 \cdot CH_2Cl + 2Na + Cl \cdot H_2C \cdot C_6H_5 = 2NaCl + C_6H_5 \cdot CH_2 \cdot CH_2 \cdot C_6H_5.$$

In its general properties it resembles diphenylmethane.

480. Stilbene, *s*-Diphenylethylene, $C_6H_5 \cdot CH = CH \cdot C_6H_5$, is prepared by the action of sodium on benzal chloride:

$$C_6H_5 \cdot CHCl_2 + 4Na + Cl_2HC \cdot C_6H_5 = C_6H_5 \cdot CH = CH \cdot C_6H_5 + 4NaCl.$$

It is a typical olefine, forming addition products in the same way as ethylene.

481. Benzoin, $C_6H_5 \cdot CH(OH) \cdot CO \cdot C_6H_5$.—When benzaldehyde is

boiled with an alcoholic solution of potassium cyanide, benzoin is formed:

$$C_6H_5{\cdot}CHO + CHO{\cdot}C_6H_5 = C_6H_5{\cdot}CH(OH){\cdot}CO{\cdot}C_6H_5.$$

Acetaldehyde does not give any analogous reaction.

Expt. 102.—*Preparation of Benzoin.*—Place 10 g. of benzaldehyde and 25 c.c. of alcohol in a 100 c.c. round-bottomed flask fitted with reflux condenser. Dissolve 2 g. of potassium cyanide in 5 c.c. of cold water, and add the solution to the contents of the flask. Heat on the water-bath for an hour. The reaction often goes suddenly and the product solidifies. On the other hand, seeding with a crystal of benzoin is sometimes necessary. Pour the contents of the flask into a beaker and leave it to cool spontaneously. Filter off the crystals, wash with a little alcohol and dry. If necessary the product may be recrystallised from a little alcohol.

Benzoin forms well-formed prismatic crystals which melt at 134° C. It is at once a ketone and a secondary alcohol. The secondary alcohol group is readily oxidised to a carbonyl group (§ 52), and accordingly benzoin is easily oxidised to *benzil* by boiling it with concentrated nitric acid (sp. gr. 1·42):

$$C_6H_5{\cdot}CH(OH){\cdot}CO{\cdot}C_6H_5 + O = C_6H_5{\cdot}CO{\cdot}CO{\cdot}C_6H_5 + H_2O.$$

In the same way the carbonyl group is readily reduced to the secondary alcoholic grouping (§ 52), and accordingly benzoin is easily reduced to hydrobenzoin or *s*-diphenylglycol:

$$C_6H_5{\cdot}CH(OH){\cdot}CO{\cdot}C_6H_5 + 2H = C_6H_5{\cdot}CH(OH){\cdot}CH(OH){\cdot}C_6H_5.$$

482. Benzil, $C_6H_5{\cdot}CO{\cdot}CO{\cdot}C_6H_5$, is a diketone. It is prepared by oxidation of benzoin, as described above.

Expt. 103.—*Preparation of Benzil.*—Powder the dry benzoin prepared in Expt. 102, and place it in a flask. Add twice its weight of concentrated nitric acid (sp. gr. 1·42), and heat on the water-bath for two hours. Pour into cold water. Filter off the crystals and wash thoroughly. Press on porous paper and recrystallise from alcohol.

It forms pale yellow crystals melting at 95° C. and boiling at 346—348° C. Its colour is of interest (*v.* § 401).

Benzil is reduced first to benzoin, then to hydrobenzoin by nascent hydrogen, $C_6H_5{\cdot}CO{\cdot}CO{\cdot}C_6H_5 \xrightarrow{2H} C_6H_5{\cdot}CH(OH){\cdot}CO{\cdot}C_6H_5 \xrightarrow{2H} C_6H_5{\cdot}CH(OH){\cdot}CH(OH){\cdot}C_6H_5$. It forms oximes, bisulphite compounds, etc., like other ketones.

483. Triphenylmethane, $(C_6H_5)_3CH$.—Triphenylmethane is a remarkable compound, which is of importance as the parent substance of several of the most important synthetic dyes.

Triphenylmethane may be prepared by the action of benzene on chloroform in presence of aluminium chloride (Friedel–Crafts reaction, § 342):

$$HCCl_3 + 3H{\cdot}C_6H_5 = HC(C_6H_5)_3 + 3HCl.$$

Triphenylmethane forms colourless crystals melting at 92° C. and boiling at 358—329° C.

It is remarkable in that, unlike most of the higher hydrocarbons, it is highly reactive.

Thus, with benzene it forms a molecular compound, $(C_6H_5)_3CH{\cdot}C_6H_6$, and similar addition compounds with many other compounds are known.

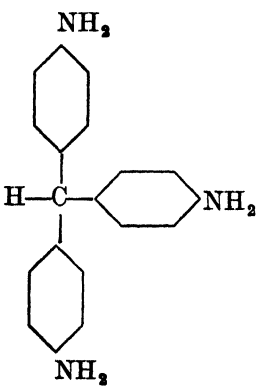
The hydrogen atom attached to the central carbon atom is very readily replaced. It is easily brominated to triphenylmethyl bromide:

$$(C_6H_5)_3{\cdot}CH + Br_2 = (C_6H_5)_3C{\cdot}Br + HBr.$$

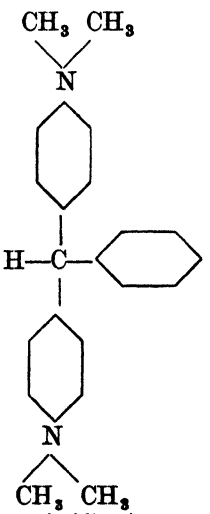
This compound, quite unlike most halides, is very readily hydrolysed, and mere boiling with water replaces the bromine by hydroxyl, triphenylcarbinol being formed:

$$(C_6H_5)_3C{\cdot}Br + H_2O = (C_6H_5)_3C{\cdot}OH + HBr.$$

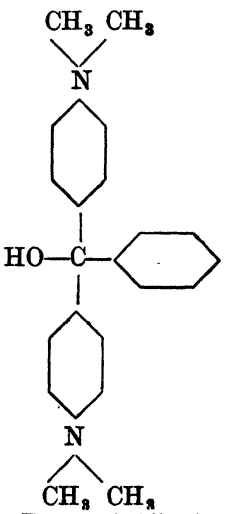
This peculiar behaviour makes it clear that the attachment of the three large electronegative C_6H_5 groups to a single carbon atom makes the attachment of the fourth group particularly loose. Much discussion has centred round the peculiar behaviour of triphenyl-



I. Tri-aminotriphenyl-methane (colourless)



II. Tetramethyldiamino-triphenylmethane (leuco-base of malachite green).

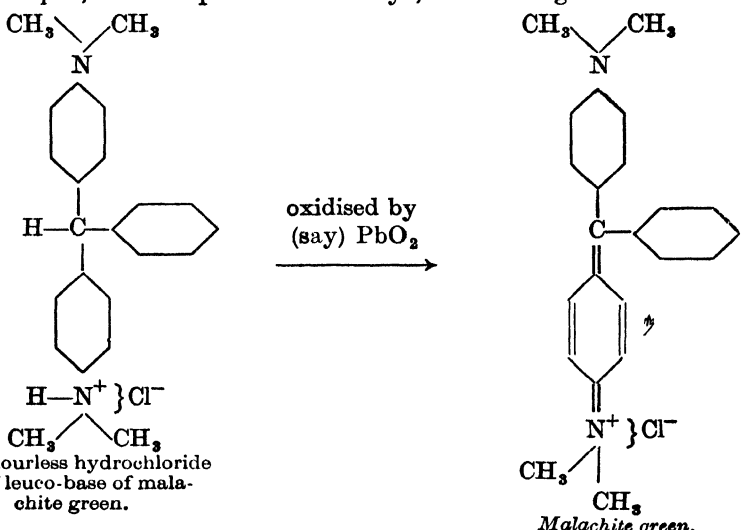


III. Tetramethyldiamino-triphenylcarbinol (dye-base of malachite green).

methane, but no theory is sufficiently well supported to require mention in a book of this scope.

484. Triphenylmethane Dyes.—Triphenylmethane is colourless, as are most of its simplest compounds. But the hydroxy- and amino-derivatives of triphenylmethane which have a quinonoid (§§ 363, 401) structure are important and brilliant dyes. The formulæ on pp. 457, 458 give an idea of the types of structure which give rise to triphenylmethane dyes.

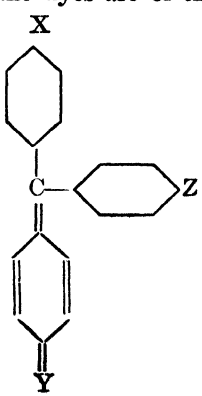
An aminotriphenylmethane, I. (p. 455), is colourless, as are also the methylaminotriphenylmethanes, *e.g.*, II. These *leuco-bases* are colourless and when oxidised give a colourless *dye-base*, III. When II. is converted into a salt and oxidised, a *quinonoid* structure is developed, and the product is the dye, malachite green:



Colourless hydrochloride of leuco-base of malachite green.

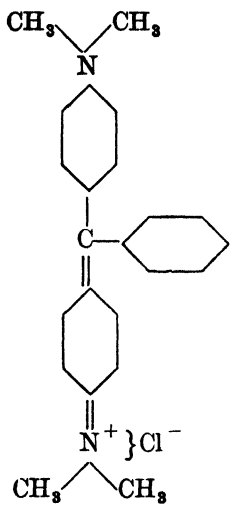
Malachite green.

All the triphenylmethane dyes are of the type

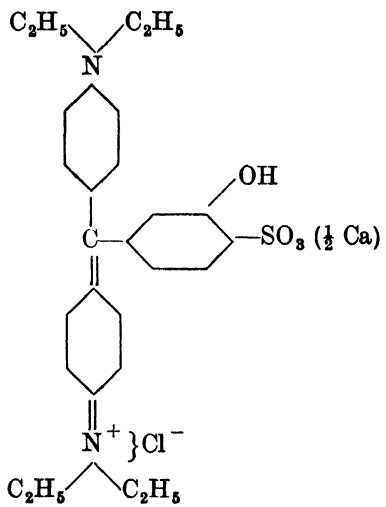


Various groups may be substituted in the benzene rings, but the essential structure is (1) the triphenylmethyl group, with (2) at least two amino- or alkylamino- or hydroxyl-groups in the para-positions (X, Y, Z), (3) a quinonoid structure being present in one ring.

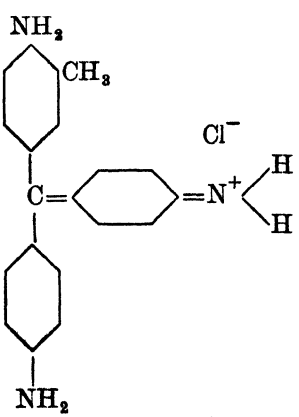
TRIPHENYLMETHANE DYES



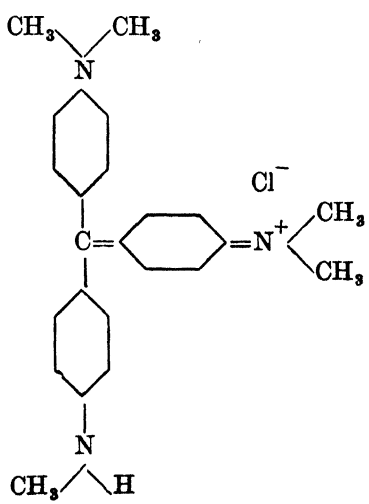
Malachite green.



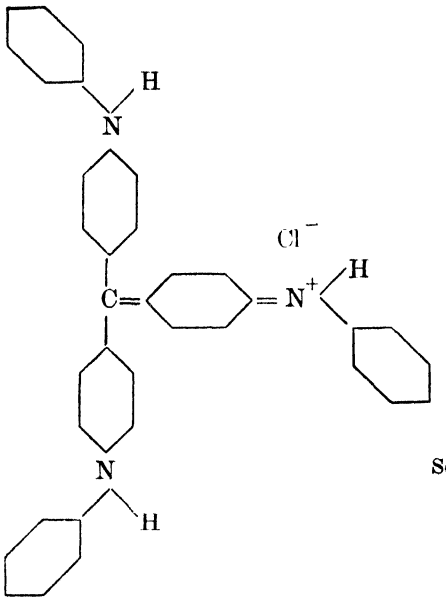
Patent blue.



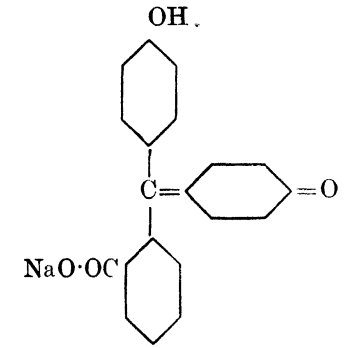
Fuchsine (magenta).



Methyl-violet.



Rosaniline-blue.



Sodium salt of phenolphthalein.

The above are the formulæ of some of the most important of these dyes. All of them conform to the above structure.

THE FUCHSINE GROUP OF DYE-STUFFS

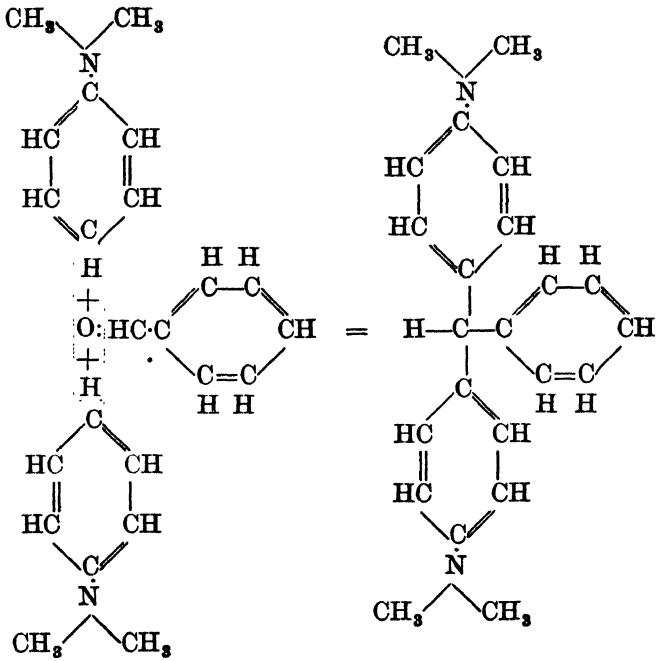
The class of dye-stuffs derived from diamino- or triamino-triphenylmethane are known as the Fuchsine dye-stuffs.

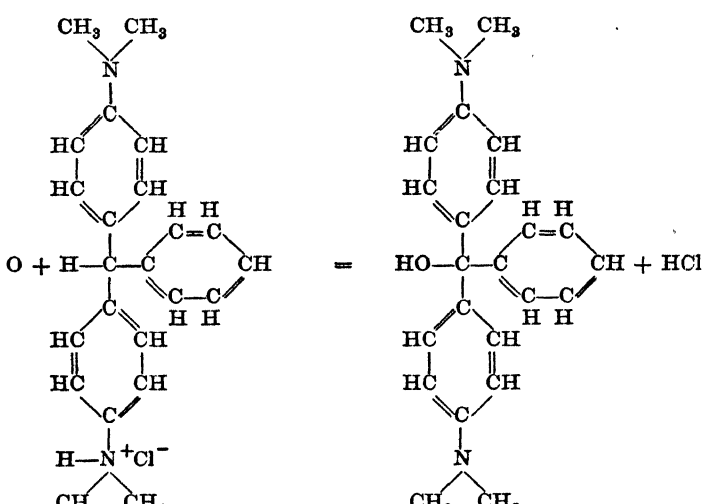
485. Malachite Green.—The simplest of the group is malachite green. This is made by heating benzaldehyde with dimethylaniline together with some substance capable of absorbing water, *e.g.*, anhydrous zinc chloride. The product of this reaction is the leuco-base of malachite green (tetramethyldiaminotriphenylmethane) (see formula on p. 459).

The leuco-base is then oxidised by heating it with a mixture of hydrochloric acid, acetic acid and lead peroxide (see equations, pp. 459–460).

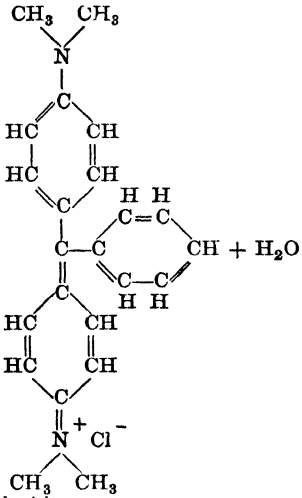
The base of malachite green is first formed, itself a colourless substance, and this reacts with hydrochloric acid, forming malachite green and water. The base of malachite green has not a quinonoid structure, and is, therefore, colourless. The salts are quinonoid and are all intensely green.

This relationship between leuco-base, dye-base and dye-stuff is





Hydrochloride of leuco-base. Malachite green base.

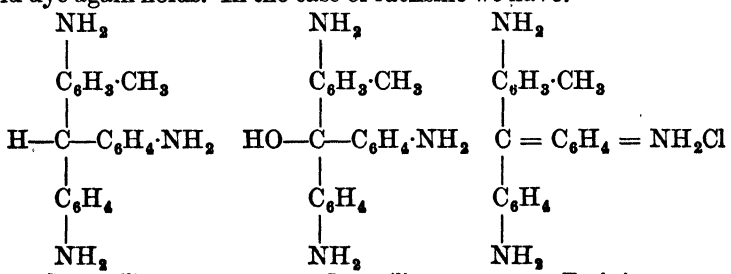


Malachite green

found in some form in all the triphenylmethane dyes. It may be summarised as:

	oxidation ⟶ ⟵ reduction		acids ⟶ ⟵ alkalis	
Leuco-base		**Dye-base**		**Dye**
L.H		L.OH		L.Cl
Colourless.		Colourless.		Coloured.

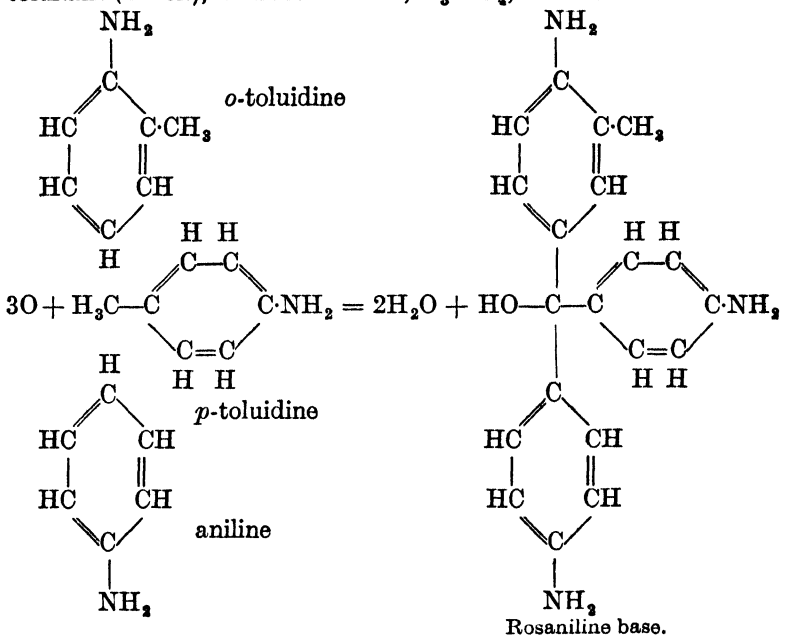
486. Fuchsine.—The dye *magenta* was one of the earliest to be discovered, and is still important both in itself and for the manufacture of rosaniline blue. The relationship of leuco-base, dye-base and dye again holds. In the case of fuchsine we have:

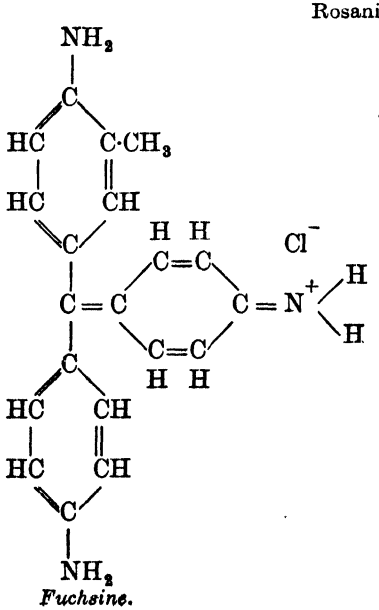


Leucaniline.	Rosaniline.	Fuchsine.
Triamino-diphenyltolyl-methane.	Triamino-diphenyltolyl-carbinol.	
Leuco-base.	*Dye-base.*	*Dye.*
Colourless.	Colourless.	Red

The case is somewhat complicated by the presence of para-rosaniline and parafuchsine, which differ from rosaniline and fuchsine in lacking the methyl group.

487. Preparation of Fuchsine.—Fuchsine is manufactured by oxidising a mixture of aniline (1 mol.), *o*-toluidine (1 mol.), *p*-toluidine (1 mol.), with arsenic acid, H_3AsO_4, or nitrobenzene.





Fuchsine.

Rosaniline is formed and on dissolving the product and treating it with hydrochloric acid, fuchsine is formed.

The original discovery of fuchsine by Sir W. H. Perkin was due to an attempt to oxidise aniline with arsenic acid. The aniline contained *o*- and *p*-toluidines, derived from toluene present in the impure benzene from which it was prepared, and consequently fuchsine was formed.

Manufacture.—The nitrobenzene process is now almost always employed. 'Aniline oil for red'—a mixture of aniline with *o*- and *p*-toluidine—is partly converted into hydrochloride with conc. HCl and heated till all water is driven off. The mixture of the amines and their hydrochlorides is then mixed with about half its weight of nitrobenzene and some 3-5 per cent. of ferrous chloride or iron filings which appear to act catalytically. The mixture is heated to about 175° C., and well stirred. The nitrobenzene oxidises the mixture as described above, and is converted into various tarry substances. The resulting mass is boiled with water under pressure, and when dissolved is precipitated by addition of salt. The product is redissolved, and is finally deposited as crystals with a greenish metallic lustre.

The fuchsine so prepared is the hydrochloride of rosaniline, and dyes wool, silk, and mordanted cotton in magenta shades. Much of it is converted into rosaniline by treatment with ammonia and used in making the important rosaniline blues.

$$C(C_6H_3(CH_3)\cdot NH_2)(C_6H_4\cdot NH_2)(C_6H_4{=}NH_2Cl) + NH_4OH = HO\cdot C(C_6H_3(CH_3)NH_2)(C_6H_4\cdot NH_2)(C_6H_4\cdot NH_2) + NH_4Cl$$

Fuchsine. Rosaniline.

Rosaniline is colourless when pure, but as made by this process is pale pink.

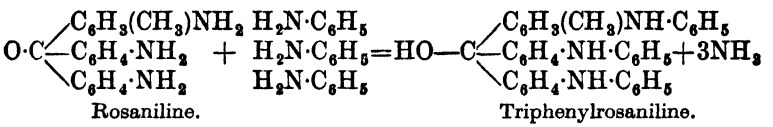
488. Methyl-violet.—By oxidising dimethylaniline, a valuable dye known as methyl-violet is obtained. It is pentamethyl para-rosaniline (p. 457). One methyl group from the dimethylaniline migrates to the *p*-position, and thus provides the central carbon atom, while the other five are attached to the nitrogen atoms. The method of oxidation is peculiar, atmospheric oxygen being used as oxidising agent, with copper salts as catalyst. Cakes are formed from a mixture of (say) 100 parts salt, 10 parts dimethylaniline, 3 parts cupric nitrate, 1 part dilute acetic acid. The salt acts merely as a means of forming a porous mass easily reached by the air. The cakes

are gently heated with free access of air, till the reaction is complete, and then dissolved in water, when the deep violet double chloride of the dye and cuprous chloride is precipitated. This is dissolved by boiling with dilute sulphuric acid, and the dye is precipitated out with a concentrated solution of sodium sulphate.

Expt. 104.—*To Prepare Methyl-violet.*—To 30 g. of salt add a solution of 1 g. of cupric nitrate in 1·5 c.c. of water and 0·5 c.c. of dilute acetic acid. Stir till evenly mixed, and stir in 3·5 c.c. of dimethylaniline. Place the mixture in a large flat evaporating dish, and warm it *very gently*, stirring continuously until the salt is of a strong deep coppery lustre (½ hr.).

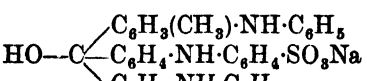
Treat the solid with 250 c.c. of water containing about 1 g. of ferric chloride, and stir till all the salt has dissolved. Pour off the suspension of the dye-stuff through a large filter. Dissolve the dye on the filter and adhering to the dish with hot water. Precipitate out the dye by stirring in common salt. Filter off the precipitated dye-stuff and dry it.

489. Rosaniline Blues.—When rosaniline is heated for a long time with aniline and a little acetic acid at 120–140° C. a peculiar reaction takes place. Ammonia is eliminated and phenyl groups substituted for the hydrogen atoms. The best blues are obtained by using pararosaniline, but ordinary rosaniline and even crude magenta are used:



Rosaniline. Triphenylrosaniline.

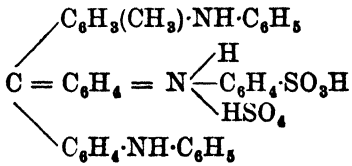
The product (opal or spirit blue) is insoluble in water, but soluble in alcohol. It is therefore converted into a soluble form by sulphonating it. The blue dye is heated with concentrated sulphuric acid at 30°–40° C.; the sulphonic acid of triphenylrosaniline is produced together with some disulphonic acid. The sodium salt of this is



Sodium salt of Nicholson blue.

called Nicholson blue. The sodium salt is colourless in alkaline solution, for as seen in the formula above, it has no quinonoid structure. When wool is dyed in an alkaline bath of Nicholson blue it remains colourless, but when removed, washed and dipped in

dilute sulphuric acid it becomes brilliantly blue owing to the formation of the quinonoid salt:



Nicholson blue.

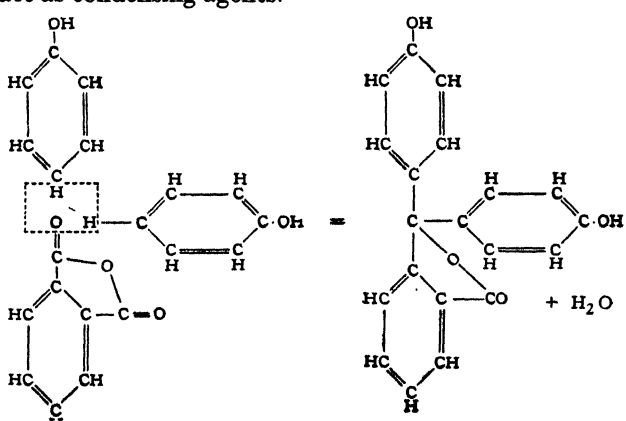
The disulphonic acids of triphenylrosaniline are readily soluble in water and much used under the names of cotton blue, water blue, etc., for dyeing all manner of stuffs.

THE PHTHALEINS

The phthaleins obtained by heating phenols with phthalic anhydride have a general resemblance to the fuchsine dyes. They can exist in two forms, one of which is non-quinonoid and colourless, while the other is a salt and has the quinonoid structure and is coloured. The coloured forms, like the fuchsine dyes, have a triphenylmethyl structure with one quinonoid ring, but in place of the amino-groups of the fuchsine dyes we have hydroxyl groups, and the quinonoid $>C=NH$ is replaced by the quinonoid $>C=O$.

The simplest member of the group is phenolphthalein.

490. Phenolphthalein.—Phenolphthalein is prepared by heating phthalic anhydride with phenol and sulphuric acid or zinc chloride, which act as condensing agents.



Two molecules of phenol and one of phthalic anhydride.

Colourless form of phenolphthalein.

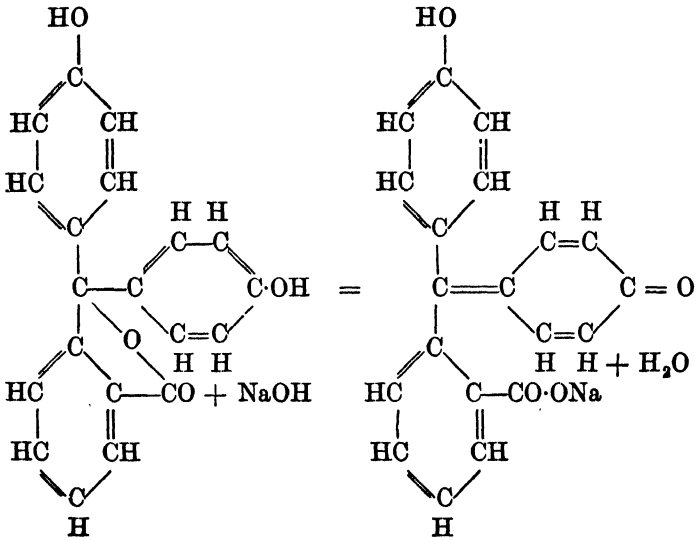
On the laboratory scale 9 g. of phenol are well mixed with 5 g. of phthalic anhydride and placed in a 100-c.c. round-bottomed flask

and 4 c.c. of concentrated sulphuric acid are added. The mixture is heated for four hours at 120° C. The resulting solid is boiled with caustic soda solution and a deep red solution of the sodium salt of phenolphthalein is obtained.

When this is acidified the phenolphthalein is precipitated. It is filtered off, dissolved in alcohol, decolourised, if need be, with animal charcoal and crystallised by cooling.

Phenolphthalein is a white powder melting at 254° C., insoluble in water, but soluble in alcohol. It is a useful laxative and is much employed medicinally. It forms a part of many proprietary medicines.

The most important fact about phenolphthalein is the formation of its deep red salts. The latter are considered to have a quinonoid structure.



I. Colourless form. II. Red sodium salt.

Phenolphthalein is not an acid at all: for it has no replaceable hydrogen atom. It is supposed that when the sodium salt is acidified a quinonoid form of the acid (Formula II with H in place of Na) is produced. This at once rearranges itself to form ordinary phenolphthalein, by the carboxylic hydrogen shifting to the $>C=O$ group and the triphenylmethyl carbon atom linking up to the $-CO-O-$ group remaining.

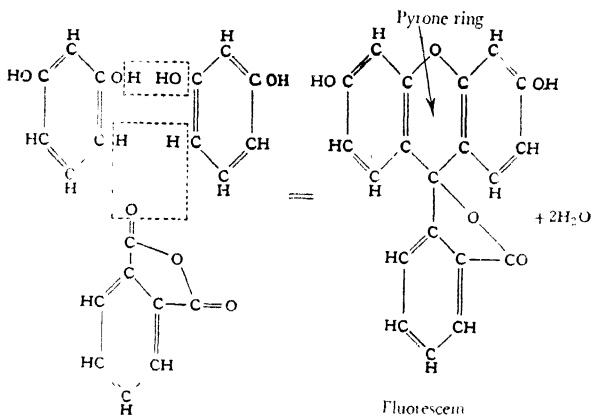
Phenolphthalein is, like phenol, a reactive substance and readily forms nitro-, bromo- and chloro-phenolphthaleins, which are indicators like itself.

Phenolphthalein is a poor dye, but some of the other phthaleins are of great value as dyestuffs.

491. Fluorescein is obtained by heating resorcinol (*m*-dihydroxybenzene) with phthalic anhydride. The reaction goes easily and no dehydrating agent needs to be added.

Expt. 105.—*To Prepare Fluorescein.*—In a test-tube place a mixture of 1 g. of phthalic anhydride with 2 g. of resorcinol and heat for a few minutes, being careful not to exceed the temperature required for reaction. Dissolve the product in caustic soda; dilute very largely and note the magnificent fluorescence.

Fluorescein is not, as might be expected, a dihydroxyphenolphthalein, for the two molecules of resorcinol lose an additional molecule of water and form a 'pyrone' ring.



The pyrone ring is a powerful chromophore and accordingly fluorescein is coloured in the solid state. Its salts have the quinonoid structure as well as the pyrone ring and have a very intense though not very deep colour.

Fluorescein is a dark brown powder which dissolves in alkalis to a solution with a beautiful and intense yellow-green fluorescence. The solutions of the sodium salt of fluorescein appear pale yellow by transmitted light, but when viewed against a dark background they have an intense luminous green tint. The sodium salt of fluorescein has been used as a yellow dye, but only to a small extent. The chief value of it is for conversion into tetrabromofluorescein which is the important dye *eosin*.

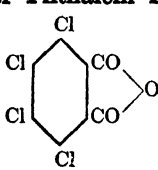
492. Eosin, Tetrabromofluorescein.—Eosin is prepared by dissolving fluorescein in acetic acid and adding the theoretical amount

(four molecules) of bromine. The eosin is precipitated by diluting the acetic acid.

$$C_{20}H_{12}O_4 + 4Br_2 = C_{20}H_8Br_4O_4 + 4HBr.$$

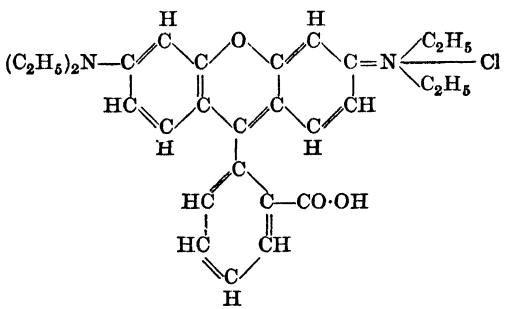
Eosin has the same formula as fluorescein except that four of the hydrogen atoms on the carbon rings derived from the resorcinol are replaced by bromine atoms.

It forms a brown powder which dissolves in alkalis to a red solution with a green fluorescence, particularly noticeable in dilute solution. It dyes materials in brilliant pinks and scarlets and is much used in red ink. It is not fast to light, but its brilliance makes it valuable. Tetraiodofluorescein has also been used as a dye-stuff.

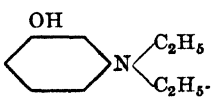
493. Other Phthalein Dye-stuffs.—If the anhydride of tetrachloro-phthalic acid,  , is heated with resorcinol, a valuable dye-stuff of bluish-red shade is obtained known as *phloxin*. Its formula is the same as that of fluorescein, save that the four hydrogen atoms of the ring which is derived from the phthalic anhydride are replaced by chlorine.

Phthalic anhydride may be condensed with pyrogallol (§ 359) to form a violet dye *gallein*, which has one more hydroxyl group than fluorescein. By heating this with sulphuric acid a valuable green dye, 'alizarin green,' is obtained.

494. The Rhodamines are a series of dyes which give pure and brilliant red shades. They are obtained by treating phthalic anhydride with alkylamino-phenols. The simplest rhodamine of any value has the formula

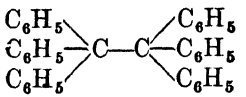


and is made by heating phthalic anhydride with *m*-diethylaminophenol.

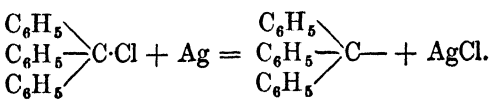


Solutions of its salts have a beautiful orange fluorescence and dye fabrics a brilliant pink colour. Many rhodamines are known.

495. Triphenylmethyl, $(C_6H_5)_3C—(C_6H_5)_3 \rightleftharpoons 2(C_6H_5)_3C$.—When triphenylchloromethane (§ 483) is heated with finely-divided silver, instead of the compound hexaphenylethane,



which might be expected, a compound is obtained which reacts as if it were triphenylmethyl.



This compound when in solution shows a remarkable degree of unsaturation, forming additive compounds with many types of organic compound. It combines with the halogens, and with oxygen it forms a peroxide $(C_6H_5)_3C—O—O—C(C_6H_5)_3$.

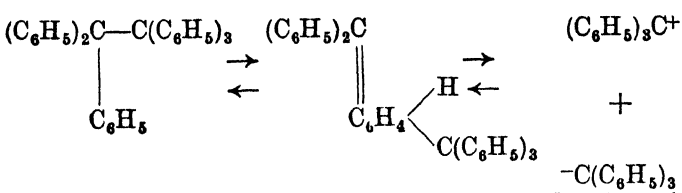
Triphenylmethyl appears to display a most remarkable form of tautomerism, no less than four isomerides apparently existing.

(1) Molecular weight determinations show that in many solvents it exists as hexaphenylethane $(C_6H_5)_3C—C(C_6H_5)_3$.

(2) The solid hydrocarbon exists in a colourless and an orange-yellow form. Analogy with the triphenylmethane dyes suggests that the latter is quinonoid.

(3) Most remarkable of all is its formation of positive and negative ions in certain solvents such as liquid sulphur dioxide.

Many different views concerning its formulæ have been expressed, but the views of Gomberg, which are probably sound, are expressed in the following equilibria:



Hexaphenylethane. In solution and colourless solid.

Coloured quinonoid form.

Positive and negative ions.

In Gomberg's view, then, the solid hydrocarbon is hexaphenylethane, while the reactive solutions contain the triphenylmethyl ions.

QUESTIONS

(1) How is Fittig's reaction employed in making diphenyl, dibenzyl, stilbene? How could the last two be distinguished by simple chemical tests?

(2) What is benzidine and how is it usually prepared? What is its commercial importance?

(3) What are benzoin and benzil? How would you prepare the latter, starting from benzaldehyde?

(4) In what respects does triphenylmethane differ from other aromatic hydrocarbons? Under what conditions are its derivatives coloured?

(5) Illustrate the use of the terms leuco-base, dye-base, and dye by discussing the case of malachite green and fuchsine.

(6) What is a phthalein? Write the formulæ for phenolphthalein and its red sodium derivative. In what respects does the structure of fluorescein differ from that of phenolphthalein?

(7) How is fuchsine made, and how can it be converted into a blue dyestuff?

CHAPTER XXIX

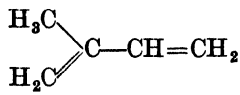
THE TERPENES

496. Classification of Terpenes.—The terpenes are a group of unsaturated hydrocarbons, found in the essential oils and oleo-resins secreted by a number of plants.

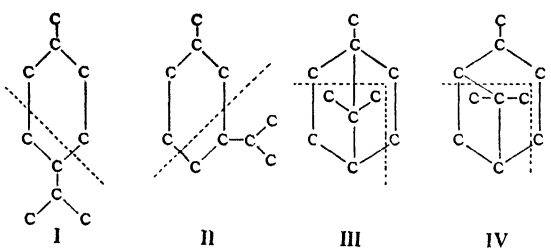
Their formula is $(C_5H_8)_n$. They are classified as:—

Hemiterpenes	C_5H_8.
Monoterpenes	$C_{10}H_{16}$.
Sesquiterpenes	$C_{15}H_{24}$.
Polyterpenes	$(C_5H_8)_4$,$(C_5H_8)_6$, etc.

The terpenes may all be regarded as built up from two or more molecules of the hydrocarbon *isoprene* (§ 180):—



The monocyclic terpenes of formula $C_{10}H_{16}$ may be regarded as built up from two molecules of isoprene, and all have the carbon skeleton I or II shown below. The bicyclic terpenes consist of two molecules of isoprene built into a double ring (III or IV).



I II III IV

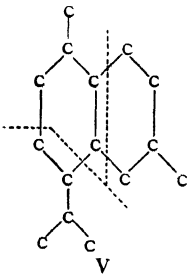
The dotted lines indicate the component isoprene skeletons.

Sesquiterpenes have the formula $C_{15}H_{24}$; their carbon skeleton is V, or some simple variation of it.

Polyterpenes of more complex structure are known. The ultimate product of condensing numerous isoprene molecules into a single structure is indiarubber

While all the common terpenes have carbon skeletons I, II, III or

IV, they differ in the arrangement of double and single bonds. Some of them are optically active and exist in *d*-, *l*-, and *dl*-isomerides.



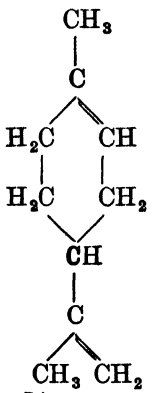
V

The terpenes form numerous derivatives, alcohols, ketones, etc., some of which are of importance in the perfume industry, while others constitute the group of camphors.

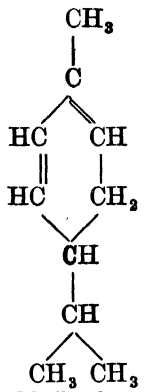
MONOCYCLIC TERPENES

497. Isomerism of the Monocyclic Terpenes.—The most important of these is d-*limonene* found in oil of orange, lemon, bergamot, etc., and α-phellandrene found in eucalyptus.

Their formulæ are as below:—

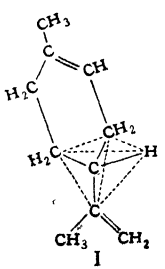


Limonene.

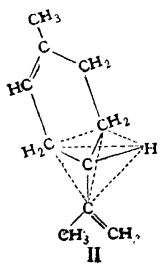


α-Phellandrene.

It will be noted that these formulæ contain asymmetric carbon



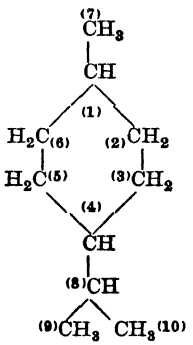
I



II

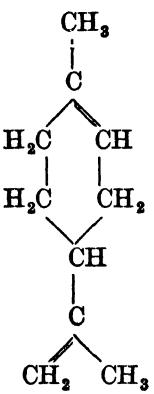
atoms. In the first formula the carbon atom is attached, it is true, to two —CH_2— groups, but the ring as a whole has a different left and right side, and the formulæ I and II cannot be made to coincide.

498. Nomenclature of the Monocyclic Terpenes.—All the monocyclic terpenes with the side chains in the *p*-position are regarded as derived from a hydrocarbon terpane (sometimes called menthane), the carbon atoms of which are numbered for reference as below:

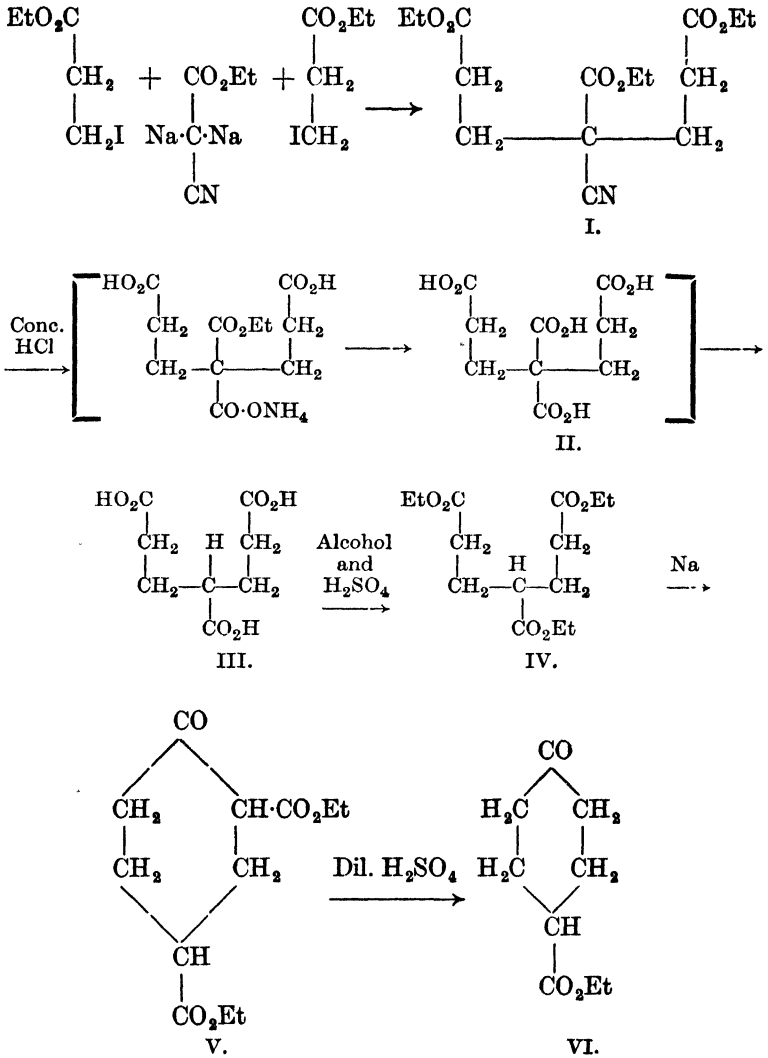


On this system limonene is called $\Delta^{1:8(9)}$-terpadiene (cf. § 167)

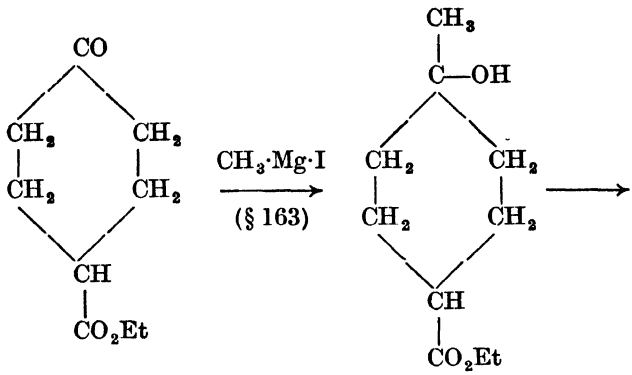
499. *d*-Limonene, *l*-Limonene and Dipentene.—These terpenes are the dextro-, lævo- and inactive modifications of the hydrocarbon,



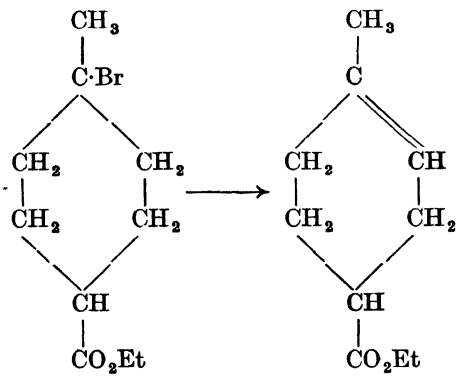
Their constitution is proved by Perkin's remarkable synthesis of dipentene, which is outlined below. Two molecules of ethyl β-iodopropionate react with one molecule of the disodium derivative of cyanoacetic ester (§§ 256, 259) forming a derivative I. This when hydrolysed gives a second derivative II, which breaks up to an acid III, which when treated with sulphuric acid and alcohol gives IV, ethyl pentane-$\alpha\gamma\epsilon$-tricarboxylate.



This when treated with sodium loses ethyl alcohol and gives ethyl *cyclo*hexanone-2 : 4-dicarboxylate V, which by digestion with dilute sulphuric acid is partly saponified and loses CO_2, giving VI, ethyl *cyclo*hexanone-4-carboxylate. The last substance is then treated with methylmagnesium iodide (§ 163) turning the ketone into a tertiary alcohol VII, which is then turned into the bromide VIII (§ 56) and finally into an unsaturated compound (§ 168) IX.

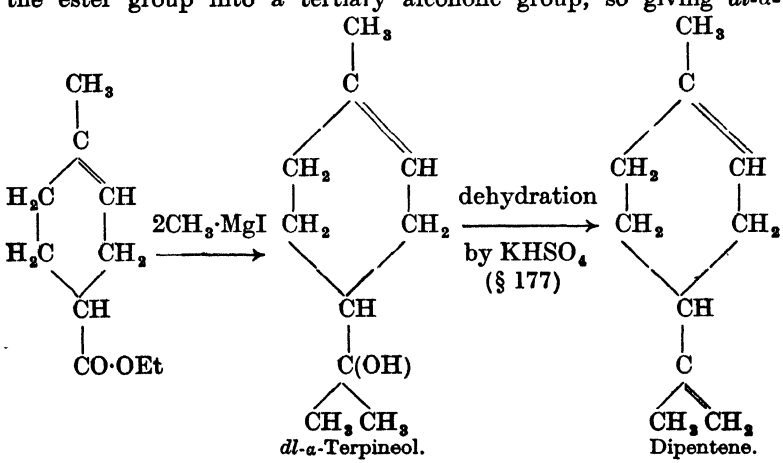


VI. VII.



VIII. IX.

This is again treated with methylmagnesium iodide which converts the ester group into a tertiary alcoholic group, so giving *dl-α-*



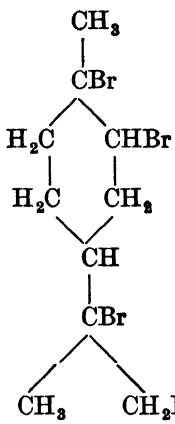
dl-α-Terpineol. Dipentene.

terpineol (§§ 163, 502). This is dehydrated by heating with potassium hydrogen sulphate (cf. § 177), when dipentene is formed.

d-*Limonene* is obtained by careful fractionation of oil of bitter oranges. It is a liquid of pleasant odour and boils at 175–176° C. It is insoluble in water.

Limonene (and all the terpenes) have the characteristics of unsaturated hydrocarbons.

Thus limonene very readily takes up bromine, giving a crystalline tetrabromide.



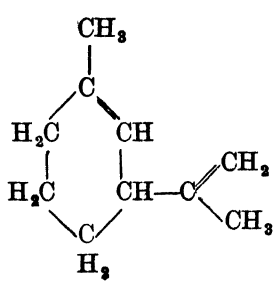
In the same way it takes up two molecules of hydrogen chloride forming a dihydrochloride, and two molecules of nitrosyl chloride, NOCl, forming crystalline nitroso-chlorides. Addition products such as these are formed by all unsaturated terpenes and, being crystalline, are of much use in purifying and identifying them.

Dipentene is the inactive form of limonene consisting of equal parts of the *d*- and the *l*-isomeride.

l-*Limonene* is found in oil of fir-cones.

a-Phellandrene occurs in eucalyptus oil. It exists in *d*- and *l*-forms. In general it closely resembles limonene.

500. Sylvestrene has a type of structure different from that of



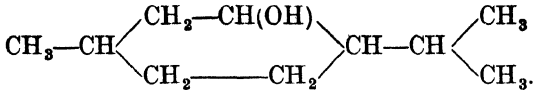
the terpenes already mentioned in that it has the side-chains in the *meta*-position.

It is an important constituent of Swedish and Russian oil of turpentine. It is rather more stable than the terpenes already mentioned. It resembles them in its formation of addition products, bromides, nitrosochlorides, etc.

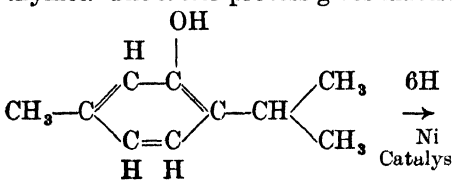
DERIVATIVES OF THE MONOCYCLIC TERPENES

In addition to the halogen compounds and nitrosochlorides already mentioned, several important alcohols and ketones are derived from the terpenes.

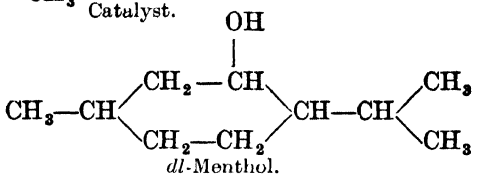
501. *d*-Menthol, $C_{10}H_{20}O$.—Menthol is 3-terpanol



It is the chief constituent of oil of peppermint. It is an article of commerce and is obtained by cooling oil of peppermint till the menthol crystallises out, or by the hydrogenation (cf. § 334) of thymol. The latter process gives inactive or *dl*-menthol.



Thymol.



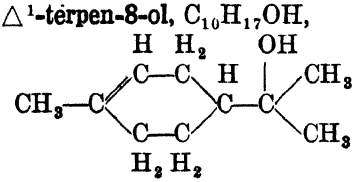
dl-Menthol.

Menthol forms white crystals with the smell and taste of peppermint. It acts as a mild local anæsthetic and is useful for relieving toothache, rheumatism and the congestion of the nasal passages associated with a common cold.

It has the properties of a secondary alcohol and when oxidised gives a ketone—menthone—or 3-terpanone.

Menthol is closely allied to the camphors (§ 517) and is sometimes called menthol camphor.

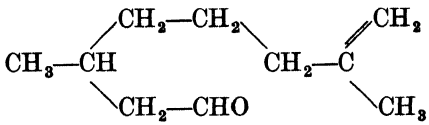
502. Terpineol, Δ^1-terpen-8-ol, $C_{10}H_{17}OH$,



the cheaper natural products, or from *synthetics* which are either the constituents of flower-oils made more cheaply by chemical methods, or are fragrant substances which do not occur naturally.

The commonest constituents of perfumes are given in the table (p. 478). The natural oils are always much superior to the blended isolates or synthetics, and these latter may be greatly improved by addition of a small proportion of the natural product.

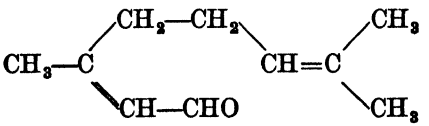
508. Citronellal.—



Citronellal is present in many essential oils, notably citronella oil. It is a liquid with a pleasant lemon-like odour, boiling at 205–208° C.

It has the usual properties of an aldehyde and also of an olefine.

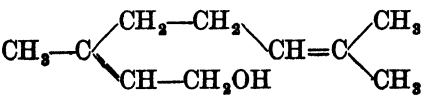
509. Citral (Geranial) is found in oil of lemon-grass, also in oil of oranges and oil of lemons. It may be purified by forming the sodium bisulphite compound and decomposing this with sodium carbonate. It is, like citronellal, an unsaturated aldehyde,



It is an article of commerce, being used in the cheaper "verbena" scents and also in the preparation of other perfumes. It can be reduced to geraniol (§ 510) and oxidised to geranic acid, the —CHO group becoming in the first case —CH_2 OH, in the second, —CO.OH.

Its chief importance is in the manufacture of geraniol, used in rose-scents, and ionone, the basis of synthetic violet perfume.

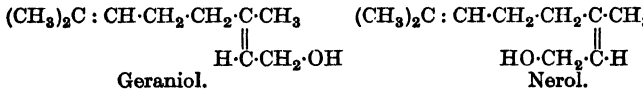
510. Geraniol is found in geranium and palma-rosa oils, and is much used for preparing artificial rose scents. Its formula is:



It is a primary alcohol; this follows from its formation by the reduction of citral. It is usually prepared from Indian geranium oil but can be made by the action of acetic anhydride on linalöol. It has the properties to be expected of an unsaturated primary alcohol. It can be oxidised to an aldehyde (citral) and further to an acid, geranic acid.

The reduction of citral and the action of acids on linalöol also yields *nerol*.

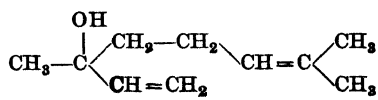
511. Nerol is a cis-trans-isomeride (§ 217) of geraniol. Geraniol and nerol may be represented as below:



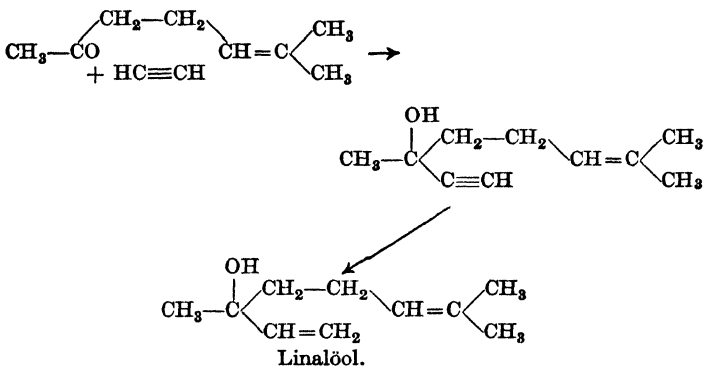
Geraniol. Nerol.

Nerol has a pleasant rose-like odour, which differs slightly from that of geraniol

512. Linalöol is isomeric with geraniol and becomes converted into it in acid solution. It has the formula

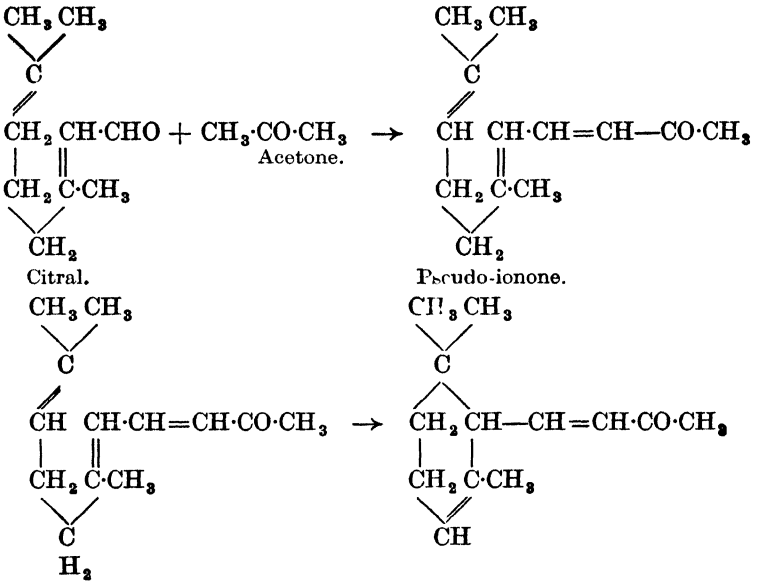


It occurs in many natural perfumes either free or, as in lavender oil, as linalyl acetate. It is often prepared synthetically. Methylheptenone is treated under suitable conditions with acetylene, thus forming the compound dehydrolinalöol: this is reduced with sodium amalgam, giving linalöol.



Linalöol.

513. Ionone.—Ionone, which is the basis of violet scents, may be mentioned here. The actual odoriferous principle of the violet cannot be made synthetically. Ionone has, however, a similar odour and can be made cheaply from citral. Equal parts of lemon-grass oil (mainly citral), acetone and water are gently heated for a long time to about 35° C. or less, with a small quantity of caustic soda solution. The acetone is distilled off, the remainder is acidified, and *pseudo-ionone* is separated by fractional distillation. This is converted into ionone by treatment with 70 per cent. sulphuric acid. α- and β-Ionone are formed, and are purified by fractional distillation.



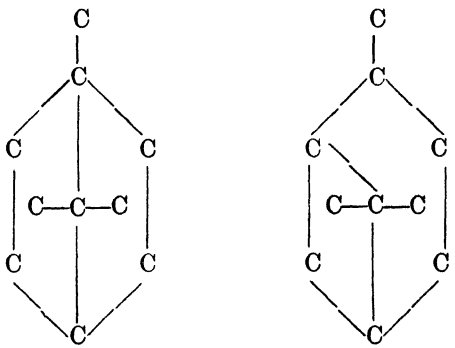
Citral. Pseudo-ionone.

Pseudo-ionone. α-Ionone.

Ionone is a white crystalline solid. Its characteristic odour of violets is only manifest in extremely dilute solution.

BICYCLIC TERPENES

The bicyclic terpenes and their derivatives have the carbon atom skeletons I and II:—



I. II.

The most important members of this series are the hydrocarbon *pinene*, the chief constituent of turpentine, and the alcohols and ketones known as *camphors*.

514. Oil of Turpentine.—The term *turpentine* strictly means the 'oleo-resins' which exude from many conifers, chiefly pines and firs.

These are of a sticky consistency and, when distilled, are converted into hard transparent rosin (colophony) and oil (or spirit) of turpentine.

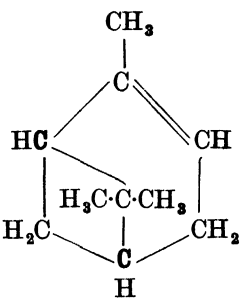
Rosin consists mainly of abietic acid, an aromatic compound containing several carbocyclic rings. Like the fatty acids it gives soaps with alkalis, and these resin-soaps are much used industrially (§ 430).

Oil of turpentine or 'turps' is a mixture of numerous terpenes, and α-pinene (§ 515) is its chief constituent.

It finds many uses, being employed in the manufacture of paints, varnishes and disinfectants. In medicine it is used in embrocations as a counter-irritant. It is decidedly poisonous, having a strong irritant effect on the bowel and kidneys.

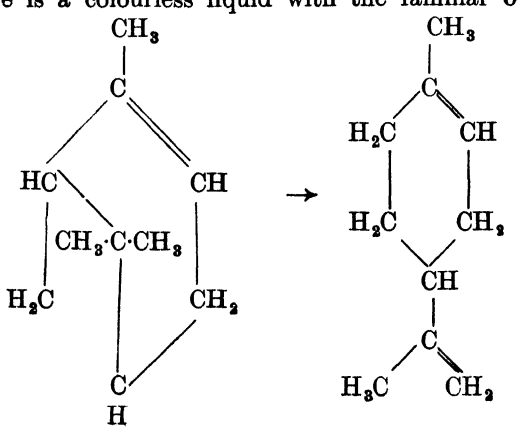
515. α-Pinene is the chief constituent of oil of turpentine. It is extracted from it by fractional distillation. The crude product is converted into the nitrosochloride (§ 499); this, on heating with aniline, gives pure pinene.

Pinene has the formula:



It will be noted that it contains asymmetric carbon atoms (shown in bold type), and therefore exists in dextro- and lævo-modifications. *d*-Pinene predominates in most (but not all) types of turpentine.

α-Pinene is a colourless liquid with the familiar odour of tur-

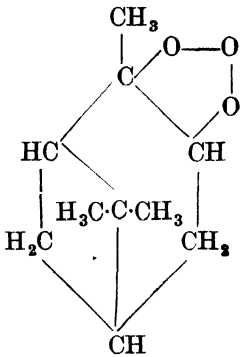


pentine. It boils at 156–157° C. It is insoluble in water, and is a good solvent for most organic substances: also for sulphur and phosphorus.

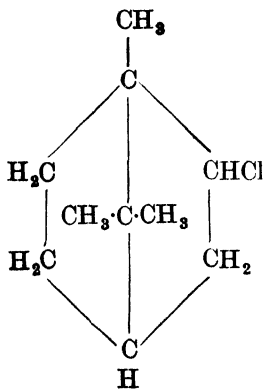
Pinene is a very reactive unsaturated compound. It absorbs oxygen from the air, forming a resinous mass. When shaken with warm water and air, a solution containing hydrogen peroxide is obtained. This has disinfectant properties and is an article of commerce.

Pinene is easily transformed into other terpenes. Thus at 250–270° C. it gives dipentene (equation on p. 482).

It forms a nitrosochloride and a dibromide, the formation of the latter showing the presence of a double bond. It also absorbs ozone, forming an ozonide, which was of use in settling the formula of ozone.



Pinene reacts with hydrogen chloride forming a white volatile substance known as 'artificial camphor.' This is often called pinene hydrochloride, but is actually bornyl chloride.

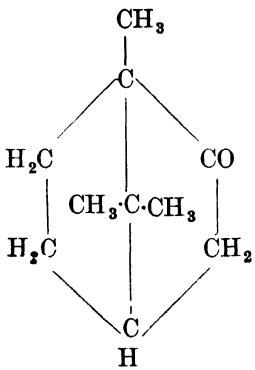


Bornyl chloride.

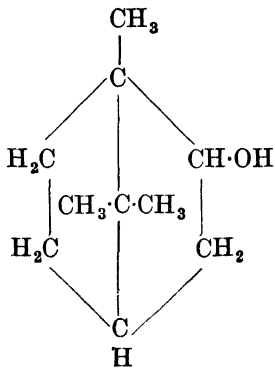
It is altogether different from true synthetic camphor (§ 517) which contains no chlorine.

The oxidation of pinene by means of nitric acid gives terpin hydrate (§ 504), while hydrogen peroxide converts it into terpineol.

516. Camphor and Borneol.—The two chief products known as camphor are Japan camphor which is a ketone and, of less importance, Borneo camphor or *borneol*, which is a secondary alcohol. It will



Camphor.



Borneol.

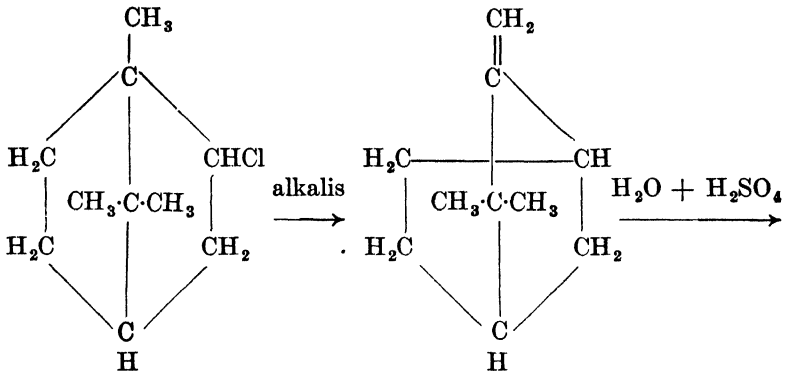
be clear that borneol can be oxidised to camphor and camphor reduced to borneol.

517. Camphors.—Camphor is obtained by steam-distilling the branches and leaves of the camphor laurel—a tree which grows in Japan and China. Crystals of camphor separate from the condensed liquid. The crude product is sublimed in order to purify it.

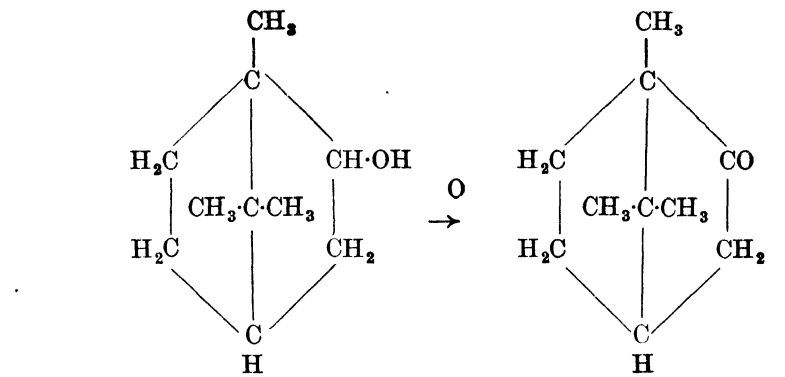
Synthetic camphor is made from turpentine. By treating this with hydrogen chloride, bornyl chloride (§ 515), 'artificial camphor' is made. This is converted into the hydrocarbon *camphene* by various methods (heating with alkalis, alkali carbonates, lead acetate, etc.).

Camphene is converted into the alcohol *iso*borneol by heating with 20 per cent. sulphuric acid, and *iso*borneol when oxidised by chromic acid, etc., gives the ketone camphor.

The camphor so obtained is the *dl*-variety, while natural camphor is dextro-rotatory. In other respects the natural and artificial products are identical. Camphor forms transparent lustrous crystals which melt at 175° C. It has a very large freezing-point depression, and is therefore used as solvent in molecular weight determinations (§ 16). It boils at 204° C., and sublimes very readily. It is perceptibly volatile even at room temperature.



Bornyl chloride Camphene.



iso-Borneol (Stereoisomeride of borneol). Camphor.

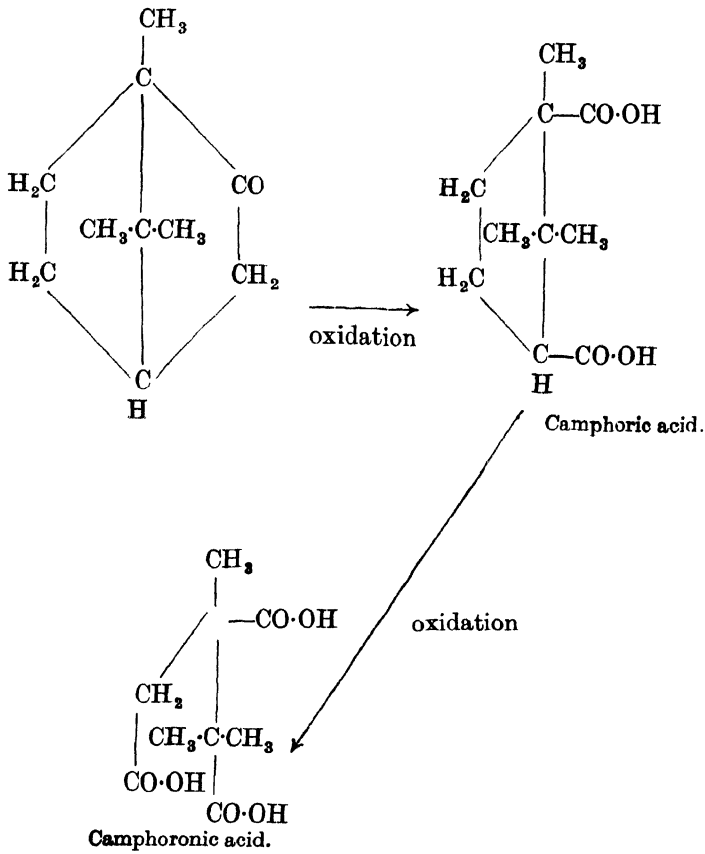
It is almost insoluble in water, but dissolves freely in organic solvents.

Camphor is not an unsaturated compound. When heated with phosphorus pentoxide it yields cymene (§ 421). Oxidation gives camphoric acid and finally camphoronic acid (p. 486).

Its ketonic properties are manifested in its formation of an *oxime*, $C_{10}H_{16}$:N·OH.

Camphor is used in the manufacture of celluloid (§ 290), and is used in medicine as a counter-irritant and mild local anæsthetic as in 'camphorated oil.'

518. Borneol, the formula of which is given in § 516 above, is obtained from a large tree, *Dryobalanops aromatica*, which grows in the East Indies—Malay and Borneo. It much resembles ordinary camphor which can be reduced to it and is formed by its oxidation.



Camphoronic acid.

SESQUITERPENES

The sesquiterpenes have the formula, $C_{15}H_{24}$, and carbon skeletons as indicated in § 496 (V). They are not of great importance but are widely distributed in various aromatic oils. Camphors derived from them are known and are found in essential oils such as that of cubebs and patchouli.

POLYTERPENES

Polyterpenes of formula $(C_5H_8)_n$ where n may be as high as 8 are known. Indiarubber is probably a highly complex polyterpene (§ 180).

QUESTIONS

(1) What arrangements of carbon atoms characterise the mono-cyclic and bi-cyclic terpenes? What relation have they (*a*) to the alkyl benzenes, (*b*) to isoprene?

(2) What are camphors? How can ordinary camphor be synthesised from turpentine?

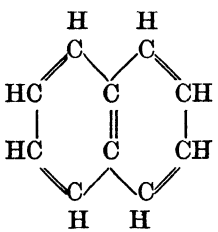
(3) Why is pinene to be regarded as an unsaturated compound? A terpene of formula $C_{10}H_{16}$, when treated with bromine gave a crystalline bromide containing 54 per cent. of bromine. How many double linkages did it contain?

(4) To what classes of compounds do perfumes usually belong? Give examples of important perfumes derived from the terpenes.

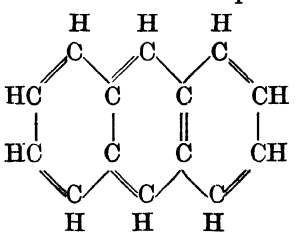
CHAPTER XXX

COMPOUNDS WITH CONDENSED BENZENE NUCLEI

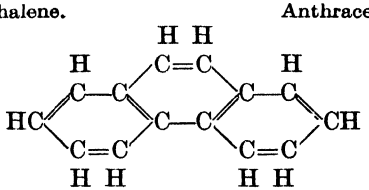
519. Condensed Benzene Nuclei.—Several important hydrocarbons consist of two or more benzene nuclei so combined as to have two carbon atoms in common. The three most important hydro-



Naphthalene.



Anthracene.



Phenanthrene.

carbons of this type are naphthalene, $C_{10}H_8$, anthracene and phenanthrene, both $C_{14}H_{10}$, but many others exist.

Thus, picene, $C_{22}H_{14}$, consists of five benzene nuclei linked together in this manner, and other hydrocarbons are even more complex.

The evidence on which these formulæ are based is considered under the heading of the individual hydrocarbons.

NAPHTHALENE AND COMPOUNDS

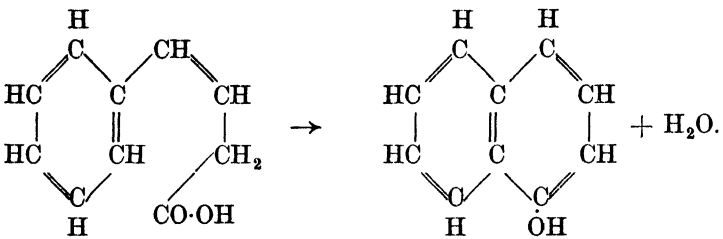
520. Manufacture of Naphthalene.—In spite of the large quantities used in the dye industry, naphthalene is a substance of which the supply exceeds the demand.

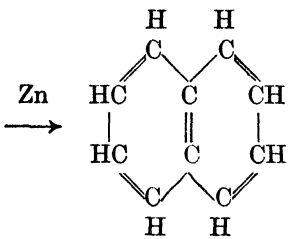
Crude coal-gas contains a notable proportion of this hydrocarbon. A part condenses with the tar, while a portion passes on as vapour. The vapour of naphthalene is objectionable in coal-gas for it tends to condense in the service pipes and block them. It is therefore removed, usually by bubbling the gas through crude oil which readily dissolves it.

Naphthalene is produced commercially from coal-tar. When this is distilled (§ 337) the fraction which boils between 180° and 250° C. crystallises on cooling. The crystals are drained from the oil and then heated and pressed. The product is heated with a little concentrated sulphuric acid which dissolves phenols and basic substances, then washed with water and alkali and finally sublimed or distilled.

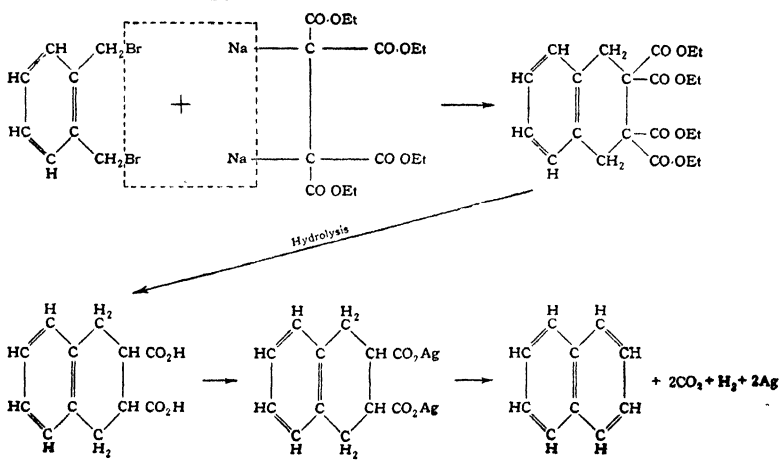
521. Syntheses of Naphthalene.—Naphthalene is not prepared in practice by synthesis but the following reactions throw a light on its composition:—

(1) γ-Phenyl*iso*crotonic acid is converted by dehydrating agents into α-naphthol which when heated with zinc dust gives naphthalene.



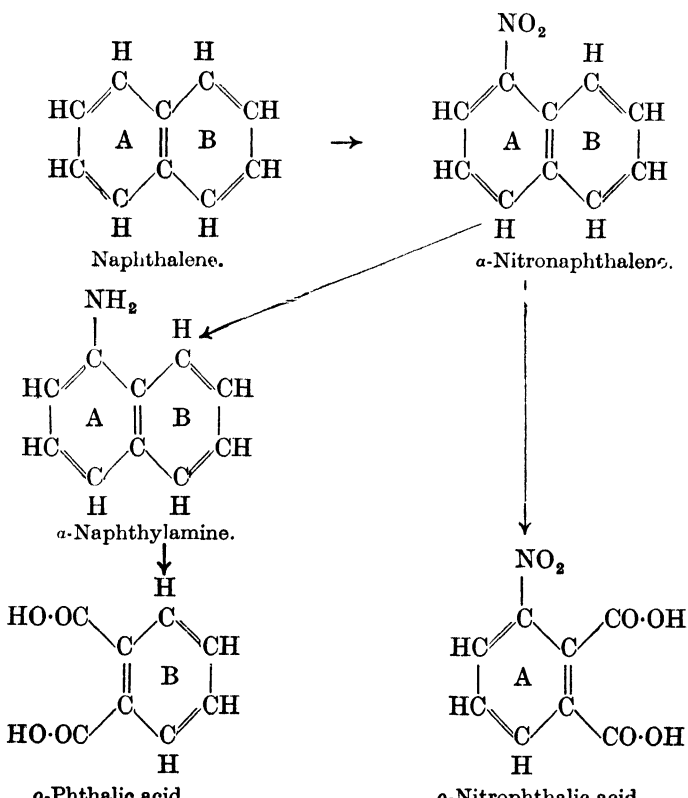


(2) *o*-Xylylene bromide reacts with sodium ethanetetracarboxylic ester, giving a compound which when hydrolysed gives tetrahydronaphthalenedicarboxylic acid, the silver salt of which breaks up when distilled, yielding naphthalene.



522. Structure of Naphthalene.—The two methods of synthesis described above indicate a pair of linked hexagonal rings, one of which is a benzene nucleus. The following proof, due to Graebe, shows that both rings are benzene nuclei. Naphthalene is converted into α-nitronaphthalene. Of this a part is oxidised and *o*-nitrophthalic acid is produced. This shows that the ring in which the nitro-group was substituted is a benzene ring; for phthalic acid (§ 468) contains such a ring.

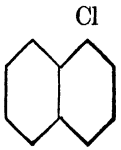
The other portion is now reduced to α-naphthylamine and then oxidised. The product is phthalic acid, not amino-phthalic acid. The ring which did not originally contain the nitro-group must therefore also be a benzene ring.



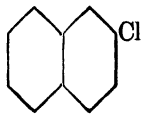
523. Substitution Products of Naphthalene.—The number of substitution products formed from naphthalene confirms the view that its molecule has the double hexagonal ring structure.

We find that:

(1) Two isomeric mono-substitution products only can be made. Thus there are two monochloronaphthalenes which we may write



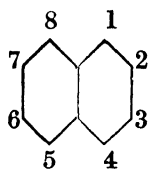
α-Chloronaphthalene



β-Chloronaphthalene.

as above. The student should satisfy himself that when the Cl group is placed in all the eight possible positions only two different isomerides can result.

(2) There are ten [1] possible disubstitution products to be predicted from the above formula, and in the case of the chloronaphthalenes all ten are known. The trichloronaphthalenes, fourteen in number, correspond with what would be expected from the above formula. The positions of the groups in polysubstitution products of naphthalene are indicated by numbers as shown below.



When the substitutents are in the same ring the terms ortho-, meta- and para- can be used as for benzene derivatives.

The 1 : 8 position is called the *peri*-position and the 2 : 6 the *amphi*-position.

524. Physical Properties of Naphthalene.—Naphthalene is a white solid crystallising in plates with a characteristic tar-like odour. It melts at 80° C. and boils at 218° C. It is volatile at temperatures even below its melting-point and is readily sublimed.

It is almost insoluble in water but is easily soluble in benzene, alcohol and ether.

525. Chemical Properties of Naphthalene.—Naphthalene burns with an exceedingly smoky flame. In its chemical properties it shows a close resemblance to benzene (§ 342).

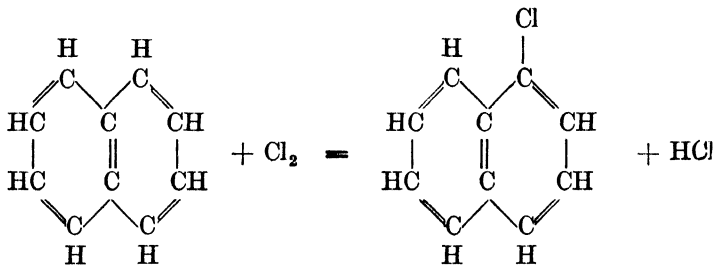
Substitution.—Naphthalene reacts with the substances which

[1] If the two substituent groups are different, fourteen disubstitution products are possible.

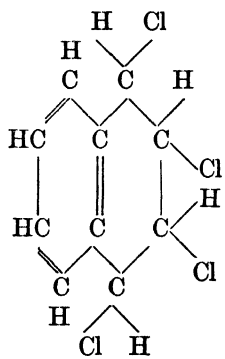
react with benzene, *e.g.*, chlorine, bromine, sulphuric acid and nitric acid.

The substituent group ordinarily enters the α-position (§ 523) but sulphuric acid gives a β-substitution product also.

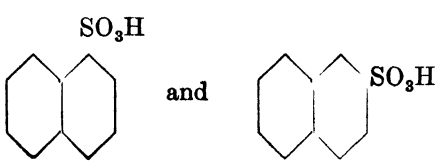
Thus when chlorine is passed into boiling naphthalene in presence of ferric chloride α-chloronaphthalene is produced.



Bromine reacts in the same manner. Like benzene, naphthalene can also form additive compounds with chlorine; these are formed by the action of chlorine on the hydrocarbon in absence of a carrier. Naphthalene dichloride and naphthalene tetrachloride are formed in this way.

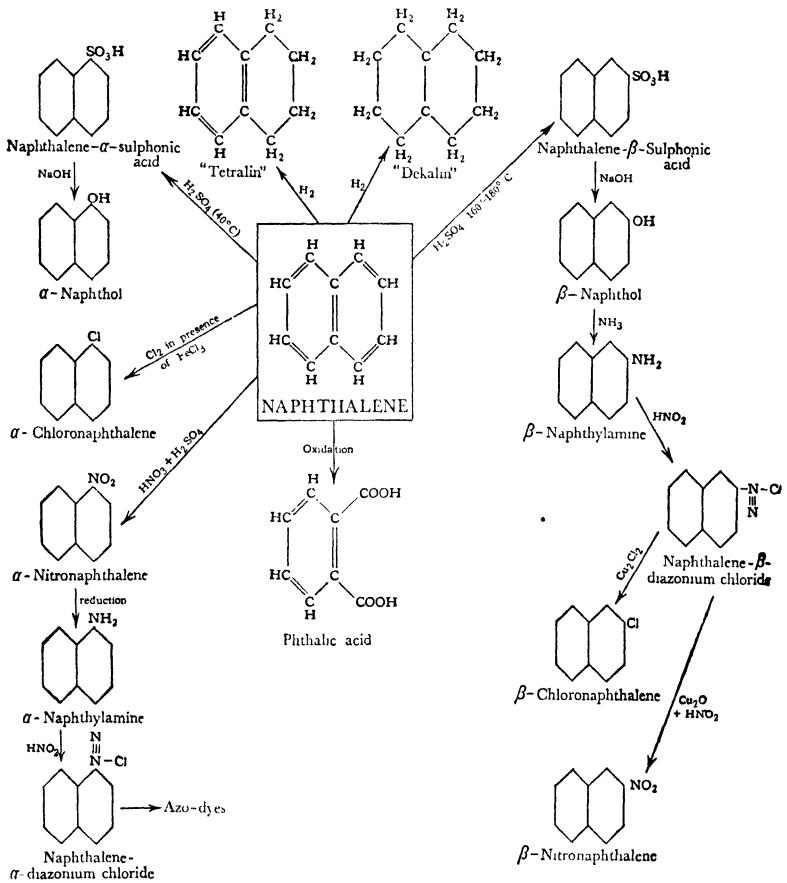


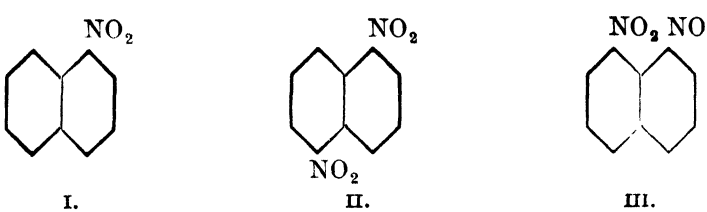
Sulphuric acid converts naphthalene into both α- and β-naphthalenesulphonic acids.



The action of nitric and sulphuric acids on naphthalene yields first α-nitronaphthalene, I., and by further action the

REACTIONS OF NAPHTHALENE



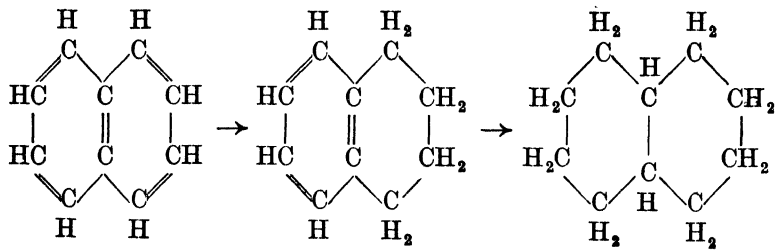


I. II. III.

1 : 5- and 1 : 8-derivatives of formulæ II. and III.

Further details are given under the headings of the respective substitution products (§§ 526—534).

When compressed hydrogen is agitated with boiling purified naphthalene in presence of a nickel and copper catalyst, tetrahydronaphthalene and decahydronaphthalene, *tetralin* and *decalin*, are formed.



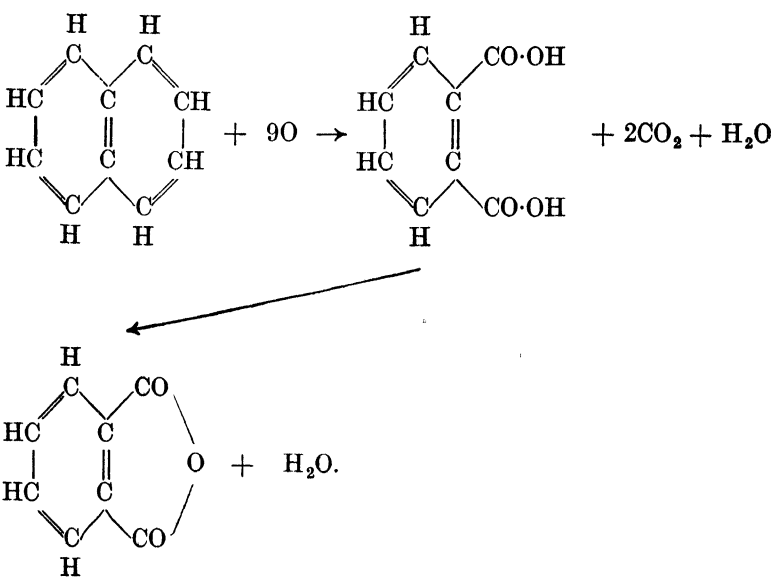
These are articles of commerce and are liquids, much used as solvents in the making of lacquers, varnishes, polishes, etc. The formation of these substances is strictly analogous to that of the hydrobenzenes.

When heated with sulphur they can be dehydrogenated to naphthalene.

$$C_{10}H_{12} + 2S = C_{10}H_8 + 2H_2S$$

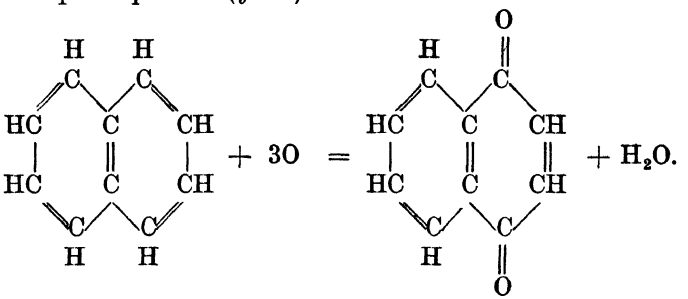
Similar reactions may be carried out with many saturated ring compounds, *e.g*, the terpenes. Selenium may replace sulphur.

The effect of oxidation on naphthalene is to form either phthalic acid or phthalic anhydride, or naphthaquinone.



Oxidation with air in presence of vanadium pentoxide, by concentrated sulphuric acid in presence of mercuric sulphate, or by acid potassium permanganate gives *o*-phthalic acid or phthalic anhydride (§§ 468, 469).

Oxidation with a solution of chromic acid in acetic acid, however, gives naphthaquinone (§ 534).

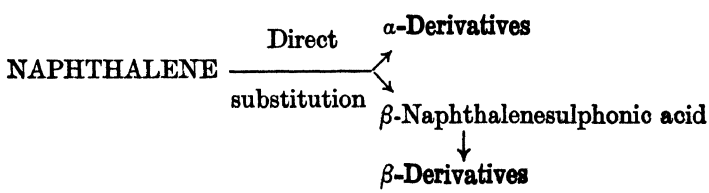


Test.—Naphthalene is recognised by its forming a yellow crystalline 'picrate,' $C_{10}H_8 \cdot C_6H_2(NO_2)_3OH$.

NAPHTHALENE SUBSTITUTION PRODUCTS

These closely resemble the corresponding compounds of benzene and in the succeeding paragraphs, 526 to 534, details will only be given of the reactions which are *not* common to benzene and naphthalene compounds.

The monosubstitution products of naphthalene exist, as already stated, in two isomeric forms α- (1, 4, 5, 8) and β- (2, 3, 6, 7). The α-forms are made directly from naphthalene while the β-forms are made from naphthalene-β-sulphonic acid.



526. Chloronaphthalenes and Bromonaphthalenes.—The direct action of chlorine or bromine on naphthalene (§ 525) yields α-mono-

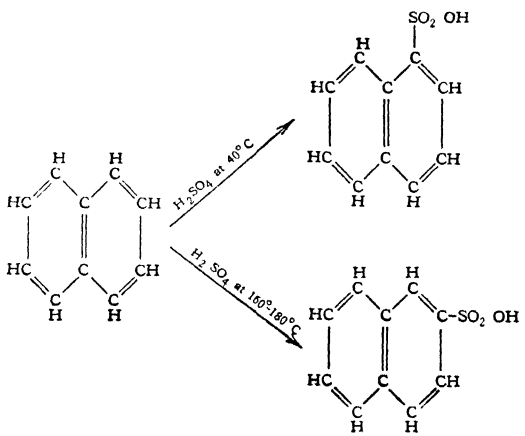
chloronaphthalene and α-monobromonaphthalene. The β-derivatives can be made by heating these with aluminium chloride or from β-naphthylamine (§ 532) by Sandmeyer's reaction (§ 399).

They closely resemble chloro- and bromo-benzene but are rather more reactive, though much less so than the alkyl halides.

Further action of the halogens gives di- and tri- substitution products.

527. Naphthalenesulphonic Acids.—When finely powdered naphthalene is stirred for many hours with concentrated sulphuric acid at 40° C., naphthalene-α-sulphonic acid is the sole product, and at temperatures up to 100° C. it predominates.

When naphthalene is heated with sulphuric acid at 160—180° C. the β-acid is obtained.



The solution in each case is poured into water, filtered from unattacked naphthalene and neutralised with calcium carbonate, giving the soluble calcium naphthalenesulphonate and insoluble calcium sulphate. Treatment of the solution with sodium carbonate gives the sodium salt of the acid.

$$C_{10}H_8 + H_2SO_4 = C_{10}H_7{\cdot}SO_3H + H_2O$$

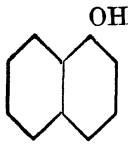
$$2C_{10}H_7{\cdot}SO_3H + CaCO_3 = (C_{10}H_7{\cdot}SO_3)_2Ca + CO_2 + H_2O$$

$$(C_{10}H_7{\cdot}SO_3)_2Ca + Na_2CO_3 = 2C_{10}H_7{\cdot}SO_3Na + CaCO_3\downarrow$$

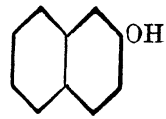
The acids and their salts resemble benzenesulphonic acid (§ 351) in most respects. Their chief use is in making the naphthols (§ 528).

Di- and tri-sulphonic acids can be made and can be converted into other hydroxy-naphthalenes.

528. The Naphthols.—The two compounds $C_{10}H_7{\cdot}OH$, analogous to phenol, are known as α-naphthol and β-naphthol:



α-Naphthol.



β-Naphthol.

The synthesis of α-naphthol from γ-phenyl*iso*crotonic acid (§ 521 (1)) shows that α-naphthol has the first formula and not the second.

They are substances of importance in the dye-industry.

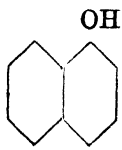
Both α- and β-naphthols are made from sodium naphthalene-sulphonates by fusion with alkali (cf. Expt. 77).

Like phenol they may be coupled with diazonium salts and yield many valuable azo-dyes (§ 402). Their sulphonic acids,

$$HO{\cdot}C_{10}H_6{\cdot}SO_3H \text{ and } HO{\cdot}C_{10}H_5(SO_3H)_2,$$

of which a great number are known, are also employed in this way.

529. α-Naphthol,



is prepared by first making sodium naphthalene-α-sulphonate and then mixing this with 40 per cent. sodium hydroxide solution. The product is fused at 300° C. for about twelve hours. The melt is dissolved in water and acidified.

$$C_{10}H_7{\cdot}SO_3Na + 2NaOH = C_{10}H_7{\cdot}ONa + Na_2SO_3 + H_2O$$

$$C_{10}H_7{\cdot}ONa + HCl = C_{10}H_7{\cdot}OH + NaCl.$$

α-Naphthol separates and can be purified by distillation under reduced pressure.

It is difficult to prepare sodium naphthalene-α-sulphonate quite free from the β-compound, and accordingly if pure α-naphthol is required it is best made by diazotising α-naphthylamine and warming the product with water (§ 399).

Physical Properties.—α-Naphthol crystallises in white needles melting at 94° C. and boiling at 278—280° C. It has an odour not unlike that of phenol. It is very sparingly soluble in water but is readily soluble in most organic solvents.

Chemical Properties.—α-Naphthol has many of the reactions of phenol (§ 354). It dissolves in alkalis giving a naphthoxide:

$$C_{10}H_7{\cdot}OH + NaOH = C_{10}H_7{\cdot}ONa + H_2O.$$

Like phenol, it is readily sulphonated and nitrated. The naphthol-sulphonic acids and nitronaphthols so produced are of importance in the dye industry.

Among the reactions which it does not share with phenol is its ready formation of α-naphthyl ethers. When heated with methyl alcohol and sulphuric acid at 140° C. under slight pressure, naphthyl methyl ether is formed:

$$C_{10}H_7OH + HO{\cdot}CH_3 = C_{10}H_7{-}O{-}CH_3 + H_2O,$$

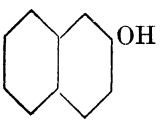
as an oil, with an orange-blossom-like odour.

Its reaction with ammonia is also a point of difference from phenol. Thus when heated for a long period with ammonia under pressure, or better, ammonium bisulphite, it gives α-naphthylamine:

$$C_{10}H_7{\cdot}OH + NH_3 = C_{10}H_7{\cdot}NH_2 + H_2O.$$

α-Naphthol forms a nitroso-compound with nitrous acid (cf. § 354).

530. β-Naphthol



is prepared from sodium naphthalene-β-sulphonate by the same method as is used for α-naphthol.

It crystallises in tables which melt at 122° C. and boil at 285—286° C. It is less volatile at lower temperatures than α-naphthol. It has decided antiseptic properties.

In its chemical properties it closely resembles α-naphthol, but is rather more reactive. Its alkyl ethers have orange-blossom-like odours and are used in perfumery. Ammonia and ammonium sulphite convert it into β-naphthylamine.

Nitrous acid gives α-nitroso-β-naphthol which is used in analysis. It gives insoluble precipitates with cobalt, iron, copper, etc., and the difficult separation of cobalt from nickel and of iron from aluminium is readily performed by precipitation with nitroso-β-naphthol.

α-Naphthol may be distinguished from β-naphthol by its reaction with ferric chloride. α-Naphthol gives an opalescent liquid which throws down a violet ppt. of αα′-dinaphthol, while β-naphthol gives a green liquid which gives a white precipitate of ββ′-dinaphthol.

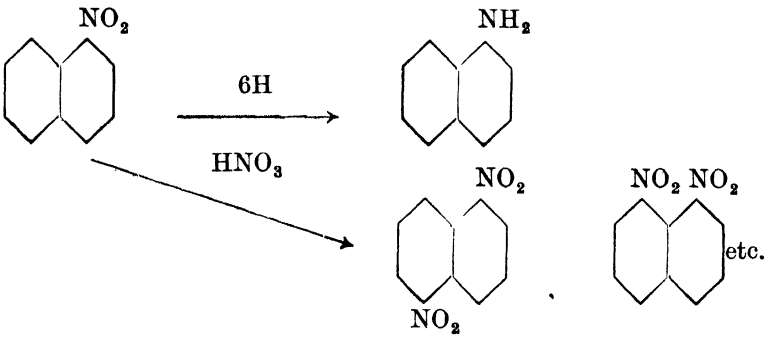
531. Nitronaphthalenes.—When naphthalene is treated with cold nitric acid ($d = 1{\cdot}33$), α-nitronaphthalene is formed:—

$$C_{10}H_8 + HNO_3 = C_{10}H_7{\cdot}NO_2 + H_2O.$$

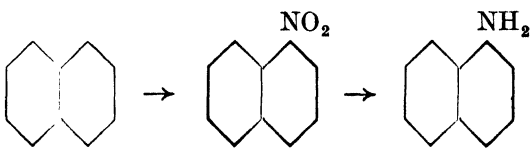
At higher temperatures various dinitronaphthalenes are produced. β-Nitronaphthalene is prepared from β-naphthylamine by the diazo-reaction (§ 399).

α-Nitronaphthalene forms yellow crystals melting at 61° C. It much resembles nitrobenzene (§ 368) in chemical properties. Thus

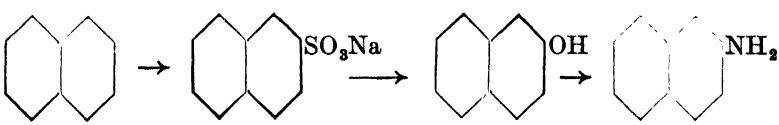
it can be reduced to α-naphthylamine and further nitrated to di-, tri- and tetra-nitronaphthalenes.



532. The Naphthylamines.—The naphthylamines, $C_{10}H_7 \cdot NH_2$, in general resemble aniline. α-Naphthylamine is made by reducing α-nitronaphthalene by a process resembling that by which aniline is made from nitrobenzene (§ 380).



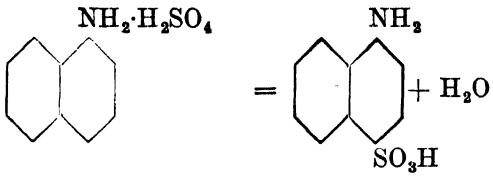
β-Nitronaphthalene cannot be made directly from naphthalene and accordingly β-naphthylamine is made by preparing β-naphthol and heating this with ammonium sulphite and ammonia solution under pressure:



Unchanged naphthol is removed by washing with sodium hydroxide solution and the β-naphthylamine is distilled under reduced pressure.

α-Naphthylamine crystallises when pure in colourless scales. It has an unpleasant fæcal odour. It melts at 51° C. and boils at 300° C.

It has the characteristic properties of a primary aromatic amine. Its salts may be diazotised and valuable azo-dyes may be prepared from these solutions. The action of heat on α-naphthylamine sulphate yields naphthionic acid, analogous to sulphanilic acid (§ 387):



This substance when diazotised couples with phenols and gives many good red azo-dyes.

β-Naphthylamine forms colourless lustrous scales which, unlike the α-compound, are odourless. It melts at 112° C. and boils at 294° C.

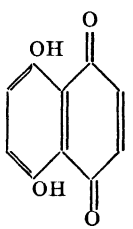
It is of not much value for the manufacture of dyes, but is useful for preparing the other β-substitution products of naphthalene by the various diazo-reactions (§ 399).

The naphthylamines may be distinguished by their odour and also by the fact that α-naphthylamine gives a blue ppt., soluble in chloroform, when ferric chloride is added to a solution of one of its salts.

All the ten possible diamino-naphthalenes are known.

533. Naphthoic Acids, $C_{10}H_7 \cdot CO \cdot OH$, are known. The hydroxynaphthoic acids, analogous to salicylic acid and made in an analogous manner (§ 459), are employed in the dye industry.

534. Naphthaquinones.—Several naphthaquinones exist. The only important derivative of these is the black dyestuff naphthazarin S, which is a dihydroxynaphthaquinone. Its likeness in structure to the important dye *Alizarin*, dihydroxyanthraquinone, is of interest.

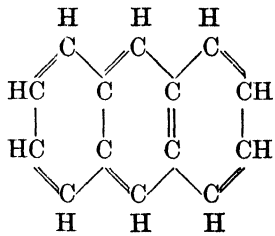


ANTHRACENE

535. Manufacture of Anthracene.—Anthracene, $C_{14}H_{10}$, forms a considerable part of the fraction of coal tar boiling above 270° C.

This fraction, when set aside, partly solidifies to a mass of anthracene crystals mixed with oil. The mass is centrifuged and subjected to heat and pressure. The crude anthracene is recrystallised from a mixture of pyridine bases (Chapter XXI.), and then sublimed.

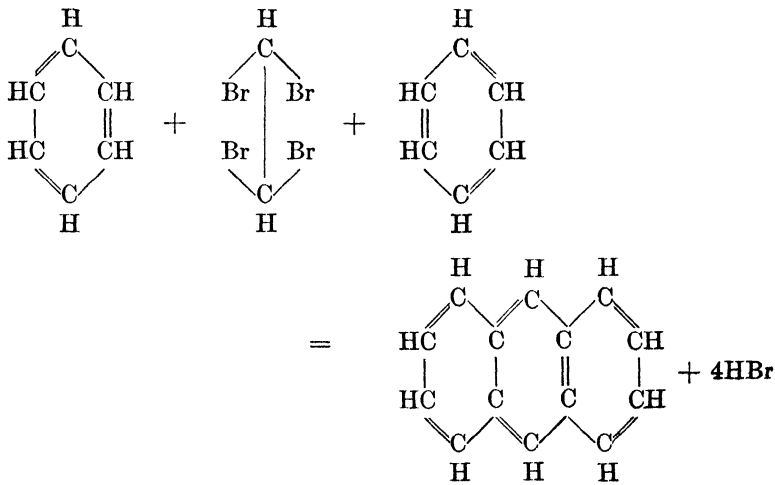
536. Synthesis and Structure.—The analogy of anthracene to naphthalene suggests a triple hexagonal formula:



I.

and such a formula will be seen to agree with most of its reactions, and to explain the fact that three monosubstitution products are known (§ 540).

Synthesis.—Anthracene has been made by the Friedel-Crafts reaction from acetylene tetrabromide and benzene in presence of aluminium chloride.



Several other methods of synthesis have been found (*e.g.*, from *o*-bromobenzyl bromide and sodium) and these also indicate a triple hexagonal formula.

537. Physical Properties of Anthracene.—Anthracene forms colourless tabular crystals which are fluorescent. It melts at 213° C. and boils at 351° C. It is insoluble in water and rather sparingly soluble in most organic solvents—most easily in benzene.

Anthracene has the peculiar property of becoming polymerised when its solutions are exposed to sunlight. Dianthracene, $(C_{14}H_{10})_2$, is formed, which differs from anthracene in being much less soluble and less reactive.

538. Chemical Properties of Anthracene.—Anthracene shows a general resemblance to naphthalene and benzene but is decidedly less reactive.

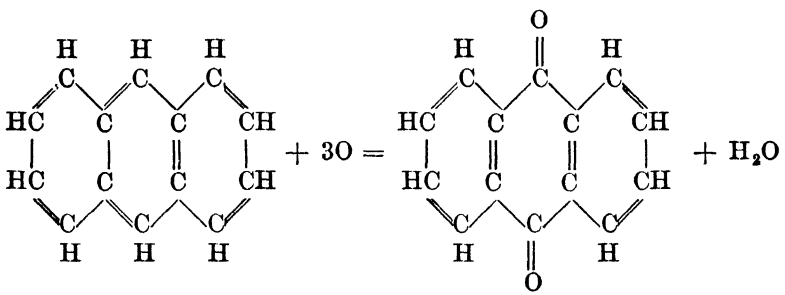
Chlorine and bromine form substitution products, *e.g.*, $C_{14}H_9Cl$, and addition products such as $C_{14}H_{10}Cl_2$.

With sulphuric acid it gives an anthracenemonosulphonic acid and several disulphonic acids.

The most marked difference from benzene and naphthalene is shown by the fact that it does not give a nitro-compound under any conditions.

Reduction converts it into hydrides such as $C_{14}H_{12}$, $C_{14}H_{16}$, $C_{14}H_{24}$.

Its most important reaction is its oxidation by chromic acid to anthraquinone, discussed under the heading of that substance (§ 541).

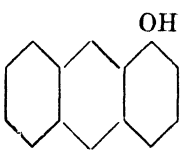


539. Anthracenesulphonic acids are obtained by heating anthracene with sulphuric acid or sodium hydrogen sulphate. When fused with alkalis they give hydroxyanthracenes.

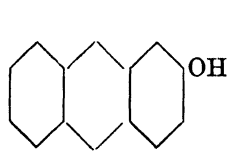
540. Hydroxyanthracenes.—Three mono-hydroxyanthracenes are theoretically possible. They are all known and have the names and formulæ indicated below.

The student should satisfy himself that no others can exist.

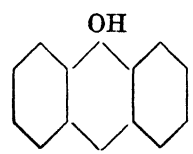
α- and β-Anthrol are made by fusing α- and β-anthracenesulphonic acids with sodium hydroxide.



α Anthrol.



β-Anthrol.

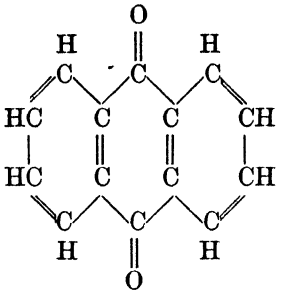


Anthranol.

Anthranol is prepared by vigorous reduction of anthraquinone (§ 541).

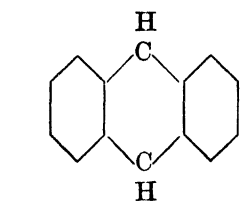
The hydroxyanthracenes somewhat resemble the naphthols. They are not of practical importance.

541. Anthraquinone.—

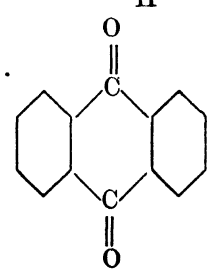


is a substance of considerable technical importance It is manufactured either from anthracene, or synthetically, from phthalic anhydride.

(1) Anthracene is exceedingly finely ground with a solution of sodium dichromate and caustic soda. The mixture is then made acid and heated. The anthracene is oxidised to anthraquinone:



$$+ Na_2Cr_2O_7 + 4H_2SO_4 =$$



$$+ 5H_2O + Na_2SO_4 + Cr_2(SO_4)_3$$

this is further purified by regulated heating with sulphuric acid which converts residual anthracene into the soluble sulphonic acid. The anthraquinone is finally sublimed.

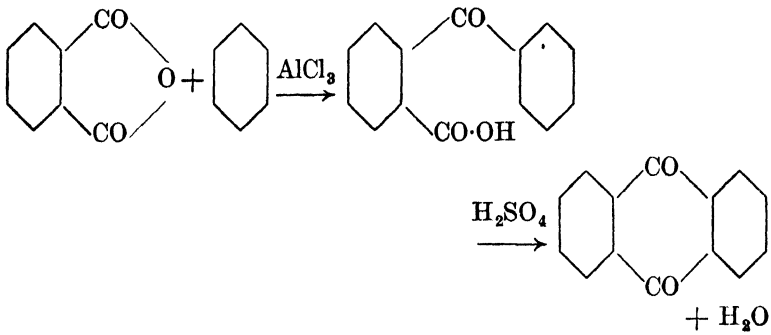
In the laboratory a solution of chromium trioxide in acetic acid may be employed.

Expt. 106.—*Preparation of Anthraquinone.*—Three grams of very finely powdered anthracene and 140 c.c. of glacial acetic acid are heated in a flask fitted with reflux condenser till all the anthracene has dissolved. If a portion remains obstinately undissolved it must be filtered off. The solution is again heated

and a solution of 30 g. of chromium trioxide in 15 c.c. of water and 15 c.c. of acetic acid is added a little at a time to the boiling solution. Heating is continued for an hour and the liquid poured into 500 c.c. of cold water. After some hours the precipitate is filtered off, washed with water, dilute caustic potash solution, and finally again with water.

(2) Much anthraquinone is now made by treating phthalic anhydride and benzene with anhydrous aluminium chloride.

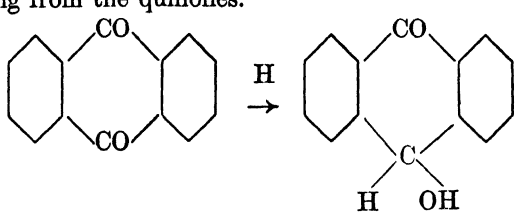
The product, *o*-benzoylbenzoic acid, when treated with sulphuric acid gives anthraquinone:



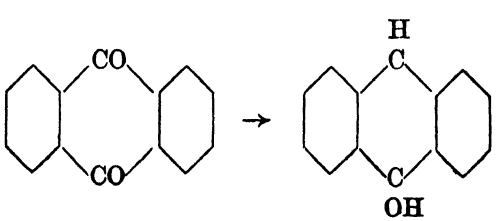
Anthraquinone forms yellow needle-shaped crystals which melt at 277° C. It boils at 379—381° C.

It is much more stable than the benzoquinones (§ 363) and rather resembles a ketone (*e.g.*, benzil, § 482) in its properties.

When reduced with zinc dust and caustic soda it gives first oxanthranol, in this respect also resembling a straight-chain ketone and differing from the quinones.

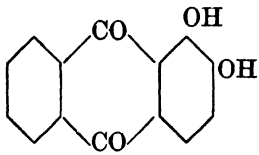


Reduction with tin and hydrochloric acid gives anthranol.



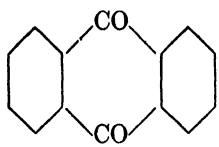
With sulphuric acid it gives anthraquinonesulphonic acids from which the important dihydroxyanthraquinone, the dye alizarin, is obtained.

542. Alizarin, 1 : 2-Dihydroxyanthraquinone.—

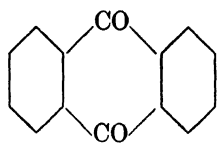


Alizarin has been known as a dye since a remote period. The plant, madder, *Rubia tinctorum*, formerly grown in great quantities, contains in its root a glucoside (§ 273) *ruberythric acid*, which is readily hydrolysed by enzymes, giving glucose and alizarin.

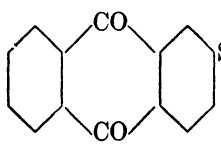
Alizarin is now invariably prepared synthetically. Anthracene (or phthalic anhydride and benzene) are converted into anthraquinone (§ 541). The anthraquinone is sulphonated, mainly to the anthraquinone-2-sulphonic acid. The sodium salt of this is sparingly soluble; sodium anthraquinone-2-sulphonate is readily obtained. The product is fused with sodium hydroxide and a little potassium chlorate, when alizarin is formed.



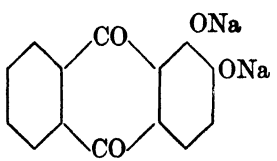
$+ H_2SO_4 =$



$+ H_2O$



$+3NaOH + O =$



$+ Na_2SO_3 + 2H_2O$

The melt is allowed to cool and is dissolved in water. The deep purple solution of the sodium salt of alizarin is acidified and the orange-red dye is precipitated.

Alizarin forms fine red crystals which melt at 289° C. It is but sparingly soluble in water.

Being a phenol, it readily dissolves in alkalis and a deep reddish-purple solution is formed. This solution reacts with numerous

metallic compounds giving insoluble metallic salts known as 'lakes.'

Alizarin is a mordant dye. The material to be dyed is impregnated with a solution of aluminium acetate and then is heated in steam. Aluminium hydroxide is formed by hydrolysis and deposits on the fibre. The material is then dyed with a solution of the sodium salt of alizarin, which reacts with the aluminium hydroxide giving the red insoluble aluminium salt of alizarin.

Tin and iron salts are also used in mordanting the material. When cotton is dyed with alizarin it is previously treated with 'Turkey-red oil' obtained by acting on castor oil with sulphuric acid. The action of this liquid is obscure, but without it the fine 'Turkey-red' cannot be obtained.

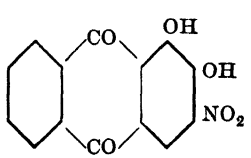
Expt. 107.—*Mordant Dyeing with Alizarin.*—To about 0·25 g. alizarin add a few drops of caustic soda solution and dissolve the product in about 10 c.c. of water. To ½ c.c. of this solution add excess of aluminium sulphate solution and filter. A fine red ppt. of the 'lake' is obtained.

To some aluminium sulphate solution add excess of ammonia and filter. Boil the precipitated aluminium hydroxide with just enough dilute acetic acid to dissolve it. Boil a small piece of cotton cloth in this solution. Squeeze out the excess of liquid and warm the damp cloth over a flame, but do not let it get dry.

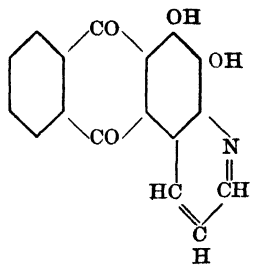
Prepare a second small piece of cloth by dipping it in dilute ferric chloride solution, drying off the excess of liquid with absorbent paper, and finally holding it in the fumes of ammonia evolved by a little 0·880 ammonia in the bottom of a beaker.

Dilute the alizarin solution to 200 c.c. and boil the mordanted cloths and also an unmordanted piece of cotton in it. Wash the pieces well in running water. The aluminium-mordanted piece is dyed red, the iron-mordanted piece violet, while the unmordanted portion is but faintly coloured.

543. Dyes Allied to Alizarin.—All the hydroxyanthraquinones with OH groups in the *ortho-position* are dyes; for example, the important *Alizarin orange.*



and *Alizarin blue,* which contains a heterocyclic ring

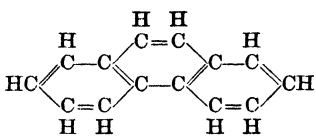


544. Chrysarobin is a glucoside of chrysophanic acid, which is a methyl-dihydroxyanthraquinone.

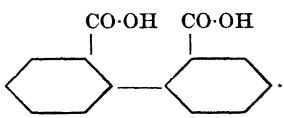
It is found in goa powder, obtained from a West African tree. Both chrysarobin and chrysophanic acid are valuable drugs for the treatment of eczema and other skin diseases.

Chrysarobin is also present in the valuable drug *rhubarb*, to which it gives its yellow colour and its purgative properties.

545. Phenanthrene, $C_{14}H_{10}$, is found in coal tar with anthracene. The formula assigned to it is

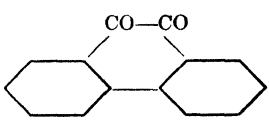


The formula is based on various syntheses and on its oxidation to diphenic acid,



It much resembles anthracene. It melts at 99° C. and boils at 340° C. Like anthracene it is fluorescent in solution.

Oxidation converts it either into diphenic acid or, if chromic acid is employed as oxidising agent, into phenanthraquinone

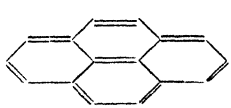


which is an orange solid resembling anthraquinone.

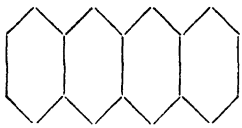
546. Other Complex Cyclic Hydrocarbons.—Many other complex cyclic hydrocarbons are known, mostly derived from the highest boiling fractions of coal-tar. Examples of such hydrocarbons are:

Ring Structure.

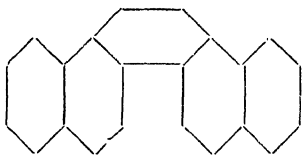
Pyrene, $C_{16}H_{10}$,



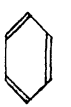
Naphthacene, $C_{18}H_{12}$,



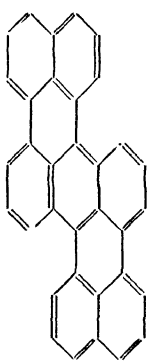
Picene, $C_{22}H_{14}$,



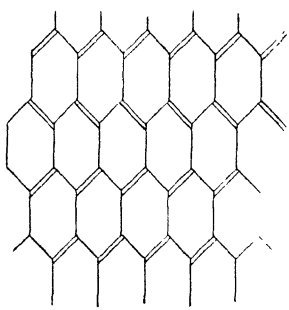
They are all stable substances of very high boiling point. One of the most complicated hydrocarbons yet prepared is di*peri*naphthyleneanthracene, which melts at 580° C.



Benzene



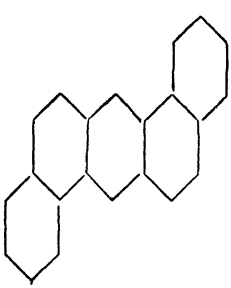
Di*peri*naphthyleneantharacene



Probable structure of Graphite

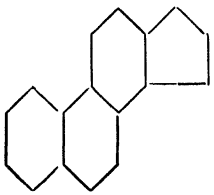
Such a hydrocarbon as the above may be regarded as a link between the simple aromatic hydrocarbons and graphite, which is shown by X-ray studies of its crystals to have an indefinitely extended structure of linked hexagonal rings.

Some of these complex hydrocarbons, such as 1 : 2 : 5 : 6 : dibenzanthracene, have been shown to be very active in producing

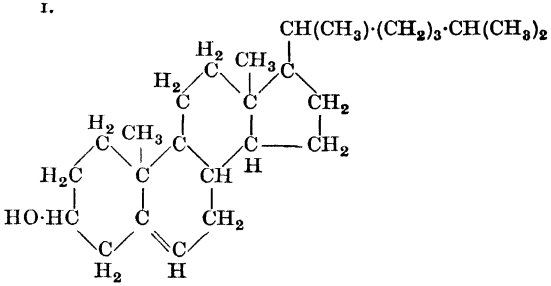


cancerous tumours, a property long known to be inherent in pitch and in certain types of mineral oil.

546a. The Steroids.—A number of biologically important substances are included in the group of *steroids*, which may be regarded as being derived from the hydrocarbon *cyclo*-pentenophenanthrene. They contain the ring system I:—



I.



II.

546b. Cholesterol has the formula given above (II). It is contained in wool-fat (lanolin) to the extent of about 70%. It is present in all parts of the human body and in especially large proportion in the brain, ovaries, and adrenal cortex. It is contained in considerable quantity in the bile, from which it may crystallise out, so forming gall-stones. Cholesterol is a white crystalline substance melting at 148°C. Though necessary to the animal economy, it is fairly inert physiologically. Other steroid derivatives are, however, intensely active in very minute quantities. These include:

(1) The substances having vitamin D activity, without which bone-formation cannot be properly achieved.

(2) The sex-hormones which bring about the changes of puberty and regulate the sexual cycle.

(3) The hormone of the adrenal cortex, absence or deficiency of which causes the fatal Addison's disease.

(4) The active principles of several plants used as drugs, e.g. strophanthus, squills, digitalis.

(5) Toad poisons.

QUESTIONS

(1) Compare the chemical properties of benzene, naphthalene and anthracene.

(2) How is naphthalene made? How can it be converted into α-naphthol and β-naphthol?

(3) What formulæ are adopted for naphthalene and anthracene, and on what grounds? Why should naphthalene not be (*a*) a straight chain compound, (*b*) a ring compound with a single ring of ten carbon atoms?

(4) Describe the preparation of α- and β-naphthylamine from naphthalene. How would you convert them into the respective naphthols?

(5) How can alizarin be made, starting from coal tar? Detail and explain the processes by which a piece of cotton cloth may be dyed with alizarin.

CHAPTER XXXI

HETEROCYCLIC COMPOUNDS

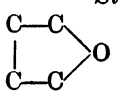
547. Heterocyclic Rings.—An enormous number of compounds are known containing rings partly built up from carbon atoms and partly from nitrogen, sulphur or oxygen atoms.

The chemistry of these compounds is very extensive and highly complex. Many important dyestuffs, the colouring matters of most plants, the respiratory pigments hæmoglobin and chlorophyll, and finally the important group of alkaloids, are all heterocyclic compounds. The chemistry of most of the above is beyond the scope of this book, but in this and the succeeding chapters a few of the more important heterocyclic compounds are studied.

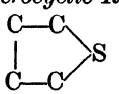
The table which follows illustrates the ring skeletons of the more important types of heterocyclic compounds.

RINGS CONTAINING ONE ATOM OTHER THAN CARBON

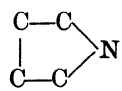
Single Heterocyclic Rings



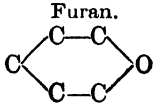
Furan.



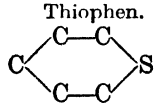
Thiophen.



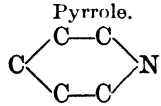
Pyrrole.



Pyran.

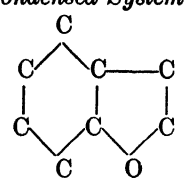


Penthiophen.

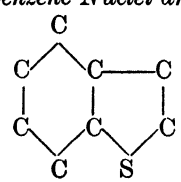


Pyridine.

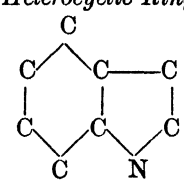
Condensed System of Benzene Nuclei and Heterocyclic Rings



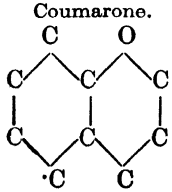
Coumarone.



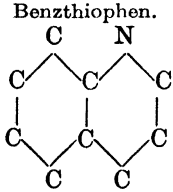
Benzthiophen.



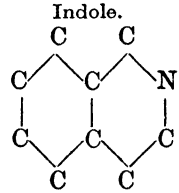
Indole.



Chromone.

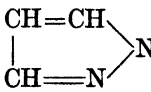


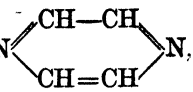
Quinoline.

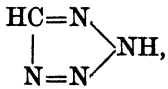


iso-Quinoline.

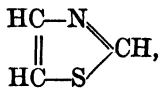
In addition to the compounds shown above many ring structures are found containing two or more nitrogen atoms, *e.g.*,

pyrazole  ,

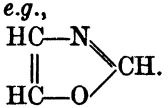
pyrazine  ,

tetrazole  ,

etc.; also rings containing nitrogen and sulphur, *e.g.*,

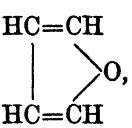
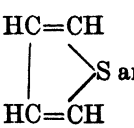
thiazole  ,

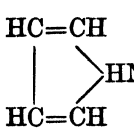
or nitrogen and oxygen, *e.g.*,

oxazole,  .

The most important *groups* of heterocyclic compounds are the *alkaloids*, mostly related to quinoline; the indigo pigments related to indole, and the anthocyanins or flower pigments derived from chromone. These are studied in Chapter XXXII.

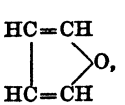
THE FURAN GROUP

Furan  , Thiophen  and

Pyrrole  show a decided resemblance.

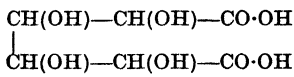
All three show some likeness to benzene and its derivatives though their rings are much more easily broken. In the case of thiophen the likeness is remarkably close and its separation from benzene is a difficult task.

548. Furan, C_4H_4O,

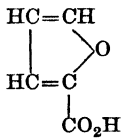
 ,

occurs in wood tar. It can also be made by distilling barium pyromucate.

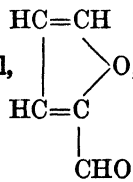
Mucic acid is obtained by oxidising the gums, various sugars, etc., and has the formula:



When heated it loses water and yields pyromucic acid (furan-carboxylic acid)



Barium pyromucate breaks up when heated, giving furan. It is a colourless liquid boiling at 32° C. It is polymerised in presence of mineral acids to an insoluble powder. Its most important derivative is furfuraldehyde.

549. Furfuraldehyde, Furfural,  , is readily obtained in quantitative yield when pentoses or substances containing them (*e.g.*, bran) are distilled with moderately concentrated sulphuric acid or hydrochloric acid. The reactions are discussed in § 270, but the general equation is

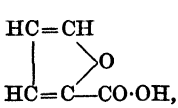
$$C_5H_{10}O_5 = C_5H_4O_2 + 3H_2O.$$

It is a colourless liquid with a pleasant characteristic odour. It boils at 162° C.

In its chemical properties it closely resembles benzaldehyde, and from it numerous furan derivatives have been prepared.

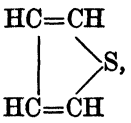
Furfuraldehyde is recognised by the pine-shaving reaction. A piece of pinewood moistened with hydrochloric acid is coloured emerald green by it. It is also recognised by the red colour it imparts to paper moistened with aniline acetate solution. The evolution of furfuraldehyde vapour is used as a test for pentoses.

550. Pyromucic acid,



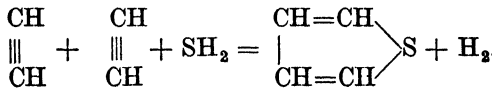
the formation of which has been discussed in § 548, much resembles benzoic acid.

551. Thiophen,



is always present in crude benzene, from which it is separated with difficulty. Its boiling point is 84° C., which is too near that of benzene (80·4° C.) to allow of adequate separation by fractional distillation. It is often separated from benzene by boiling with mercuric acetate. An insoluble mercury derivative of thiophen separates, which when distilled with acids yields thiophen.

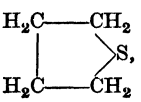
Thiophen has been synthesised by the reaction of acetylene and hydrogen sulphide at 400° C. in presence of alumina as a catalyst,



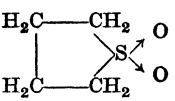
Thiophen is a liquid boiling at 84° C. and having an odour resembling that of benzene.

It resembles benzene most closely in its reactions. It forms a nitrothiophen (which can be reduced to aminothiophen), a thiophensulphonic acid and a hydroxy-compound analogous to a phenol. All these thiophen derivatives are remarkably like the corresponding derivatives of benzene. It should be noted that thiophen is quite unlike the thio-ethers which also contain the group >S. Thus it has no unpleasant odour and is not oxidised to a sulphone.

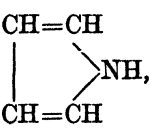
Tetrahydrothiophen,



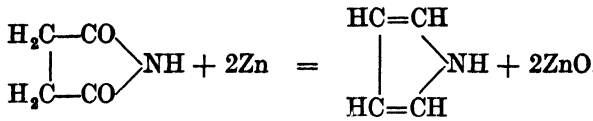
however, resembles a thio-ether in its odour and in its reaction to form a sulphone:—



552. Pyrrole,

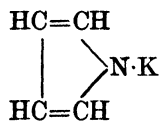


C_4H_5N, occurs in coal-tar and in bone-oil (§ 556). It may be made by heating succinimide (§ 214) and zinc dust.



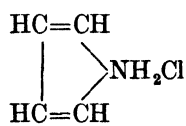
It can also be made from acetylene and ammonia (cf. § 551) or from ammonium pyromucate.

It is best prepared by fractionating bone-oil and treating the fraction boiling between 98° C. and 150° C. with solid potassium metal. Potassium pyrrole,

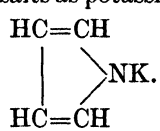


is formed as a solid; this, when treated with water, gives pyrrole (with some other bases), which is then purified by fractional distillation.

Pyrrole is a colourless liquid boiling at 131° C. and having an odour like that of chloroform. As in many other compounds the =NH group is both basic and acidic in character. Thus it reacts both as a base giving salts such as

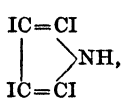


and as an acid giving such salts as potassium pyrrole,



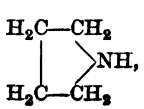
The latter is decomposed by water. Pyrrole is recognised by the bright red colour it gives to a pine-shaving moistened with hydrochloric acid.

Tetraiodopyrrole (iodole),

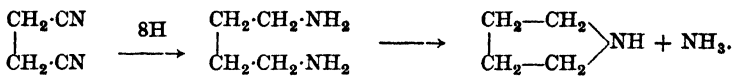


is obtained by the action of iodine and alkalis on pyrrole. It is used as a substitute for iodoform, and has the advantage of possessing the latter substance's antiseptic properties without its unpleasant odour.

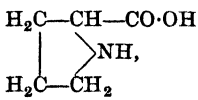
553. Pyrrolidine,



is obtained by reducing pyrrole very vigorously or by reducing ethylene cyanide with sodium and alcohol.



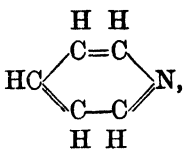
Pyrrolidine-carboxylic acid,



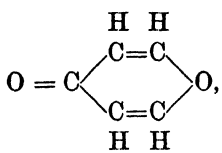
is known as *proline*, and is one of the amino-acids from which the proteins are built up. Hydroxyproline is also a constituent of some proteins.

SIX-MEMBERED HETEROCYCLIC RINGS

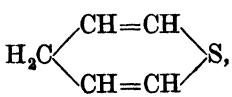
Pyridine,



is the best-known heterocyclic compound with a 6-membered ring. Pyrone,

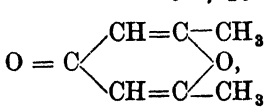


gives an example of a six-membered ring containing oxygen, while penthiophen,

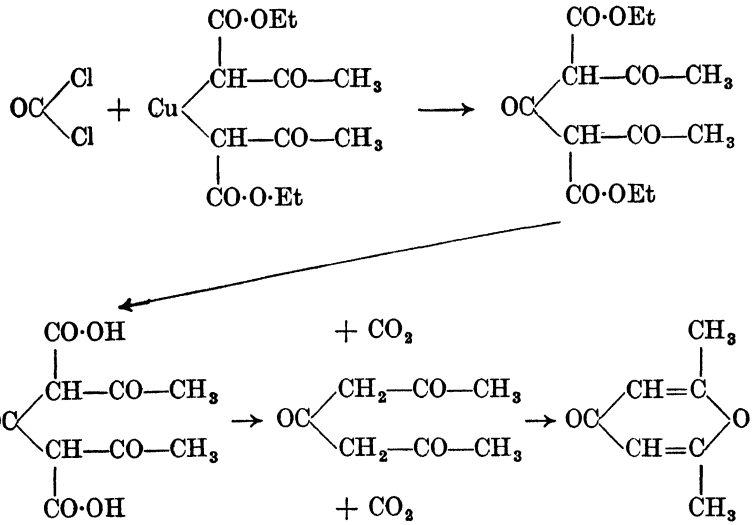


is of small importance.

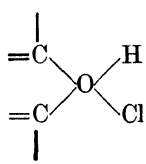
554. Pyrone Compounds.—Dimethyl-γ-pyrone,



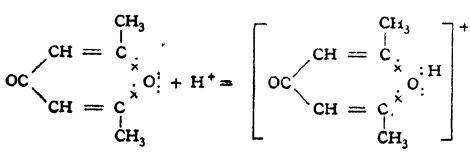
can be made from the cupric salt of acetoacetic ester (§ 258) and carbonyl chloride. An ester is produced which on hydrolysis with sulphuric acid gives dimethylpyrone:



555. Oxonium Salts.—The chief interest of dimethylpyrone is in its basic properties. With acids it forms well-defined, though unstable *oxonium salts*. These were at one time formulated as containing a grouping such as



with a quadrivalent oxygen atom. A truly quadrivalent oxygen atom is unlikely as it would involve a ring of ten valency electrons instead of the eight always found in the compounds of the elements



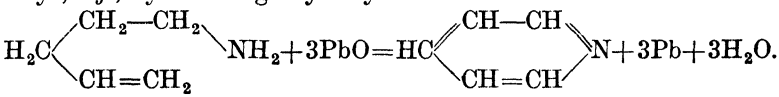
in the first period of the periodic table. The analogy of the oxonium salts to the ammonium salts makes it clear that they are the result of the reaction of the oxygen atom with hydrion giving a positive ion, the oxygen atom remaining bivalent as usual.

556. Pyridine.—*Manufacture.*—Pyridine together with other similar bases, is contained in coal-tar and to a greater extent in *bone-oil*, the product of the dry distillation of bones in retorts similar to those used in the preparation of coal-gas. Bone-oil is a dark

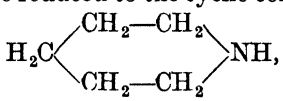
liquid of most offensive odour. It contains nitriles of fatty acids, pyrrole and alkyl pyrroles, pyridine, quinoline and many other compounds.

Pyridine is manufactured by shaking the light oil (§ 337) from coal-tar or bone-oil with dilute sulphuric acid. Pyridinium sulphate dissolves together with the sulphates of other bases. The separated acid layer is made alkaline, when pyridine, etc., separates. Pure pyridine is separated by fractional distillation.

Synthesis and Constitution.—It may be synthesised in several ways, *e.g.*, by distilling allylethylamine over lead oxide:



Its likeness to benzene (*v.* below) indicates a similar ring structure, and the fact that it can be reduced to the cyclic compound piperidine,



also supports the accepted formula.

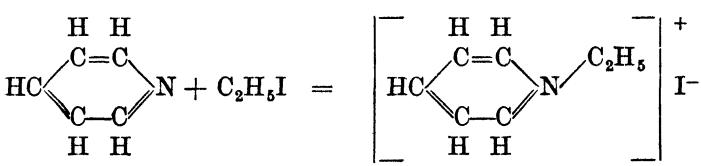
Physical Properties.—Pyridine is a colourless liquid with an unpleasant odour recalling that of burnt feathers. It boils at 115° C. It is miscible with water but is easily salted out.

Chemical Properties.—Pyridine reacts:

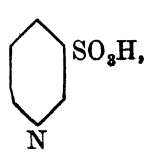
(1) as a tertiary amine (§ 127),

(2) in a manner resembling benzene or nitrobenzene.

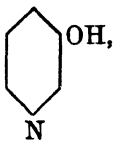
Thus, pyridine is a fairly strong base and with acids forms salts such as the hydrochloride $C_5H_5 \equiv NHCl$. It forms a well-crystallised platinichloride and aurichloride. Like other tertiary amines it reacts with alkyl iodides forming quaternary ammonium salts. Thus with ethyl iodide it gives ethylpyridinium iodide:



It resembles benzene in that, although it is unsaturated, it forms substitution products more readily than addition products. Thus with sulphuric acid at high temperatures it forms a sulphonic acid,

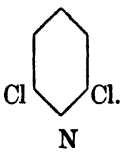


and by fusing this with caustic potash a β-hydroxypyridine,



analogous to phenol, is produced.

Phosphorus pentachloride converts it into chloropyridines such as



In its substitution reactions it differs from benzene most notably in that it can be nitrated only with difficulty.

Like benzene, pyridine is highly resistant to oxidation. Reduction with nascent hydrogen gives hexahydropyridine, known as piperidine (§ 559).

Uses.—Pyridine is employed for denaturing alcohol, and, very widely, as a solvent. It is also used for preparing piperidine. It is employed as a catalyst in the preparation of chloro- and bromobenzene (§ 348), etc.

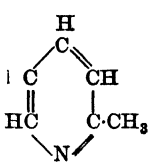
Expt. 108.—*Reactions of Pyridine.*—(1) Note odour, solubility in water, weak effect on litmus.

(2) To a solution of pyridine in dilute sulphuric acid, add potassium ferrocyanide. Crystalline ppt. of pyridine ferrocyanide separates.

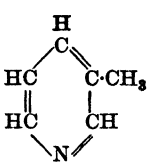
(3) To ½ c.c. of the base add ½ c.c. of methyl iodide and warm, shaking well. A vigorous reaction ensues, methylpyridinium iodide being produced; on heating with solid potash, an irritating and disagreeable odour is noticeable.

(4) Show that CrO_3 does not oxidise it.

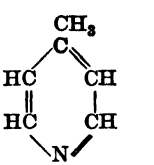
557. Homologues of Pyridine.—Three different monomethylpyridines known as picolines exist:



α-Picoline.



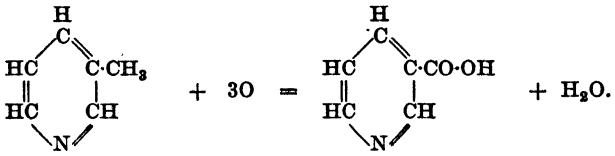
β-Picoline.



γ-Picoline.

Six dimethylpyridines or *Lutidines* and six trimethylpyridines or *Collidines* are known. The homologues resemble pyridine. Like the methylbenzenes, they are easily oxidised to acids.

Thus β-picoline is oxidised to β-pyridinecarboxylic acid, known as nicotinic acid:

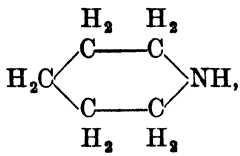


The amide of nicotinic acid is the vitamin, whose absence from the human diet brings about the disease, *pellagra*.

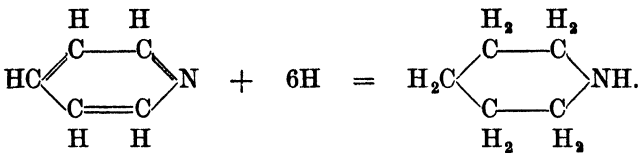
558. Derivatives of Pyridine.—The substituted pyridines have, in general, the reactions of the corresponding aromatic compounds.

Thus the sulphonic acids when fused with caustic soda give hydroxypyridines. These resemble the aminophenols, being both acidic and basic in character. The aminopyridines can be diazotised. The pyridinecarboxylic acids resemble aromatic acids in that, when heated with lime, they regenerate pyridine.

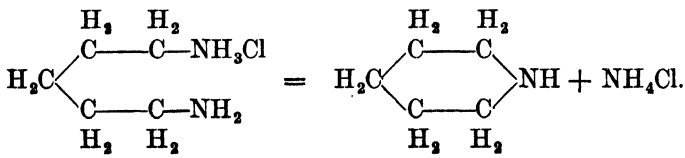
559. Piperidine,



is the ultimate product of the reduction of pyridine with sodium and alcohol or electrolytically:



Its structure is made clear by its production when pentamethylenediamine hydrochloride is heated:



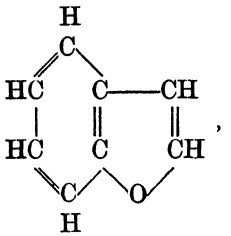
Its constitution can also be demonstrated by the process of exhaustive methylation explained on p. 534. It can also be obtained from the alkaloid *piperine* contained in pepper (§ 586).

Piperidine is a colourless liquid with an odour somewhat resembling that of pepper. It boils at 106° C. and is readily soluble in water.

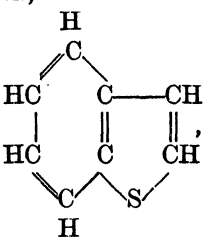
It is a stronger base than pyridine and forms numerous stable crystalline salts. It is a secondary amine (§ 126). When oxidised by heating with sulphuric acid to 300° C. it forms pyridine.

SYSTEMS OF A FIVE-MEMBERED HETEROCYCLIC RING CONDENSED WITH A BENZENE NUCLEUS

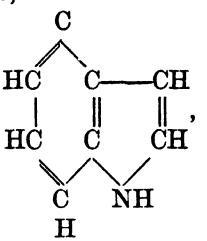
The compounds coumarone,



benzthiophen,

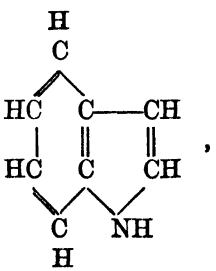


and indole,

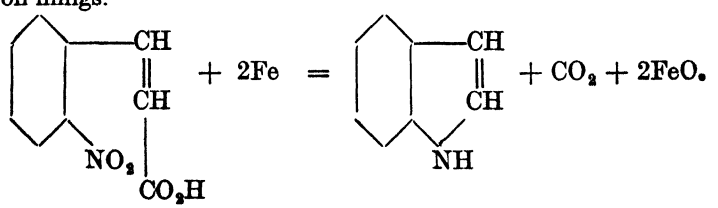


bear the same relation to furan, thiophen and pyrrole (§§ 548, 551, 552) as naphthalene does to benzene. While coumarone and benzthiophen, both found in coal-tar, are unimportant, indole is to be regarded as the parent substance of the very important indigo dyestuffs.

560. Indole,



may be synthesised by heating *o*-nitrocinnamic acid with potash and iron filings.



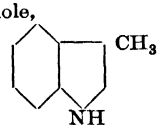
The amino-acid tryptophan (p. 556), which is a constituent of many proteins, is an indole derivative and accordingly indole may be obtained from proteins, notably albumen (§ 615), in various ways. The digestion of albumen by the pancreatic enzymes produces it and it is accordingly present in fæces. Fusion of albumen with caustic potash produces both indole and its methyl derivative, skatole.

Indole is found in oil of jasmine and although when pure it has an unpleasant fæcal odour, when much diluted it is a valuable constituent of certain perfumes.

Indole is a somewhat volatile solid which melts at 52° C.

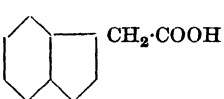
It resembles pyrrole (§ 552) in most respects. Thus it is feebly basic, and colours a pine splinter moistened with hydrochloric acid red.

561. Skatole, β-methylindole,



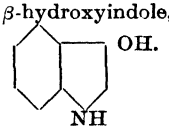
is contained in fæces, and is also produced when albumen is fused with potash. It has an unpleasant fæcal odour.

561a. Indole-acetic acid

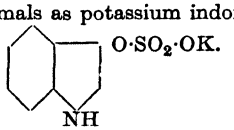


is of considerable interest as having the property of causing root-formation in plant-tissues. It is used commercially for promoting the rooting of cuttings. Phenylacetic acid, naphthaleneacetic acid, indolebutyric acid have similar effects.

562. Indoxyl.—Indoxyl is β-hydroxyindole,

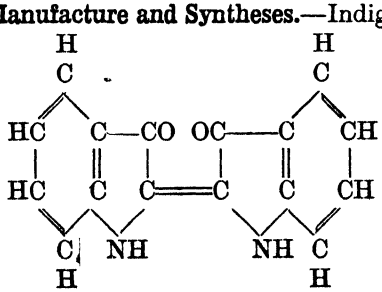


It occurs in the urine of mammals as potassium indoxylsulphate,



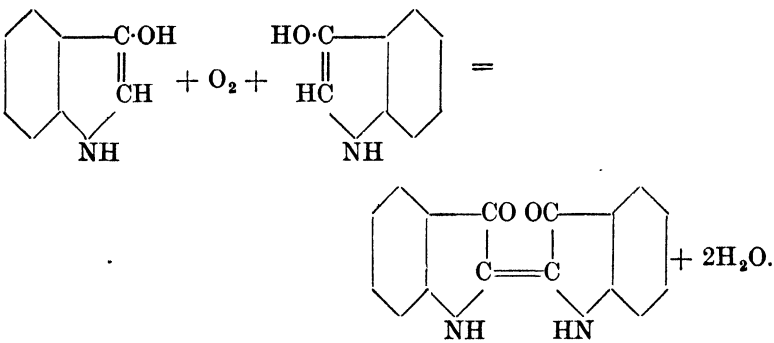
It is very readily oxidised to indigo (*v.* Diagram), p. 524.

563. Indigo, Manufacture and Syntheses.—Indigo has the formula



which shows it to be derived from two molecules of an indole derivative. Indigo is the most important of dye-stuffs and probably the most anciently known.

Natural Indigo.—Until some forty years ago all the world's indigo was made from certain plants, chiefly of the genus *Indigofera*. These plants all contain a glucoside *indican*, which when hydrolysed yields glucose and indoxyl. The latter is readily oxidised to indigo by atmospheric air:

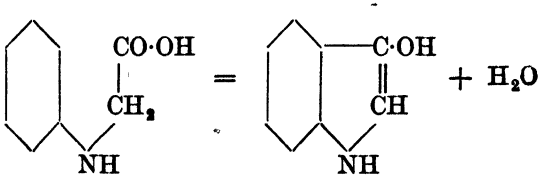


The plants were cut down and steeped in water. An enzyme present in the plant and the bacteria present in the liquid transformed the indican to indoxyl (§ 562). This dissolved in the water. The solution was run off and agitated with air by paddle wheels, etc. Indigo was precipitated, pressed into moulds and dried. The process is now almost obsolete and almost all the world's indigo is made synthetically.

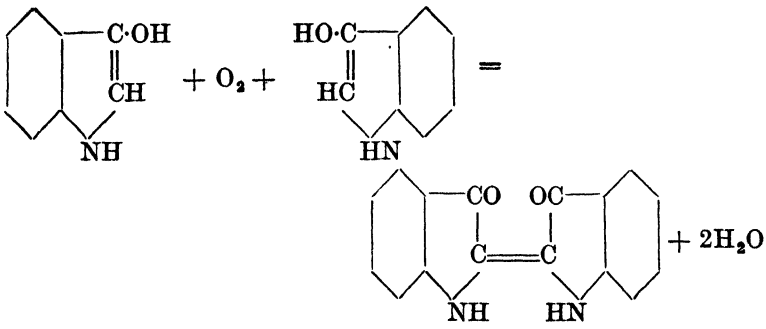
Synthetic Indigo.—Several processes have been developed for the synthesis of indigo. Aniline and chloroacetic acid react and yield phenylglycine:

$$C_6H_5{\cdot}NH_2 + Cl{\cdot}CH_2{\cdot}CO{\cdot}OH = C_6H_5{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}OH + HCl.$$

This when fused with alkali (or better with a mixture of sodium, sodium oxide and sodamide) gives indoxyl, which by oxidation with air gives indigo.

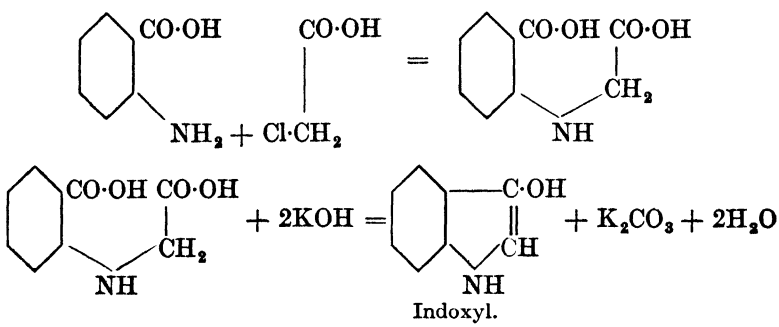


Phenylglycine. Indoxyl.



Indigo.

A similar process, employed for many years, started with naphthalene, which was converted into anthranilic acid (§ 470). This was condensed with chloroacetic acid yielding *o*-carboxyphenylglycocoll. This, when fused with alkali, gave indoxyl which was oxidised, as described above, to indigo.



Indoxyl.

As might be expected, in view of the commercial importance of indigo, a large number of synthetic processes have been devised for its preparation. The above are the only ones, however, which have had any considerable success.

564. Properties of Indigo.—Indigo is a deep blue powder of a coppery lustre. It may be sublimed, when it forms coppery lustrous prisms. It is insoluble in most solvents but may be dissolved in aniline.

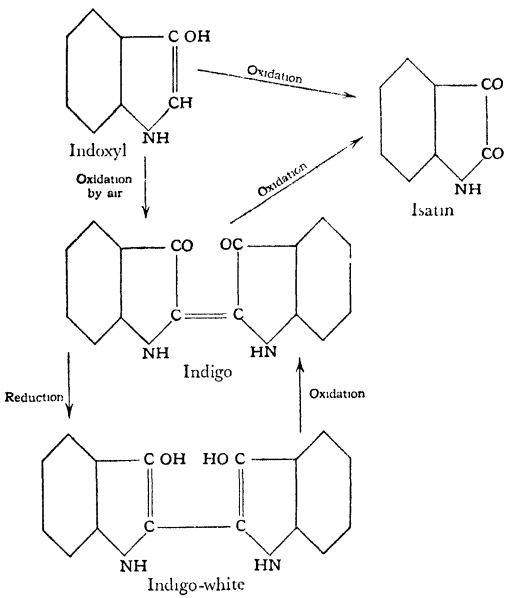
Its insolubility makes it necessary either to use indigo as a vat dye or to convert it into the soluble indigo-sulphonic acid.

Indigo when treated with concentrated sulphuric acid forms indigo-monosulphonic acid and indigo-disulphonic acid. The sodium salt of the latter is soluble in water and is sold as *indigo-carmine.*

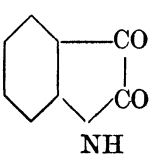
Indigo may be reduced to indigo-white (Diagram, p. 524) by

treatment with glucose and caustic soda or with ferrous hydroxide. This process is used in dyeing with indigo (§ 565 below).

REACTIONS OF INDIGO



Powerful oxidation by nitric acid, chlorates, etc., converts indigo into two molecules of the reddish compound isatin,



Expt. 109.—*Reactions of Indigo.*—(1) Heat a little in a dry test-tube, note violet vapour and sublimation.

(2) Heat a little with concentrated sulphuric acid. Cool and dilute. Note intensely blue solution of indigo-sulphonic acid.

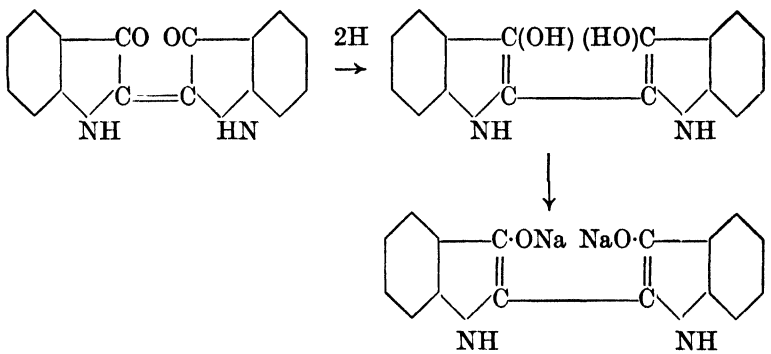
(3) Warm a little indigo with conc. nitric acid. A reddish-yellow solution of isatin is obtained.

(4) Mix about 0·2 g. of indigo with 1 g. of glucose and warm with a few c.c. of sodium hydroxide solution. Dilute and filter. The greenish

filtrate contains indigo-white. Moisten a piece of cotton cloth with a portion and expose to air. The cloth will become dyed blue as the indigo-white oxidises.

(5) Heat some indigo with zinc dust. The unpleasant odour of indole is noticed.

565. Indigo-dyeing.—Indigo, being insoluble, is ordinarily employed as a vat dye. The indigo is reduced to indigo-white by a hyposulphite (hydrosulphite) or glucose in presence of alkali. This, being a phenol, forms a soluble sodium salt:

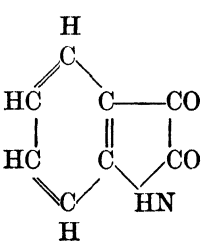


Sodium salt of indigo-white.

The fabric is dipped in this solution and then exposed to the air. Oxidation takes place and the indigo-white is converted into indigo, which is deposited both in and on the fibre.

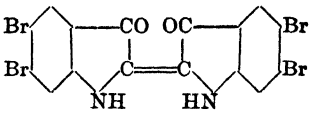
The dye is remarkably fast, neither acids, alkalis, soap nor light having any appreciable effect upon it. Silk and wool may be satisfactorily dyed with indigo merely by heating them with a solution of indigo-carmine.

566. Isatin,



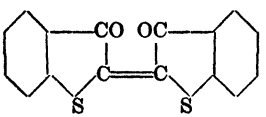
is obtained when indigo is oxidised (Diagram, p. 524). It may also be made by vigorous oxidation of indoxyl. It forms reddish-yellow crystals, slightly soluble in water.

567. Indigoid Dyestuffs.—Several dyes are known which may be regarded as derivatives of indigo, and possess as a rule its valuable dyeing properties. Tetrabromoindigo (Ciba Blue 2B) has the formula



and dyes in brighter shades than indigo.

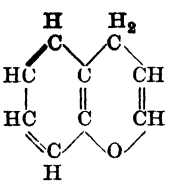
A class of dyestuffs known as the *thio-indigo* series with a ring structure of the type



are much in use and give very fast and stable colours.

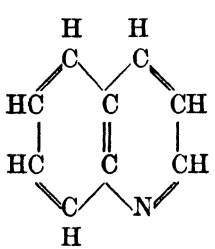
SYSTEMS OF BENZENE NUCLEUS CONDENSED WITH A SIX-MEMBERED HETEROCYCLIC RING

568. Chromane,

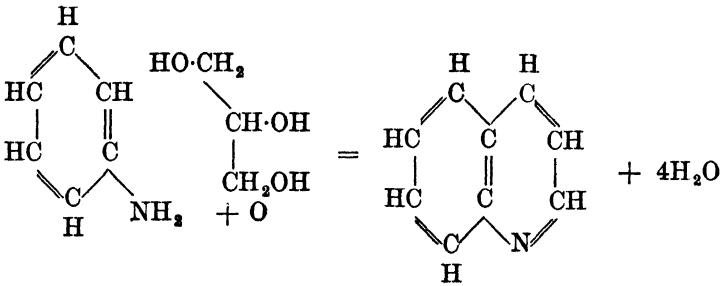


is only of importance as the parent of a great number of the coloured substances found in plants. These, the flavone derivatives, are discussed in the next chapter, §§ 602—604.

569. Quinoline,



is contained in bone-oil. Quinoline and its homologues are ordinarily made by Skraup's synthesis in which aniline, glycerol and sulphuric acid are heated with an oxidising agent, usually nitrobenzene or arsenic acid, H_3AsO_4.



The practical details are given in Expt. 110 below.

Expt. 110.—*Preparation of Quinoline.*[1]—In a 1,000 c.c. flask fitted with a wide reflux condenser, place 10 c.c. of nitrobenzene, 19 c.c. of aniline, and 120 c.c. of glycerol.[2] Shake well, mix and add gradually 55 c.c. of conc. sulphuric acid, shaking the flask to mix the constituents. Heat the flask on a sand-bath till the reaction begins, as shown by the appearance of white fumes. The flask is then raised from the sand-bath to allow the reaction to moderate, and when the reaction slackens the mixture is boiled for three hours.

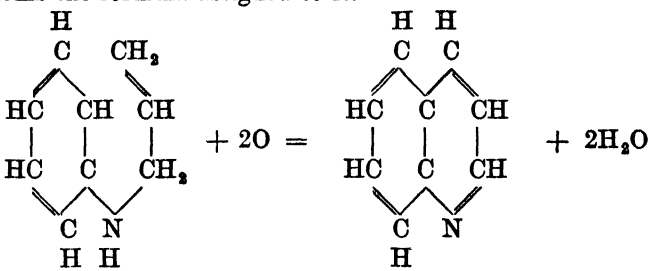
To extract the quinoline (present as sulphate) the mixture is diluted with 200 c.c. water and first steam-distilled from a large flask (1,500 c.c.) (§ 381) till no more nitrobenzene comes over. The residual liquid is then made strongly alkaline by addition of 150 g. of caustic soda dissolved in 200 c.c. of water. The resulting liquid is steam-distilled into a fresh receiver as long as oily drops come over. The product contains both aniline and quinoline. The former is removed by adding dilute sulphuric acid to the distillate until the aniline and quinoline have dissolved. Sodium nitrite is then added until a specimen of the liquid no longer gives a violet colour with bleaching powder. The aniline is thus converted into benzenediazonium sulphate while quinoline is unaffected. The solution is boiled, converting the aniline into phenol, and made alkaline with sodium hydroxide. The quinoline is thus liberated while the phenol forms sodium phenoxide. The liquid is steam-distilled once more. The distillate is extracted with ether and the ethereal extract is dried over solid potash and then distilled first on the water-bath to remove ether, then with the naked flame. Quinoline comes over above 200° C. (B.P. 239° C.).

Quinoline may be synthesised in several other ways. Its formation

[1] Requires eight or nine hours.

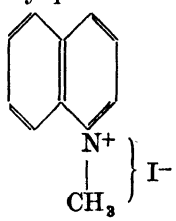
[2] Anhydrous glycerol, obtained by heating ordinary glycerol to 180° C. for some time, should be used.

by passing the vapour of allylaniline over heated lead monoxide conforms the formula assigned to it:



Quinoline is a colourless liquid of a peculiar odour. It boils at 239°. It is insoluble in water.

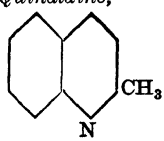
Quinoline is a tertiary amine and forms well-marked salts. The dichromate $(C_9H_7NH)_2Cr_2O_7$, unlike most quinoline salts, is sparingly soluble and affords a means of recognising the base. Like other tertiary amines it reacts with alkyl iodides, giving *alkylquinolinium salts* such as methylquinolinium iodide



These quaternary salts of the methylquinolines are of use in making the cyanine dyes, used as photographic sensitisers (§ 570). Reduction of quinoline yields hydroquinolines analogous to the hydronaphthalenes.

The action of halogens, sulphuric acid and nitric acid is to substitute Cl, Br, SO_3H, NO_2, etc., in the benzenoid ring. Products substituted in the pyridine ring are more difficult to prepare.

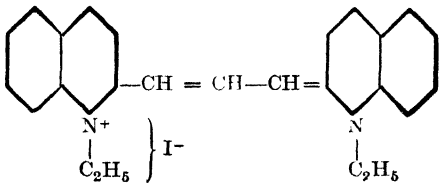
570. Methylquinolines.—*Quinaldine,*



occurs in coal-tar and can be synthesised from aniline and acetaldehyde (as paraldehyde).

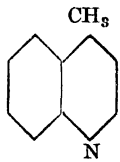
It finds uses in preparing the dye quinoline yellow which is formed when it condenses with phthalic anhydride.

The cyanine dyes are prepared by heating a mixture of formaldehyde and quinaldine with alkyl iodides and then treating them with caustic soda. They contain two systems of the quinoline type linked by a chain of unsaturated groupings, *e.g.*,



As dyes for fabrics, etc., they are useless, being so readily faded by light, but when added to the emulsion which coats a photographic plate they render it sensitive to the yellow and red rays which otherwise do not affect it.

Lepidine,



and several other alkylquinolines are known.

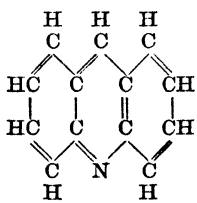
571. *iso*-**Quinoline,**



differs from quinoline in the position of the nitrogen atom. Some of the alkaloids (§§ 596—597) are *iso*quinoline derivatives. Its properties nearly resemble those of quinoline.

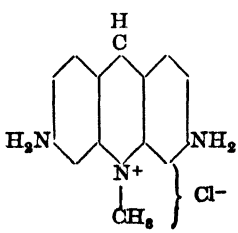
HETEROCYCLIC SYSTEMS CONTAINING MORE THAN TWO RINGS

572. Acridine,



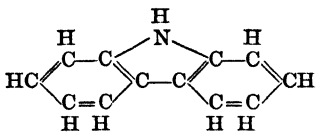
is the heterocyclic analogue of anthracene. Like quinoline it has basic properties. It is a solid, remarkably irritating to the skin and membranes of the throat and nose. Its salts have a powerful fluorescence. Some important yellow dyes are derived from it.

Acriflavine,



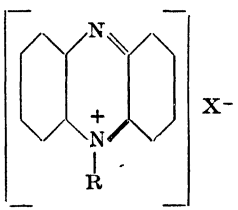
is used in surgery as an antiseptic, as also are several similar acridine derivatives.

573. Carbazole,

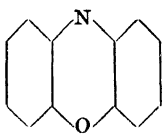


is contained in coal-tar. It is a highly stable substance showing a resemblance to pyrrole (§ 552). Thus it forms a potassium salt, gives the pine-shaving reaction and is a feeble base.

574. Complex Heterocyclic Dyes.—Several important classes of dyestuffs are heterocyclic in character. The fluoresceins and rhodamines contain a pyrone ring (§§ 491, 554). The azines, which contain the ring system

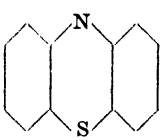
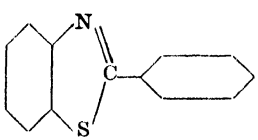


include many important dyestuffs, such as the red *safranines*, blue *indulines* and black *nigrosines*. The *oxazines* of the ring structure



also include many important dyes.

Ring systems containing sulphur and nitrogen such as

 and 

occur in the important dyes, methylene blue, primuline, and the sulphide dyes.

The chemistry of these compounds is of great industrial importance but is beyond the scope of a work of the present type.

QUESTIONS

(1) Point out the analogies between the heterocyclic bases, *e.g.*, pyridine, and (*a*) the aliphatic amines, (*b*) the benzene hydrocarbons.

(2) What are oxonium salts? Indicate their analogy in structure to the ammonium salts.

(3) How is indigo obtained synthetically? What reactions does it undergo during the process of indigo-dyeing?

(4) How may quinoline be prepared? Explain the method by which it can be separated from aniline.

CHAPTER XXXII

THE ALKALOIDS AND PLANT PIGMENTS

575. Alkaloids.—The term alkaloid has been used in the past to cover all organic bases found in plants and animals. Thus caffeine and the ptomaines were formerly classified as alkaloids.

These comparatively simple compounds are now usually excluded and the term 'alkaloid,' in its modern usage, may be defined as 'the more complex basic substances which occur naturally in living organisms and exhibit a high degree of physiological activity.'

All the alkaloids contain heterocyclic ring structures.

576. Sources of the Alkaloids.—The more important alkaloids are all found in plants or are prepared from other alkaloids. Some few have been synthesised, but in no case is the synthesis sufficiently easy to allow of its being used as a method of manufacture. The alkaloids are therefore extracted from the plants in which they occur.

The table which follows gives a list of the chief useful alkaloids and their sources.

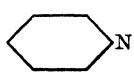
Alkaloid.	Source.	Uses.
Apomorphine	Manufactured from morphine.	Emetic.
Atropine	Deadly nightshade and other *Solanaceæ*.	Mydriatic, local anæsthetic.
Cocaine	*Erythroxylon coca*, a Peruvian plant.	Local anæsthetic.
Codeine	Opium poppy.	Sedative.
Emetine	Ipecacuanha.	Emetic, specific for dysentery.
Hyoscine	Belladonna and various *Solanaceæ*.	Sedative.
Morphine	Opium poppy.	Anodyne and hypnotic.
Nicotine	Tobacco.	Insecticide.
Pelletierine	Pomegranate.	Anthelmintic.
Quinidine	Cinchona bark.	Antimalarial.
Quinine	Cinchona bark.	Antimalarial.
Strophanthine	*Strophanthus kombe*, a West African plant.	Action on heart.
Strychnine	*Strychnos nux-vomica*.	Tonic; destruction of vermin.

Over eight hundred alkaloids are known; the above are those included in the British Pharmacopœia together with one or two more of practical importance.

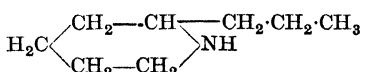
577. Extraction of the Alkaloids.—The plant material rarely contains more than a small proportion of the alkaloids. It is finely ground and percolated with alcohol or with dilute acid, in which the basic alkaloid dissolves forming a salt. If alcohol is used it is then distilled off and the residue dissolved in dilute acid. The solution of the salt of the alkaloid is filtered or otherwise purified and then made alkaline with sodium carbonate. The alkaloid is precipitated if insoluble, or if soluble is extracted from the liquid by shaking with an immiscible solvent, such as chloroform. Usually more than one alkaloid is contained in the plant material and more or less elaborate methods have to be used to separate any one in a pure condition.

578. Structure of the Alkaloids.—The alkaloids may be classified according to the type of ring structure they contain. The following is a list with examples of the types of structures encountered.

Alkaloids containing a pyridine ring



Coniine
Pelletierine
Nicotine
Piperine

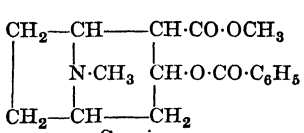


Coniine (*d*-*α*-*n*-propylpiperidine).

Alkaloids containing the tropine ring

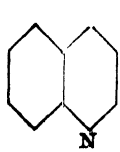


Atropine
Hyoscyamine
Cocaine
Hyoscine
Ecgonine

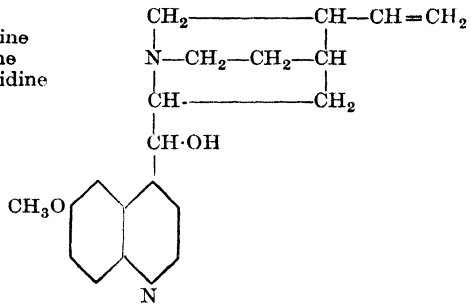


Cocaine.

Alkaloids containing a quinoline ring

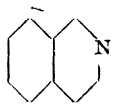


Quinine
Cinchonine
Quinidine
Cinchonidine

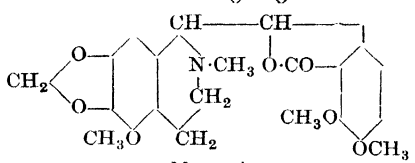


Quinine.

Alkaloids containing an isoquinoline ring



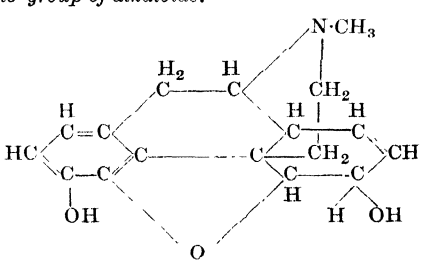
Papaverine
Laudanosine
Narcotine
Hydrastine
Berberine
Corydaline
Emetine



Narcotine.

The 'phenanthrene' group of alkaloids.

Morphine
Codeine
Apomorphine



Morphine.

Alkaloids containing other ring systems.

Aconitine.
Strychnine.
Brucine.

These compounds are of the highest degree of complexity and the ascertaining of their formulæ and structure has been one of the most difficult of tasks. Thus the formula of strychnine, after a century of research, is still not quite certain.

579. Elucidation of the Structure of Alkaloids.—The principle adopted throughout is to break the large molecules into recognisable

fragments in several different ways, and so to arrive at the whole structure. The chief means at the disposal of the chemist are the following:

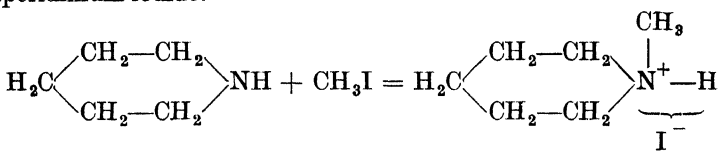
(1) Hydrolysis. This breaks up ester linkages (as in cocaine or atropine), but does not as a rule disturb the rest of the molecule.

(2) Formation of acetyl derivatives, so arriving at the number of hydroxyl groups (*cf.* §§ 84, 86).

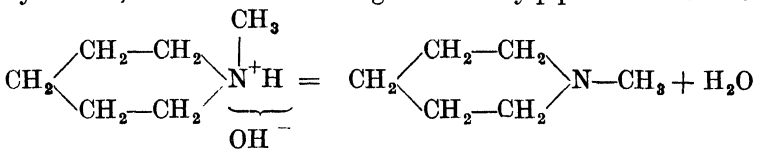
(3) Treatment with hydrogen iodide, which splits off methoxy-groups (as in narcotine) as methyl iodide,

$$\cdot X{\cdot}OCH_3 + HI = X{\cdot}OH + CH_3I.$$

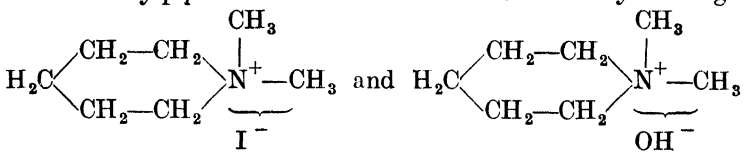
(4) The most important means of ascertaining the structure of these compounds is *exhaustive methylation* (Hofmann's method). If a cyclic amine, say piperidine, is treated with methyl iodide, a quaternary ammonium salt is formed (§ 128), in this case methyl-piperidinium iodide:



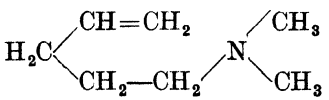
Treatment with moist silver oxide gives methylpiperidinium hydroxide, which when distilled gives a methylpiperidine and water:



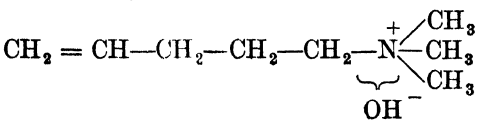
The methylpiperidine is now treated in the same way forming



This latter compound breaks up when distilled giving a straight-chain compound:—



The same treatment again repeated yields a compound:



which when distilled gives trimethylamine and $\Delta^{a\delta}$-pentadiene,

$$CH_2 = CH—CH_2—CH_2—CH_2—\underbrace{N^+(CH_3)_3}_{OH^-}$$

$$= CH_2 : CH—CH_2—CH : CH_2 + N(CH_3)_3 + H_2O.$$

which isomerises to piperylene $\Delta^{a\delta}$—pentadiene,

$$CH_2 : CH \cdot CH : CH \cdot CH_3.$$

From the fact that these compounds are finally obtained we can deduce that piperidine contains a chain of *five* carbon atoms linked into a ring by one nitrogen atom, and in this way the structure of many complex heterocyclic ring systems can be elucidated.

(5) Oxidation, distillation with zinc dust, etc.; often give recognisable products. Thus morphine (§ 599), when distilled with zinc dust, gives phenanthrene (§ 545).

(6) In a few cases a large fragment of the molecule may be synthesised, a process which usually gives the formula with some degree of certainty.

580. Evidence for the Structure of an Alkaloid.—While it is obviously impossible in a work of this scope to give the reasoning leading up to the formulæ of all the common alkaloids, a study of the way in which the formula of one moderately complex alkaloid has been arrived at may be of value. For this study we select atropine, an alkaloid found in deadly nightshade and some other plants, and used in medicine as a *mydriatic* for dilating the pupil of the eye.

(1) *Hydrolysis.*—Atropine, $C_{17}H_{23}O_3N$, is readily hydrolysed by dilute alkalis to two substances: *tropine*, $C_8H_{15}ON$, and tropic acid, $C_9H_{10}O_3$. These may be made to recombine and form atropine. Tropine is a secondary alcohol, for it may be oxidised to a ketone (*v.* below, and § 52). Atropine contains one less hydroxyl group than tropine and tropic acid together. Hence we may suppose that it is an ester of tropine and tropic acid. Tropic acid is found to be identical with phenyl-hydracrylic acid $C_6H_5—CH\begin{<}{CH_2 \cdot OH}{CO \cdot OH}$. We may then write the equation for the hydrolysis of atropine as

$$C_{17}H_{23}O_3N + H_2O = \underset{\text{Tropine.}}{(C_8H_{14}N)OH} + \underset{\text{Tropic Acid.}}{\begin{matrix} HO \cdot OC \\ \diagdown \\ CH \cdot C_6H_5 \\ \diagup \\ HO \cdot CH_2 \end{matrix}}$$

and write a preliminary formula for atropine

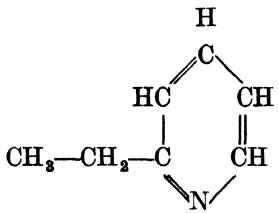
$$(C_8H_{14}N)O \cdot CO \cdot \underset{\displaystyle CH_2 \cdot OH}{\underset{|}{CH}} \cdot C_6H_5$$

(2) *Presence of a Pyridine Ring in Tropine.*—The problem is now to discover the structure of tropine, $C_8H_{15}NO$. It contains one hydroxyl group and forms an acetyl derivative and is oxidised to a ketone *tropinone*. It therefore contains a $>CH\cdot OH$ group.

When treated with glacial acetic acid tropine loses water and gives a base *tropidine* which contains no oxygen:

$$C_8H_{15}NO = C_8H_{13}N + H_2O.$$

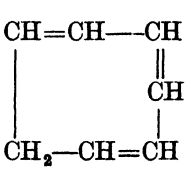
This is unsaturated, for it can be reduced to hydrotropidine $C_8H_{15}N$. This when distilled in a current of hydrogen chloride loses methyl as methyl chloride, giving *norhydrotropidine*, $C_7H_{13}N$. This when distilled with zinc dust gives α-ethyl-pyridine,



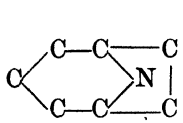
which can be made synthetically. This proves the presence of a pyridine ring in tropine.

(3) *Presence of a Seven-membered Carbon Ring in Tropine.*—But tropidine when treated with methyl iodide gives a compound, $C_8H_{13}N\begin{matrix}CH_3\\ \diagup\\ \diagdown\\ I\end{matrix}$, and this, treated with moist silver oxide, gives $C_8H_{13}N\begin{matrix}CH_3\\ \diagup\\ \diagdown\\ OH\end{matrix}$. This, on boiling, gives a methyltropidine $C_8H_{12}N\cdot CH_3$, and water. This is again treated with methyl iodide, giving $C_8H_{12}N(I)(CH_3)(CH_3)$, and this with silver oxide gives $C_8H_{12}N(OH)(CH_3)_2$.

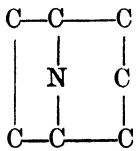
This, on boiling, gives trimethylamine and *cyclo*heptatriene which has the formula



Tropine must therefore contain a seven-membered carbon ring *as well* as a pyridine ring. In view of the formation of a pyrrolidine (§ 553) derivative from tropinone [(4) below], these can only be combined in the carbon skeleton I, usually written as II.

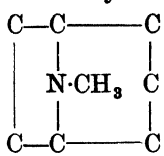


I.



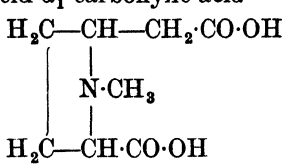
II.

That in tropine a methyl group is attached to the N atom is shown by the formation of *trimethylamine* (above) when only *two* methyl groups have been added on, also by the removal of methyl chloride from hydrotropidine in (2). We may therefore write

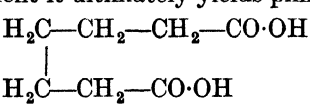


as indicating the position of the eight carbon atoms in tropine.

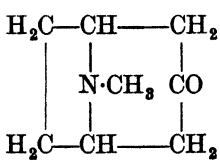
(4) *Structure of Tropinone.*—Tropinone when oxidised gives a pyrrolidine (§ 553) compound which proves to be *N*-methyl-pyrrolidine-α-acetic acid-α_1-carboxylic acid



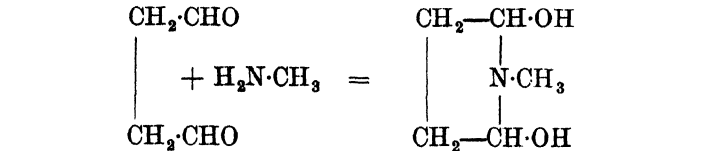
which can be identified by exhaustive methylation and reduction under which treatment it ultimately yields pimelic acid



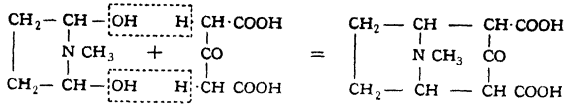
Tropinone is therefore

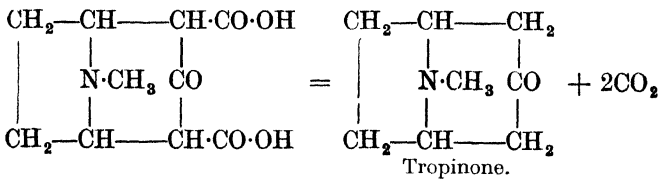


This formula has been supported by its synthesis from succindialdehyde, methylamine and the calcium salt of acetonedicarboxylic acid.



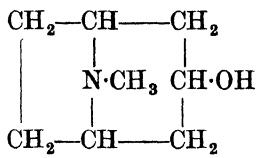
Succindialdehyde + methylamine. $\alpha\alpha'$-Dihydroxymethylpyrrolidine.



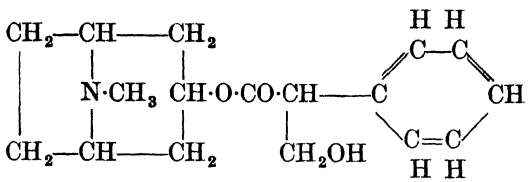


Tropinone.

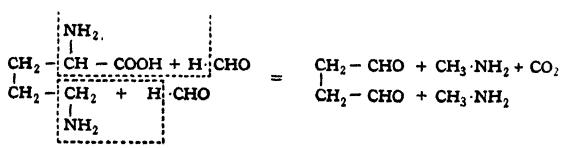
Now tropinone is produced by oxidising **tropine**, which must be



and since atropine is the tropate of this alcohol (1) its formula is

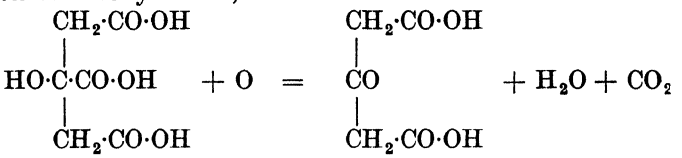


581. Formation of Alkaloids in the Plant.—The synthesis of tropinone gives a hint of the process by which alkaloids may be formed in the plant-cell. Ornithine, 1 : 4-diaminovaleric acid (§§ 226, 609), is certainly a constituent of plant proteins. This when treated with formaldehyde undergoes methylation and gives succindialdehyde and methylamine.



These condense, as already described (§ 580 (4)), to $\alpha\alpha'$-dihydroxymethylpyrrolidine.

Now citric acid, a common plant product, is easily oxidised to acetonedicarboxylic acid,



and so all the materials for the synthesis of tropinone are provided in the plant.

Such explanations can be extended to cover the formation of many other alkaloids.

582. Tests for the Alkaloids.—Since the alkaloids are in common medical use and since they are very potent poisons, accurate methods of recognising them and determining them are desirable. If the alkaloids are mixed with other organic matter, *e.g.*, the contents of a dead man's stomach, they are separated therefrom by methods similar to those employed for their extraction from plant material (§ 577). Great manipulative skill is required on account of the small quantities present.

Certain reagents give precipitates with alkaloids in general.

Auric chloride, $AuCl_3$, in presence of hydrochloric acid, gives pale yellow crystalline ppts. of the chloraurate of the base.

$$B + HCl + AuCl_3 = BHAuCl_4.$$

These can be recrystallised and then have characteristic melting points which may serve to identify the alkaloid. By heating the precipitates a residue of metallic gold is obtained the proportion of which in the salt serves to indicate the molecular weight of the base (§ 17). This affords a further means of identification.

Mayer's reagent, a solution of potassium mercuri-iodide in iodide solution, gives precipitates with almost all alkaloids. They may be recovered by decomposing the precipitate with hydrogen sulphide.

Phosphomolybdic acid, phosphotungstic acid, picric acid and tannic acid also precipitate alkaloids.

The certain identification of an alkaloid is a difficult task on account of the great number known, but if the alkaloid is known to be one of the commoner ones the colour reactions given below may be employed. They are readily obscured by impurities.

Physiological tests applied to animals are often used.

Tests for Alkaloids.

Atropine.—Evaporate to dryness with fuming nitric acid. Residue becomes violet when moistened with alcoholic potash. Dilates pupil of cat's eye in dilutions of 1 : 100,000 or less.

Cocaine.—Pale-yellow ppt. (m.p. 127° C.) with K_2CrO_4, in weakly acid

solution. A drop of very dilute solution causes numbness of tongue and lips.

Codeine.—Blue coloration with conc. H_2SO_4 and trace of $FeCl_3$.

Morphine.—When dissolved in conc. H_2SO_4 and a drop of conc. HNO_3 added, a carmine colour develops: liberates iodine from iodic acid.

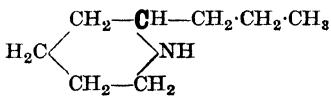
Nicotine.—Drop of formaldehyde, then a drop of nitric acid, gives rose colour.

Quinine.—Solution in dilute H_2SO_4 shows blue fluorescence. Weak chlorine or bromine water is added to this solution only till a faint yellow colour appears. Ammonia is then added drop by drop. A dark green colour appears, turned red by acids. (Quinidine also gives this test.)

Strychnine.—Gives colourless solution with a drop of concentrated H_2SO_4. A small crystal of potassium dichromate stirred into the drop gives a blue colour passing through violet and red to yellow.

ALKALOIDS OF THE PYRIDINE GROUP

583. Coniine,

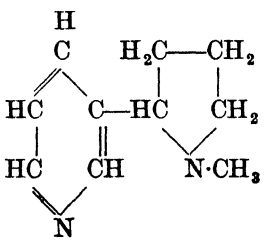


n-propylpiperidine, is the simplest of the alkaloids. It occurs in hemlock, *Conium maculatum*, being present as coniine malate. It is extracted by crushing the unripe seeds, making the solution alkaline and steam distilling.

It is a colourless liquid with a penetrating odour and boils at 166–167°. It is dextrorotatory, the asymmetric carbon atom being shown in bolder type. It is a powerful poison. Like piperidine, it is a fairly strong base.

584. Pelletierine.—Pelletierine is contained in pomegranate-root bark. It is used medically as an anthelmintic to expel tapeworms.

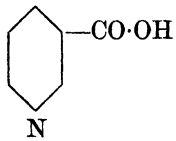
585. Nicotine,



is β-*N*-methylpyrrolidylpyridine. It is of much importance both as being the active principle of tobacco and as an insecticide. Tobacco contains, as a rule, about 4 per cent. of nicotine. To prepare nicotine, waste tobacco is extracted with water and the concentrated liquors are made alkaline and steam-distilled. The distillate is extracted with ether, which is then distilled off.

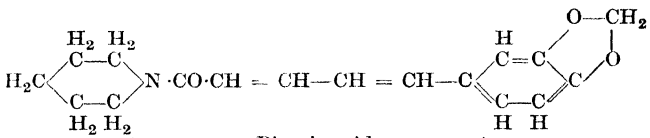
Nicotine is a colourless pungent liquid which soon becomes brown in the air. It is very poisonous. As little as 2·5 g. of ordinary tobacco may contain a fatal dose, but in the process of smoking, much but not all of the nicotine is destroyed. The symptoms of mild nicotine poisoning are known to most smokers.

Nicotine is a fairly strong base. Oxidation converts it into nicotinic acid



the amide of which has proved to be an important vitamin, deficiency of which causes the disease of pellagra in man.

586. Piperine.—Piperine is contained to the extent of 5–10 per cent. in pepper as piperidine piperate and has the formula:—

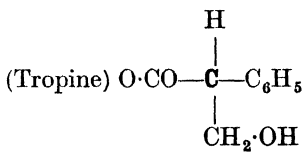


←Piperidine component→ ←Piperic acid component→

It is a crystalline solid with a pepper-like taste. It is readily hydrolysed by alkaline solutions to piperidine and piperic acid.

ALKALOIDS CONTAINING A TROPINE RING

587. Atropine.—Atropine has the formula shown in § 580. It will be noted that it contains an asymmetric carbon atom in the tropic acid group.



Atropine is the *d*-isomeride. Atropine is contained in various *Solanaceæ*, belladonna, henbane, stramonium, etc., but is usually prepared by treating the much more abundant hyoscyamine with dilute alkali.

It is used in medicine as a mydriatic for dilating the pupil of the eye for optical examination and as liniment or plaster for relieving local pain. It is also used for checking undue sweating, secretion of saliva, etc. It is highly poisonous, the usual dose being 0·00025–0·001 g.

Various derivatives of tropine are used as mydriatics in place of atropine as being less toxic.

588. Hyoscyamine.—Hyoscyamine is found, like atropine, but more abundantly, in various *Solanaceæ*. It is a stereoisomeride of atropine. It is used in the preparation of atropine (§ 587 above).

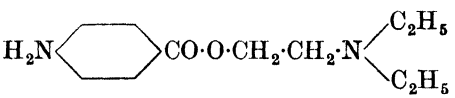
589. Hyoscine.—Hyoscine, also known as *scopolamine*, is also isolated from

henbane, belladonna, etc. It is a sedative in small doses (0·0003–0·0006 g.) and is extremely poisonous. It is used with morphine for inducing 'twilight-sleep,' and in larger doses for inducing sleep or, at least, unconsciousness in the violent insane.

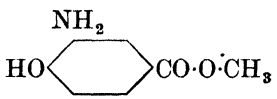
590. Cocaine.—Cocaine is extracted from the leaves of the *coca* plant chiefly grown in South America. Its formula is given on p. 532, and it is therefore nearly related to atropine which it resembles in its physiological action. It is mydriatic like atropine, though much less so. It is a much more vigorous local anæsthetic and found great use in dental work until replaced by less poisonous derivatives (*v.* below).

The chief importance of cocaine to-day is its use by drug-addicts. It stimulates the brain and causes a feeling of well-being followed later by headache and depression. A habit is rapidly formed and mental and moral degeneration soon set in.

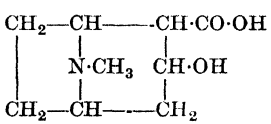
Numerous substitutes for cocaine have been synthesised. *Procaine* (also known as *novocaine*) has the formula



while *orthocaine* is methyl *m*-amino-*p*-hydroxybenzoate



591. Ecgonine.—Ecgonine is the simplest of the cocaine type of alkaloid. It has the formula



and is therefore a tropine-carboxylic acid. It can be converted into cocaine which is the methyl ester of its benzoyl derivative (*v.* formula, p. 532).

ALKALOIDS CONTAINING A QUINOLINE RING

592. Cinchona-bark Alkaloids.—These include the alkaloids isolated from the bark of the various species of cinchona tree, a native of the mountainous parts of South America. It is much cultivated in Java and India. The bark contains some 5–6 per cent. of mixed alkaloids, chiefly quinine and cinchonidine.

The bark is powdered, mixed with slaked lime, moistened and dried. The resulting substance is thoroughly extracted with boiling petroleum, ether or alcohol. The solvent is removed and the alkaloids

dissolved in dilute hydrochloric acid and re-precipitated with an alkali. The mixture of alkaloids so obtained is treated with just enough acid to convert them into the normal sulphates,[1] and by careful adjustment of concentration and temperature quinine sulphate (which is less soluble than the sulphates of the other alkaloids) will crystallise out and can be completely purified by recrystallisation.

The other alkaloids are separated by fractional crystallisation of the 'hydrochlorides' and by other means.

593. Quinine.—The very complex formula of quinine is given on p. 533. Its preparation has been described in § 592 above.

Quinine is a white solid. The anhydrous alkaloid melts at 174° C.: the trihydrate melts at 57° C. and becomes anhydrous at 125° C. It is invariably employed medicinally in the form of one of its salts. The sulphate, or occasionally the hydrochloride, is employed. Quinine and its salts have an intensely bitter taste.

Quinine sulphate $(C_{20}H_{24}O_2N_2H)_2SO_4$, $8H_2O$, is sparingly soluble in water and alcohol. Its solutions are strongly fluorescent, appearing colourless by transmitted light, but blue when indirectly illuminated.

In medicine it is chiefly employed as an antimalarial. It is poisonous to bacteria in general, but seems to exert a much more vigorous destructive action on more highly organised protozoa and in particular the malarial parasite. Apart from this action it is the most valuable of antipyretics. The normal temperature is not affected, but the high temperature of fever is often lowered by several degrees.

Overdoses produce ringing in the ears and deafness, but quinine is far less poisonous than most of the alkaloids, doses of 1 g. and over being tolerated by most persons.

594. Quinidine.—Quinidine, which is the dextrorotatory stereoisomeride of quinine, is also used as an antimalarial.

595. Cinchonine and Cinchonidine.—Cinchonine and cinchonidine are *d*- and *l*-stereoisomerides. They are similar in properties to quinine, but of less therapeutic value. They have been used in separating the stereoisomerides of optically active acids (*v.* § 236).

ALKALOIDS CONTAINING AN *ISO*QUINOLINE RING

These include several of the less important alkaloids of opium, emetine from ipecacuanha and several less important alkaloids.

596. Narcotine.—Narcotine (formula, p. 533) remains in the less soluble part of opium after morphine (§ 599) has been extracted. It can be extracted from this residue with boiling ether.

[1] The acid sulphate $C_{20}H_{24}O_2N_2$, H_2SO_4, $7H_2O$, of quinine is very soluble.

It is a very poisonous crystalline solid which is but rarely used in medicine. Its chief importance is that it contributes largely to the poisonous character of opium.

597. Emetine.—Emetine is the chief active principle of ipecacuanha root. In very small quantities it acts as an expectorant, in larger doses as an emetic. It has recently been found very valuable in the treatment of amœbic dysentery.

ALKALOIDS OF THE PHENANTHRENE GROUP

598. Opium.—Opium is the dried and coagulated milky juice of the opium poppy (*Papaver Somniferum*). Other poppies yield a similar though less valuable product. The opium poppy is grown chiefly in Turkey, India and Persia. The fruit capsules are scored with a knife and the exuded juice is scraped off from time to time and finally compacted into cake-like masses.

Opium contains resinous matter together with a large number of alkaloids, of which the chief are:

Morphine.	Papaverine.
Codeine.	Narcotine.
Thebaine.	Laudanosine.

Of these, only morphine and codeine are employed in medicine. Opium itself, or the extract of it, 'laudanum,' is still much employed in medicine, though it is less certain and effective than morphine and is very dangerous to young children owing to the strychnine-like action of the thebaine it contains. Opium is smoked and eaten in the East, but in the West its chief use is for conversion into morphine and codeine.

599. Morphine.—Morphine (probable formula, p. 533) is extracted from opium which contains some 10 per cent. of the alkaloid in the form of the meconate.[1] This salt is soluble in water, and consequently the morphine goes into solution. The solution is treated with calcium chloride, when insoluble calcium meconate is precipitated and morphine (and codeine) hydrochloride remain in solution. The addition of ammonia precipitates the morphine with some codeine which can be removed by careful extraction with ether or benzene.

Morphine crystallises in colourless prisms containing water of crystallisation. It is a fairly strong base and, like quinine, it is almost always used in the form of a salt, the hydrochloride or sulphate being commonly employed. It is very poisonous. Its value in medicine is considerable. It relieves pain in a manner unequalled by any drug and also produces deep sleep. Its danger is the ready establishment of a morphine habit very difficult to break and producing rapid physical and mental degeneration.

[1] Meconic acid is a hydroxy-pyrone-dicarboxylic acid.

The formula of morphine is not to be regarded as wholly certain, but the accepted formula (p. 533) with a phenanthrene ring system spanned by a heterocyclic 'bridge' is probably correct.

Morphine contains a phenolic hydroxyl group and consequently has acidic properties as well as basic. The hydroxyl group may be attacked by the usual reagents and morphine can thus be converted into numerous useful derivatives. Methoxy-morphine is *codeine*, an alkaloid which occurs in opium. *Heroin* is *diacetyl-morphine*. Codeine and heroin are similar to morphine in their physiological action, but are safer in use.

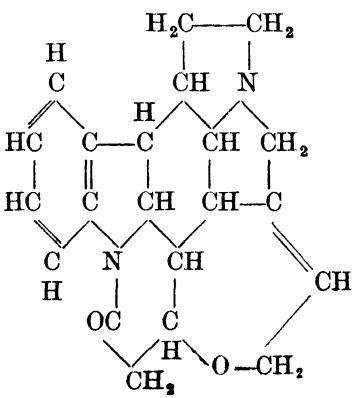
When morphine is heated under pressure with hydrochloric acid it loses a molecule of water and forms *apomorphine*, an alkaloid which is a valuable emetic in poisoning cases owing to its very rapid action.

OTHER ALKALOIDS

600. Aconitine.—Aconitine is contained in the root of the various plants of the aconite family. The common monk's-hood is one of these. The alkaloid is intensely poisonous, about 0·002 g. having been recorded as a fatal dose. The root is used in medicine as a liniment for external application where it acts as a local anæsthetic. Its formula has not yet been worked out.

601. Strychnine and Brucine.—Strychnine and brucine are contained in the seeds of the tropical plants of the Strychnos family, notably *Strychnos Nux-vomica*, from which they are extracted by a method similar to that described under quinine (§ 592). Recrystallisation from dilute alcohol separates the more soluble brucine. Brucine is occasionally used for separating the stereoisomerides of acids (§ 236) but is not otherwise of value. Strychnine is much used in medicine and also for destroying vermin.

The constitution of strychnine is not quite certain. It contains a combination of a quinoline and a carbazole nucleus. The formula



is fairly well substantiated. Brucine is a dimethoxy-derivative of this.

Strychnine crystallises in colourless prisms very sparingly soluble in water. It has an intensely bitter taste, and is very poisonous. In very small doses it acts as a tonic and injections of strychnine act as a vigorous stimulant to the heart and respiratory centres. In larger doses it causes violent tetanic convulsions and death.

Brucine is very much less poisonous than strychnine.

PLANT PIGMENTS

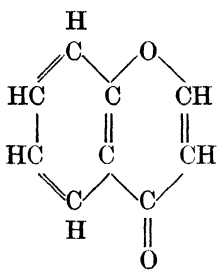
602. Anthocyanins and Anthoxanthins.—The substances which give the varied and brilliant colours to plants and their products—flowers, fruit, etc.—are of three types.

(1) The anthoxanthins, which give the feebler yellow tints.

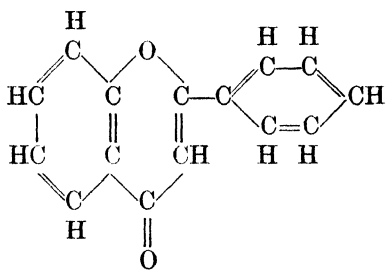
(2) The anthocyanins, which give red, mauve, violet and blue colours.

(3) Chlorophyll, carotin and xanthophyll, which give green and yellow tints.

The anthoxanthins and anthocyanins are closely allied, and are both derivatives of *flavone* which is phenyl-chromone.



Chromone.

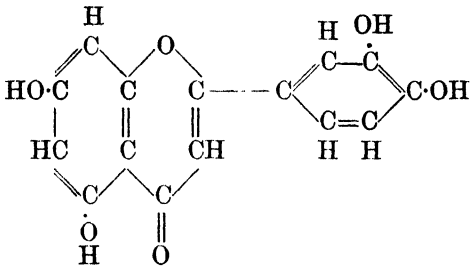


Flavone.

603. Anthoxanthins.—Most yellow flowers owe their colour to carotin or xanthophyll, which are insoluble in aqueous media and are found only in the plastid bodies within the cell.

The anthoxanthins are less brilliant in colour but are widely distributed in plants. Many of the older yellow mordant dyestuffs, used before the development of synthetic dyes, are anthoxanthins. Among these dyestuffs are weld (the dried plant *Reseda luteola*), Persian berries, fustic, etc.

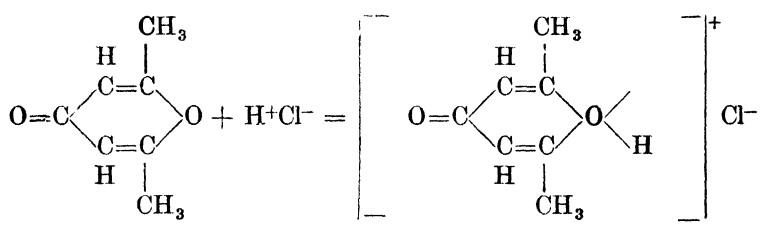
These anthoxanthins occur in the plant as glucosides of hydroxyflavones, the actual hydroxyflavone itself being the dyestuff. Thus *luteolin*, the active principle of weld, has the formula



It is a bright yellow substance with feebly acidic properties due to its phenolic hydroxylic groups. It dyes mordanted silk and wool in beautiful yellow shades. Its strong colour is due to the pyrone ring, a strong chromophore (§ 401), and the auxochrome hydroxyl.

604. Anthocyanins.—The varied and brilliant colours of flowers might be expected to derive from a wide range of colouring matters. In fact, however, these colouring matters are glucosides of only a dozen or so different substances closely similar in composition, all oxonium salts of hydroxyflavones.

Just as dimethylpyrone (§§ 554, 555) forms with hydrochloric acid a dimethylpyronium chloride,



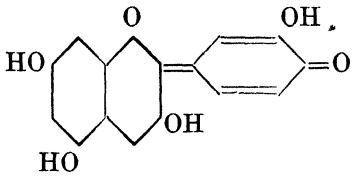
so also do the hydroxyflavones form hydroxy-flavonium salts. These salts are the anthocyanidins and the glucosides of the anthocyanidins are the anthocyanins, which are the actual colouring matters of the flowers.

The best example of such a pigment is cyanin, present in the cornflower, red dahlia, rose, etc.

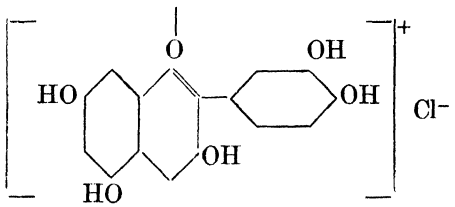
The pigment cyanin in its blue state is a glucoside of a cyanidin base; in its red state it is a glucoside of a cyanidin salt.

Cyanin = Cyanidin derivative + glucose.

Since cyanin is a blue base with red salts, the flowers coloured by it may be of all shades between blue and red, the colour depending on the *p*H value of the cell-sap. The blue cyanidin base combines with acids, as shown in the following equation, giving red salts.

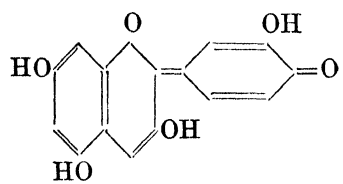


Blue cyanidin base.

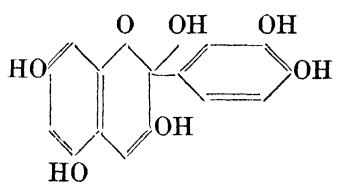


Red cyanidin salt.

A colourless 'pseudo-base' of cyanidin also exists, and is formed when solutions of the coloured base are much diluted.



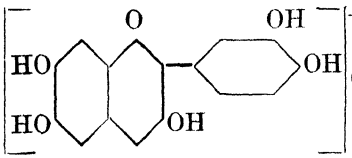
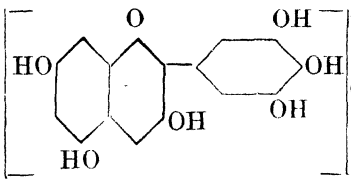
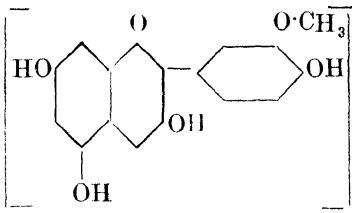
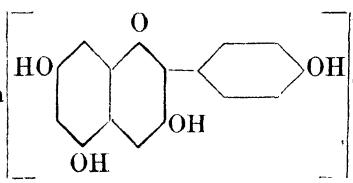
Cyanidin colour base (quinonoid structure).



Cyanidin pseudo-base (non-quinonoid and colourless).

Acids convert it into coloured cyanidin salts.

The accompanying table gives a list of the best-known anthocyanidin pigments with some of the plants in which they occur.

Anthocyanidin.	*Formula of Chloride.*	*Occurrence.*
Cyanidin		As various glucosides[1] in the rose, some dahlias, cornflower, poppy, chrysanthemum.
Delphinidin		As glucosides in delphinium, viola.
Pæonidin		As glucosides in peony.
Pelargonidin		As glucosides in salvia, 'geranium,' some dahlias, radish skins.

Numerous other anthocyanidins exist but differ only in the number and position of their hydroxyl groups and the presence or absence of methoxy-groups.

605. Chlorophyll.—Chlorophyll bears a distant resemblance to the alkaloids, being built up mainly from heterocyclic nitrogen compounds.

The green pigment which is extracted from, say, a leaf is not a compound, but contains:—

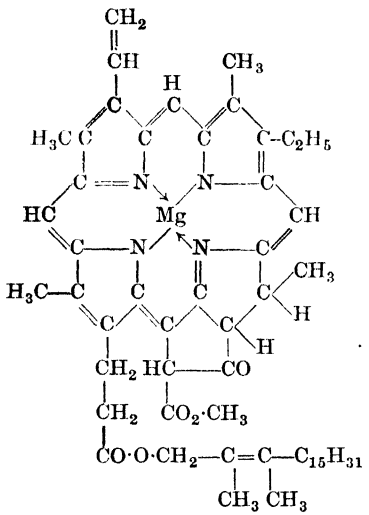
(1) Chlorophyll-*a*	Green pigments.
(2) Chlorophyll-*b*	
(3) Carotin, a hydrocarbon, $C_{40}H_{56}$.	Yellow pigments.
(4) Xanthophyll, $C_{40}H_{56}O_2$ . .	

Chlorophyll-*a* and chlorophyll-*b* are very similar in properties and

[1] The point of attachment of the glucose molecule affects the colour and other properties.

composition. The composition of chlorophyll-*a* is probably $C_{56}H_{72}N_4O_5Mg$, and its formula is probably:—

The chlorophylls are to be regarded as built up from *œtioporphyrin* (which contains four pyrrole rings), from phytyl alcohol (probably a terpene derivative), a methyl ester group, and a magnesium atom. Ætioporphyrin bears a near resemblance to the derivatives obtainable from hæmoglobin (§ 623), and the general resemblance between the structure of the green respiratory pigment of the leaf and the red respiratory pigment of the blood is of great interest. The probable structure of chlorophyll-*a* is



Porphyrin group.

Phytyl group.

The mode of action of chlorophyll in bringing about the synthesis of sugars from carbon dioxide and water is unknown: a summary of the accepted facts is given in § 300.

CHAPTER XXXIII

THE PROTEINS

606. Occurrence of Proteins.—The name protein is applied to a number of highly complex nitrogenous compounds which occur as constituents of all living matter. The essential living protoplasmic contents of the plant cell are composed mainly of proteins and water, though the framework and main body of the plant is composed of carbohydrate material, cellulose, lignins, etc.

Animals, apart from water, the mineral matter of their bones and of dissolved salts, and the glycogen (§ 298) and fat used by them as storage material, are almost wholly composed of proteins. As examples of proteins we may name egg-albumin, gelatin, casein from milk, keratin from hair.

607. General Characteristics of Proteins.—Proteins always contain carbon, hydrogen, oxygen and nitrogen, and commonly also sulphur and phosphorus. They are of high molecular weight, are non-volatile, and, being decomposed by a very moderate degree of heat, do not melt or boil.

Some of the proteins have been crystallized, but as ordinarily met with they are typical lyophile colloids.

Thus many proteins readily form gels. Their solutions are opalescent in a powerful beam of light, and they are thrown out of solution by electrolytes, a property of use for their identification and purification (§ 611).

The proteins behave towards acids and alkalis in much the same way as do amino-acids (§ 227). They combine both with acids and with alkalis, and, in view of the phenomena connected with the *isoelectric point*, it is probable that they also form "zwitter-ions."

The solute in a colloidal solution is normally electrically charged. Proteins in solution in acids are positively charged, and in solution in alkalis are negatively charged. At a certain *p*H value of the solution, the dissolved protein apparently carries no charge. This *p*H value is known as the *isoelectric point* and is a constant for each individual protein. Thus for egg-albumin it is 4·8, for gelatin 4·7, and for oxyhæmoglobin 6·7.

These facts have been explained by regarding proteins as very complex amino-acids capable of forming *zwitter-ions* (§ 227). The

isoelectric point is that at which the protein is in equilibrium with its neutral zwitter-ions,

$$NH_2{\cdot}X{\cdot}CO{\cdot}OH \rightleftharpoons {}^{+}[NH_3{\cdot}X{\cdot}CO{\cdot}O]^{-}.$$

The addition of acid will convert these into the basic ion,

$${}^{+}[NH_3{\cdot}X{\cdot}CO{\cdot}O]^{-} + H^{+} \rightleftharpoons {}^{+}[NH_3{\cdot}X{\cdot}CO{\cdot}OH],$$

and will thereby cause further dissociation and solution of the protein.

Alkalis will convert the zwitter-ions into the acidic ion, also increasing the degree of dissociation and thus the solubility of the protein.

$$^{-}HO + {}^{+}[NH_3{\cdot}X{\cdot}CO{\cdot}O]^{-} \rightleftharpoons H_2O + [NH_2{\cdot}X{\cdot}CO{\cdot}O]^{-}$$

A consequence of the above reactions is that proteins act as buffers. Hydrion or hydroxyl ion added to them will be largely removed by combination with the zwitter-ions, and consequently a comparatively large quantity of acid or alkali can be added to a protein solution before its *p*H value is appreciably lowered or raised. This phenomenon is doubtless of much importance, in view of the fact that the protein-containing liquids of the body, such as the blood, are, in fact, maintained at a closely regulated *p*H value.

The chief chemical characteristics by which proteins in general are recognised are given below.

(1) Their hydrolysis by acids, enzymes, etc., to simpler compounds, the ultimate products being amino-acids [1] (§ 609).

(2) A series of reactions with various reagents, most of which are in reality tests for amino-acids derived from the proteins and not for proteins themselves.

The chemical reactions employed to detect or identify the proteins include the following:—

(*a*) *The Biuret Reaction* (§ 312).—To a solution of a protein, made strongly alkaline with caustic soda, is added a solution of copper sulphate, drop by drop. A pink or violet colour indicates a protein or some substance containing at least two —NH—CO— groups linked together. Thus it is given, not only by proteins, but also by most of their products of hydrolysis.

(*b*) *Xanthoproteic Reaction.*—Proteins when heated with nitric acid give a yellow precipitate or solution, which on addition of alkali becomes orange. The reaction is due to the presence of amino-acids containing benzene rings (tyrosine, tryptophan or phenylalanine), aromatic nitro-compounds being formed.

(*c*) *Millon's Reaction.*—A solution of mercuric and mercurous nitrates in water containing free nitrous acid (Millon's reagent)

[1] With other products in the case of the nucleo-proteins, chromo-proteins and sclero-proteins.

gives a pink or red coloration and precipitate when warmed with a protein. The reaction is due to the amino-acid tyrosine (§ 609). Hence gelatin, which yields no tyrosine on hydrolysis, does not give this reaction.

(*d*) *The Lead Sulphide Reaction.*—The protein is warmed with caustic soda and a few drops of lead acetate. A deep brown to black colour is produced. Only those proteins which contain sulphur give this test. Gelatin contains no sulphur and consequently does not respond to the test.

(*e*) *Glyoxylic Reaction.*—A solution of glyoxylic acid (prepared by reducing oxalic acid with magnesium or with sodium amalgam) gives a violet coloration with such proteins as yield tryptophan (§ 609) on hydrolysis. Certain proteins (gelatin, zein) yield no tryptophan, and accordingly do not give the reaction.

(*f*) *Molisch Reaction.*—A few drops of alcoholic α-naphthol are added to the solution of the protein and then concentrated sulphuric acid. A violet colour, which turns yellow on addition of alcohol, ether or caustic soda, is produced. This reaction only indicates the presence of a carbohydrate grouping in the protein molecule, and is, therefore, not given by many proteins.

(*g*) *Precipitants for Proteins.*—Proteins are precipitated by the reagents mentioned in § 582 as giving precipitates with the alkaloids.

STRUCTURE OF THE PROTEINS

608. Molecular Weight of the Proteins.—Like all colloids, the proteins are of very high molecular weights. Rough estimates of these magnitudes have been reached both by physical and by chemical methods.

Physical methods are not easily applicable. Determinations of the osmotic pressure and freezing point of their solutions indicate for egg albumin a molecular weight of about 30,000. The determination is at best approximate as it is difficult both to purify these compounds and to be sure that no alteration in them has taken place. Moreover, it is doubtful whether the simple application of the gas laws to the osmotic pressures of solutions is strictly valid for molecules which physical measurements indicate to be as much as 4 $\mu\mu$ (4×10^{-7} cm.) in length. Svedberg has recently determined the molecular weight of proteins by measuring their rate of sedimentation under an intense gravitational field induced by a centrifuge. He finds that there are two classes of protein: (1) those having a molecular weight of the order of 10^6. These are few in number and include hæmocyanin, the blood pigment of the snail, which according to his measurements has a M.W. of *ca.* 5,000,000, and a

radius of 12 $\mu\mu$. (2) The remainder of the proteins which he finds to have molecular weights of approximately $n \times 17{,}600$ where n is a small whole number.

Chemical methods of deducing the molecular weights of proteins, based on their composition, give a fairly reliable minimum value. Thus egg albumin contains 1·30 per cent. of sulphur, and on hydrolysis yields it up mostly as cystine (§ 609), which contains two atoms of sulphur per molecule. Accordingly the molecule of egg-albumin must contain *at least* two atoms of sulphur and may be represented as XS_2. It follows that one M.W. of albumin contains 64 units of sulphur. But 1·3 units of sulphur are contained in 100 units of albumin. Therefore 64 units of sulphur are contained in $\frac{100 \times 64}{1{\cdot}3}$ units of albumin. The molecular weight is therefore at least 4,920. But it seems fairly certain that all the sulphur is not present as cystine, some being present as cysteine (§ 226); also there may be more than one cystine group per molecule of protein. Consequently we can say that egg albumin has a molecular weight of *not less than* 5,000; Svedberg's work indicates a value of about 40,000.

A favourable case for the application of this method is oxyhæmoglobin which contains 0·4—0·5 per cent. of iron. It follows then that, if only one iron atom is present per molecule, its molecular weight is about 14,000. Svedberg's method gives 68,000, suggesting that four or five atoms of iron may be present in the molecule.

609. The Hydrolysis of Proteins.—When a protein is boiled with concentrated hydrochloric acid or with 25 per cent. sulphuric acid for some hours a complex mixture of *amino-acids* is obtained. The simpler proteins yield no other substance, but the nucleo-proteins, chromo-proteins and sclero-proteins yield other substances in addition.

The hydrolysis may also be carried out by the use of an enzyme. Trypsin, present in the pancreatic ferment, and papain from the papaya fruit accomplish complete hydrolysis of proteins. Pepsin, present in the gastric juice, breaks up proteins only to peptones, which appear to be complexes formed from several amino-acid molecules. Our knowledge of the constitution of proteins is gained from a study of these mixtures of amino-acids. The separation of these acids from the mixture obtained by hydrolysis is a process requiring the highest degree of manipulative skill. The method developed by Fischer depends on the following general principles of procedure.

The protein is hydrolysed by heating it with concentrated hydrochloric acid, thus forming the hydrochlorides of the various amino-

acids, *e.g.*, $CH_2\begin{cases}CO\cdot OH\\NH_3Cl\end{cases}$. It is then saturated with gaseous hydrogen chloride and treated with alcohol, so converting the hydrochlorides of the amino-acids into the hydrochlorides of their ethyl esters [1] (cf. § 90):

$$CH_2\begin{cases}CO\cdot OH\\NH_3Cl\end{cases} + HO\cdot C_2H_5 \rightleftharpoons CH_2\begin{cases}CO\cdot OC_2H_5\\NH_3Cl\end{cases} + H_2O.$$

These hydrochlorides are very carefully made alkaline, avoiding any excess which might hydrolyse the ester:

$$CH_2\begin{cases}CO\cdot OC_2H_5\\NH_3Cl\end{cases} + NaOH = CH_2\begin{cases}CO\cdot OC_2H_5\\NH_2\end{cases} + NaCl + H_2O.$$

The free esters of the amino-acids are extracted with ether.

Now the original amino-acids were non-volatile and almost impossible to separate, but the esters of these acids can be fractionally distilled under very low pressures of, *e.g.*, 0·2 mm. without decomposition. This process, of considerable technical difficulty, yields a series of fractions of esters boiling over a range of 100° C. or more. The esters are then hydrolysed to the free amino-acids, which are further purified by fractional crystallisation.

Other methods of separation have now been devised, such as extraction of the mixed acids with butyl alcohol.

Twenty-two amino-acids have been separated by these methods. The most important and abundant of them are given in the list which follows. It is probable that other amino-acids not yet isolated are present in the proteins.

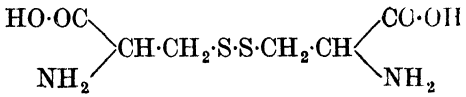
Monoamino-monobasic Acids

Glycine . .	α-Aminoacetic acid	$NH_2\cdot CH_2\cdot CO\cdot OH$
Alanine . .	α-Aminopropionic acid	$CH_3\cdot CH\begin{cases}CO\cdot OH\\NH_2\end{cases}$
Serine . .	α-Amino-β-hydroxy-propionic acid.	$HO\cdot CH_2\text{—}CH\begin{cases}CO\cdot OH\\NH_2\end{cases}$
Leucine .	α-Amino-γ-methylvaleric acid	$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!CH\cdot CH_2\cdot CH\begin{cases}CO\cdot OH\\NH_2\end{cases}$

[1] Alternatively the acids may be converted into their lead salts, which may then be converted into the esters. The method gives better yields, as water can be removed (§ 90).

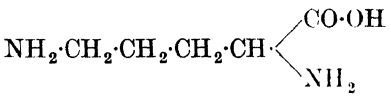
Diamino-dibasic acid containing Sulphur

Cystine . .

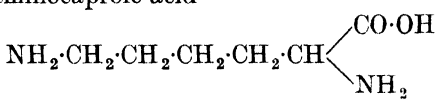


Diamino-monobasic Acids

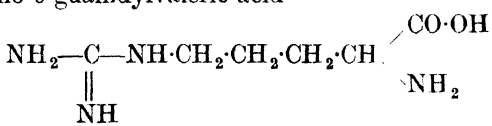
Ornithine . $\alpha\delta$-Diaminovaleric acid



Lysine . . $\alpha\epsilon$-Diaminocaproic acid

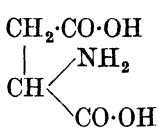


Arginine . α-Amino-δ-guanidylvaleric acid

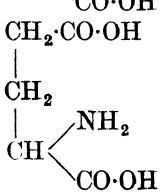


Monoamino-dibasic Acids

Aspartic acid . Aminosuccinic acid

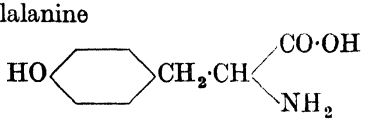


Glutamic acid. α-Aminoglutaric acid

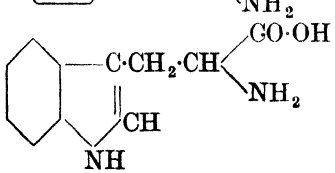


Amino-acids containing Cyclic Systems

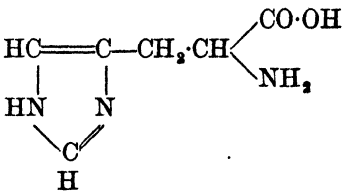
Tyrosine . *p*-Hydroxyphenylalanine



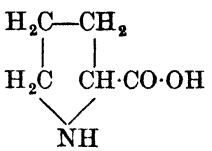
Tryptophan . β-Indolylalanine



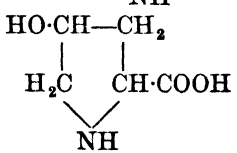
Histidine . β-Iminazolylalanine



Proline . . Pyrrolidine-α-carboxylic acid



Hydroxyproline

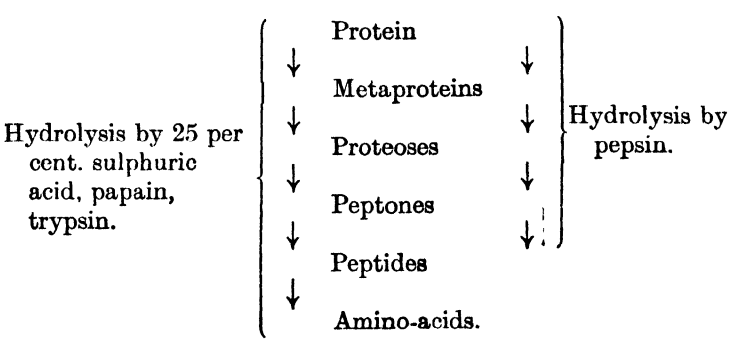


610. Arrangement of Amino-acids in the Protein Molecule.—By careful hydrolysis of the proteins certain simpler compounds intermediate between them and the amino-acids have been isolated. The stages in hydrolysis or digestion seem to be:

(1) formation of *metaproteins* very little different from the proteins themselves;

(2) formation of *proteoses*. These are colloidal in character. They have smaller molecules than the proteins as shown by their more ready diffusion through membranes;

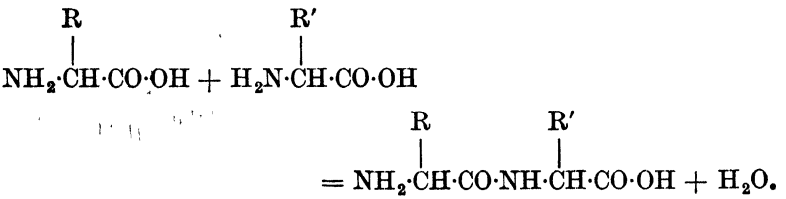
(3) formation of *peptones*. These diffuse still more readily. They are not precipitated by salt solutions.



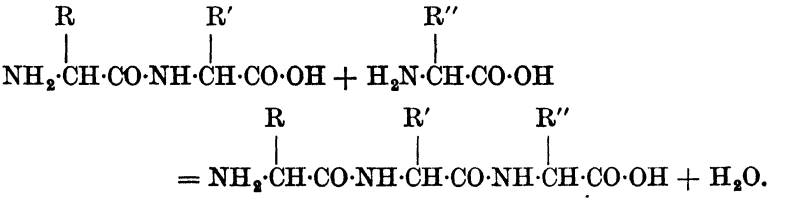
Very few of these substances have been prepared in a pure condition or in a quantity which might enable their constitution to be investigated. Substances resembling the peptones have, however,

been synthesised and this is the chief piece of evidence bearing on the structure of the proteins.

It was observed that proteins when treated with nitrous acid gave very little nitrogen (§ 122); accordingly it was inferred that the $-NH_2$ groups of the amino-acids were not present as such in the protein molecule. It was concluded that the linkage between the amino-acids might be of the type  resulting from a reaction such as

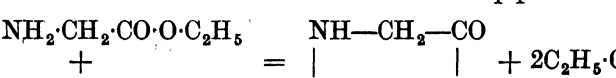


The complex so formed could again be linked in the same manner:



It will be seen that an indefinite repetition of this process might build up molecules of indefinitely large size and composed only of amino-acids. Such compounds have been synthesised and are known as *polypeptides*. Several methods of forming them were found successful, of which the following was probably the best. As an example the synthesis of leucylglycylglycine may be given.

Glycocoll ester when heated forms 2 : 5-diketopiperazine:



which when hydrolysed gives glycylglycine:



Glycylglycine.

This simple dipeptide was then converted into its ester and treated with α-bromocapronyl bromide:

$$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!CH\cdot CH_2\cdot CHBr\cdot COBr + H_2N\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot CO\cdot OC_2H_5$$

$$= \begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!CH\cdot CH_2\cdot CHBr\cdot CO\cdot NH\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot CO\cdot OC_2H_5 + HBr$$

Careful hydrolysis converts this ester into the free acid and treatment with ammonia replaces the bromine atom by an amino group, yielding leucylglycylglycine, a tripeptide.

$$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>\!CH\cdot CH_2\cdot \underset{\displaystyle NH_2}{\underset{|}{CH}}\cdot CO\cdot NH\cdot CH_2\cdot CO\cdot NH\cdot CH_2\cdot CO\cdot OH.$$

Similar processes have enabled Abderhalden to prepare a polypeptide containing 18 amino-acid units.

These polypeptides bear a close resemblance to the natural peptones made by the hydrolysis of proteins. They have the same bitter taste, give the biuret reaction, and most significantly, if they are composed of the same amino-acids[1] as occur in natural proteins, they can be 'digested' by trypsin, the pancreatic ferment.

The first stage, then, in the building of amino-acids into proteins is probably the formation of large polypeptide molecules. This stage is probably that of the natural peptones. The peptone molecules are not, however, bound into proteose or protein molecules by —NH—CO— linkages, for such linkages are not broken by pepsin digestion. The proteins are broken up by pepsin into peptones which cannot themselves be further broken up by this agent, though trypsin or acids easily hydrolyse them to amino-acids. We are able then to visualise the protein molecule as an aggregate of peptone molecules, themselves aggregates of amino-acids bound by —NH·CO— linkages.

The nature of the linkages connecting the peptone molecules is at present unknown.

611. Purification of Individual Proteins.—Methods of purification involving distillation are obviously inapplicable to the proteins which are non-volatile and decomposed by a very moderate degree of heat, and it is only in a few cases that crystallisation is possible.

[1] The amino-acids are all optically active, containing the grouping

$$R'\cdot \underset{\displaystyle NH_2}{\underset{|}{\overset{\displaystyle H}{\overset{|}{C}}}}\cdot CO\cdot OH.$$

The *l*-isomerides are usually found in the products of protein hydrolysis.

In most of their properties the proteins are very much alike and their separation is not easy to accomplish. The purification of a protein falls into two parts: (1) removal of non-protein substances; (2) separation of the proteins present.

The means used to accomplish the purification of protein material from impurities of lower molecular weight is dialysis. The protein solution is placed in a parchment bag or thimble round which circulates clean water. The crystalloid impurities diffuse through the parchment, while the colloidal protein remains within.

The separation of one protein from another is usually accomplished by precipitation with ammonium sulphate. Each protein is thrown out of solution when the concentration of ammonium sulphate reaches a certain definite level. It is thus possible to precipitate the proteins in a mixture separately and successively by increasing the concentration of ammonium sulphate.

612. Classification of the Proteins.—The proteins fall into several well-marked groups.

(1) Protamines	SIMPLE PROTEINS.
(2) Histones	
(3) Albumins	
(4) Globulins	
(5) Gliadins	
(6) Glutelins	
(7) Phosphoproteins	CONJUGATED PROTEINS.
(8) Nucleoproteins	
(9) Glycoproteins	
(10) Scleroproteins	
(11) Chromoproteins	

The above classification is convenient, but in view of our small knowledge of the constitution of these bodies, it may well prove to be a very artificial one.

613. Specific Characteristics of Proteins.—Any description of the chemical properties of the proteins must be inadequate, for only their crudest and most extensive reactions are appreciable by our technique. We can detect and to some extent estimate their constituents by the tests of § 609, measure their rotatory power, ascertain the effect of heat on them and study their products of hydrolysis. For such a complex and reactive molecule, these properties serve most inadequately as a description, since points of difference, which are of the first importance in the biological reactions of the proteins, are quite undetectable by chemical methods. Thus the albumins from the eggs of a hen and of a duck appear chemically identical. If, however, a guinea-pig be sensitised by injection of a minute dose of hen's egg albumin and, after a few days, injected with a small

dose of a hen's egg albumin, death follows rapidly from 'anaphylactic shock,' while if duck's egg albumin be administered on the second occasion no effect whatever results. Thus each protein which we regard chemically as an individual appears to exist in a different form in each animal species.

It is not surprising, however, that such a vast number of proteins exist. A fairly simple protein molecule contains some 300 amino-acid residues, of up to 22 different kinds. The possible permutations of these may obviously give rise to millions of different proteins.

614. Protamines and Histones.—These proteins are obtained only from conjugated proteins (§§ 618, 619) in which they occur as compounds with nucleic acid, etc.

They contain no sulphur and by hydrolysis give mainly diamino-acids (ornithine, lysine, arginine) and histidine.

615. Albumins.—This important class of protein includes egg albumin from white of egg and serum albumin from blood serum.

Egg albumin has been obtained in a pure crystalline condition by beating it with its own bulk of saturated ammonium sulphate. The other proteins present are precipitated and are filtered off. Ten per cent. acetic acid is added till a permanent precipitate is reached, and a slight excess of acid is then added. An amorphous precipitate is formed which becomes crystalline after a few hours. It is by no means certain that this crystalline substance is identical with the protein present in egg-white, but it is at least a pure protein closely related to it. It may possibly be an acetate of a protein.

Egg albumin, both dried and liquid, is an article of commerce, several thousand tons being prepared yearly for various purposes, chiefly the manufacture of foodstuffs. It is employed also as a thickening for the colouring matter applied to cloth in the process of textile printing. Egg albumin forms a transparent horny solid which dissolves to a lævorotatory colloidal solution. It gives all the tests for proteins described in § 607. When heated to 75° C. it is *coagulated*, *i.e.*, converted irreversibly into a white jelly-like substance. Nothing is known about the chemistry of this change. It occurs at different temperatures with different proteins.

The coagulation does not take place at an exactly fixed temperature, the rate of heating having some influence.

Serum albumin much resembles egg albumin. It is obtained from blood. This is whipped with a bunch of twigs, when fibrin separates out as threads adhering to the twigs. The liquid residue is centri-

fuged to remove blood corpuscles and then half-saturated with ammonium sulphate. This precipitates serum globulin. The solution is then dialysed till free from ammonium sulphate, when serum albumin remains.

In its general properties it closely resembles egg albumin, but has a greater specific rotation and differs slightly in its ease of precipitation. Like egg-white, it coagulates when heated.

It is used like egg albumin in textile printing.

616. Globulins.—These proteins include many found in animals and plants. The most important are (1) *Serum globulin*, contained in blood serum; (2) *Fibrinogen*, also occurring in the plasma and converted into fibrin when the blood clots; (3) *Zein*, from maize; (4) *Legumin*, from beans.

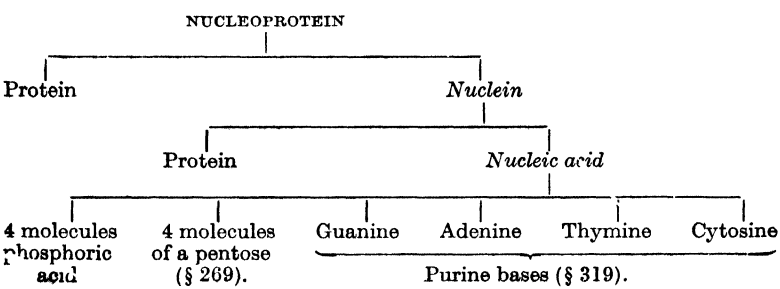
They are distinguished from the albumins by being insoluble in pure water though soluble in weak salt solutions. They are more easily precipitated by ammonium sulphate than the albumins.

617. Gliadins and Glutelins are contained in cereal grains. *Gluten*, which is obtained by washing wheat flour so as to remove the starch grains, contains several proteins of this type, notably *gliadin*. It is a tough, insoluble, elastic, greyish-yellow solid which dries to a horny mass. Gluten gives coherence and tenacity to bread. It is also of much value as a foodstuff, affording the nitrogenous element which bread would otherwise lack.

618. Phosphoproteins.—The phosphoproteins contain phosphorus which is split off by dilute caustic soda as phosphoric acid. They are insoluble in water, but soluble in alkalis and acids. They include *vitellin* from yolk of egg and *caseinogen* from milk.

Caseinogen exists in solution in milk. In presence of acids or of rennet (a ferment prepared from the calf's or pig's stomach) it becomes changed into the insoluble *casein*. The milk is then said to be curdled. The curd, consisting of casein, is the starting point of cheese. Casein is an article of commerce and is prepared from the skim-milk left after the separation of cream. It is employed in foodstuffs and also for making artificial ivory, distempers, dressings for papers, etc.

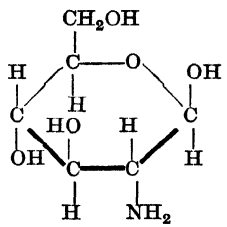
619. Nucleoproteins are of great interest as being invariable constituents of the nuclei of all cells. They are very complex substances and are composed of several groupings, themselves very complex. Their composition is expressed in the diagram which follows:



The tremendous complexity of such a molecule gives a sufficient notion of the difficulties which confront the biochemist.

620. Glycoproteins.—The slimy substances present in mucus, the slime of snails, etc., are compounds of proteins and carbohydrates—the latter in the form of glucosamine (or galactosamine).

Thus *ovomucoid* which occurs with egg albumin in egg-white gives on hydrolysis about 70 per cent. protein and 30 per cent. glucosamine.



Glucosamine.

621. Scleroproteins.—A number of insoluble protein substances occur as skeletal tissues in the body. Notable among these are *collagen*, the chief constituent of cartilage and white fibrous tissue, *elastin*, contained in yellow fibrous tissue, and *keratin*, the constituent of skin, horns, wool, hair, nails, etc. None of these can be purified, as they are insoluble and non-volatile.

They show considerable resistance to hydrolysis and the action of digestion. Collagen on hydrolysis gives much glycine and hydroxyproline, while keratin is remarkable for the high proportion of the sulphur-containing *cystine* which it yields.

When *collagen* is heated with water for some time it is converted into the important substance *gelatin*.

Gelatin is obtained by treating bones with dilute hydrochloric acid to remove calcium phosphate and heating the product to 60—70° C. for some time. The collagen dissolves and the product on cooling sets to a jelly which is sliced and dried.

Less pure gelatin is made from skins, while glue is prepared from bones of less good quality together with scraps of hides, slaughter-house refuse, etc.

Gelatin when pure is a colourless, transparent, horny solid. When immersed in water it swells, and on warming finally dissolves. The resulting solution, if it contains as little as 1 per cent. of gelatin, sets to a jelly on cooling.

Gelatin is remarkable as giving neither tryptophan nor tyrosine on hydrolysis. It therefore does not respond to Millon's or the glyoxylic reaction for proteins. If pure it does not give the lead sulphide test. The chief acids produced by its hydrolysis are glycine, proline and hydroxyproline.

Gelatin is used for a great variety of purposes. Pure gelatin is used in making all manner of jellies, ice-creams, sweets, etc., and finds some uses in medicine. Photographic emulsions have gelatin as a base. Glue is used mainly as an adhesive, but also as a size for treating walls, paper, etc., to diminish their absorbent powers.

622. Chromoproteins.—The chromoproteins consist of a protein combined with a colouring matter. Various substances of this type are known, but the hæmoglobins, or red blood-pigments, are by far the most important.

Hæmoglobin is contained in the red corpuscles of the blood. The corpuscles are destroyed by addition of a little ether or toluene or by other means, and the blood cooled to $-10°$ C. Crystals of oxyhæmoglobin come out on standing. The crystals differ according to the animal used, showing that the oxyhæmoglobin, like other proteins, differs according to its source. The shapes of the crystals have been used to identify blood as belonging to a particular species.

623. Hæmoglobin and Oxyhæmoglobin.—Hæmoglobin, which is dark purple, readily takes up free oxygen from the air and forms oxyhæmoglobin, which is scarlet in colour. This latter compound is readily broken up, and in a vacuum gives off all the oxygen taken up:

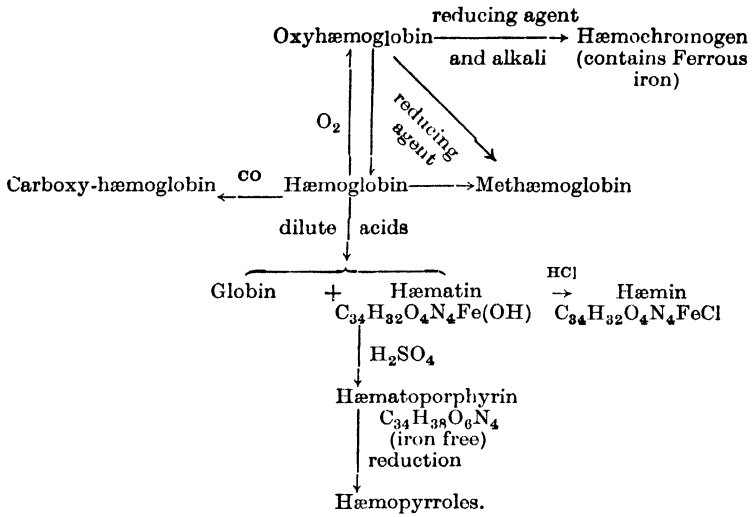
$$\text{Hæmoglobin} + O_2 \rightleftharpoons \text{Oxyhæmoglobin.}$$

Reducing agents remove the oxygen very readily. Hæmoglobin also forms compounds with carbon monoxide and with nitric oxide: the carboxy-hæmoglobin formed from the first of these is very stable and no longer combines with oxygen. Accordingly, carbon monoxide renders the blood useless for respiratory purposes and rapidly causes death.

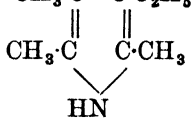
The function of the hæmoglobin in the blood is to take up oxygen in the lungs and carry it, in the form of oxyhæmoglobin, to the tissues. The concentration of oxygen in the tissues is low owing to the oxidative processes going on therein, and the oxyhæmoglobin gives up its oxygen and is then returned as hæmoglobin to the lungs where it receives a fresh supply.

Constitution of Hæmoglobin.—Gentle hydrolysis splits hæmoglobin into two parts: (1) a protein, globin (94 per cent), which differs according to the animal from which the blood was derived; (2) hæmatin (4·5 per cent.), which is always the same whatever the source of the blood.

Hæmatin forms bluish-black crystals. With acids it gives hæmin, probably a hydrochloride; concentrated sulphuric acid converts it into the deep purple hæmatoporphyrin.

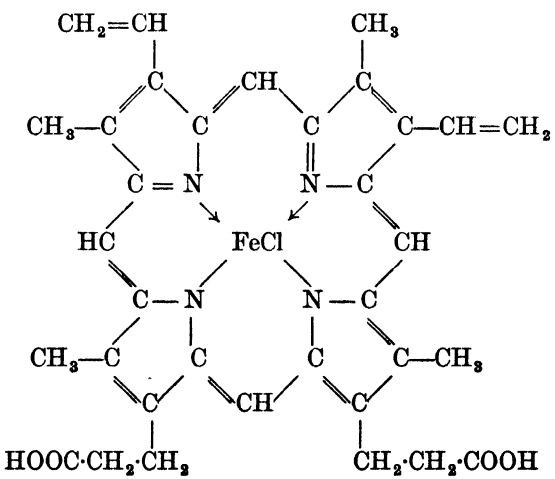


Vigorous reduction of this latter substance with phosphorus and iodine gives *hæmopyrroles* such as $CH_3{\cdot}C{=}C{\cdot}C_2H_5$ identical with



those obtained from chlorophyll.

Hæmatin and hæmin have been synthesised by Hans Fischer and the formula of the latter is fairly certainly



This formula should be compared with that of chlorophyll. The iron in all these compounds is present as a co-ordination complex (cf. the ferrocyanides) and so does not give the reactions of ferrous or ferric iron. The iron is tervalent in all these compounds except hæmochromogen.

Hæmatin prepared synthetically can be made to combine with natural globin, so giving hæmoglobin, recognisable by its spectrum.

Methæmoglobin, which seems to be intermediate between hæmoglobin and oxyhæmoglobin, is formed by the action of mild oxidising agents on hæmoglobin or of mild reducing agents on oxyhæmoglobin. It is produced in the blood in cases of poisoning by chlorates, nitrobenzene, etc. It is not available for respiratory purposes.

Hæmochromogen does not occur in blood but is readily formed from it by the action of alkalis and reducing agents. Its spectrum is readily recognisable and affords a means of identifying old bloodstains. The iron in it is probably in a lower state of oxidation than in the hæmoglobins.

APPENDIX I

PROOF THAT THE FOUR HYDROGEN ATOMS IN METHANE ARE EQUIVALENT

THAT the same compound is formed when each of the hydrogen atoms in methane is replaced by a substituent is not self-evident. The fact that only one methyl iodide exists is evidence in favour of this, but not complete proof, for, if one particular hydrogen atom were more reactive than the others, it might well be that all specimens of methyl iodide were produced as a result of that particular hydrogen being attacked. Henry, in the latter part of last century, proved the equivalence of the four hydrogen atoms by making nitromethane,[1] $CH_3{\cdot}NO_2$, in such a way that a different hydrogen atom was replaced in each of four specimens which he prepared. These four specimens were found to be identical in all respects.

The explanation of his method is made clearer by labelling the four hydrogen atoms in methane and calling it $CH^{\alpha}H^{\beta}H^{\gamma}H^{\delta}$.

(1) Henry started with methyl iodide I which he regarded as $CI^{\alpha}H^{\beta}H^{\gamma}H^{\delta}$. This he converted into nitromethane by treatment with silver nitrite. He thus obtained $CH_3NO_2{}^{\alpha}$.

(2) Another specimen of the same methyl iodide he converted into methyl cyanide II (see diagram) by treatment with potassium cyanide. The methyl cyanide was hydrolysed (§ 144) giving acetic acid III. The —CO·OH group replaces the original —I, and the acid III must be $CH_3(CO{\cdot}OH)^{\alpha}$. This is chlorinated (§ 220) and the chlorine atom which enters the molecule must replace some other hydrogen atom than the one already replaced. Calling this H^{β}, the chloroacetic acid IV must be $CH_2Cl^{\beta}(CO{\cdot}OH)^{\alpha}$. Now by heating this with potassium nitrite, nitroacetic acid is obtained, which can be hydrolysed, giving nitromethane.

$$CH_2Cl^{\beta}(CO{\cdot}OH)^{\alpha} + KNO_2 = CH_2{\cdot}(NO_2)^{\beta}(CO{\cdot}OH)^{\alpha} + KCl$$

$$CH_2(NO)_2{}^{\beta}(CO{\cdot}OH)^{\alpha} + H_2O = CH_3{\cdot}NO_2{}^{\beta} + H_2O + CO_2.$$

This nitromethane must have the NO_2 group replacing a different hydrogen atom from that replaced in (1) above.

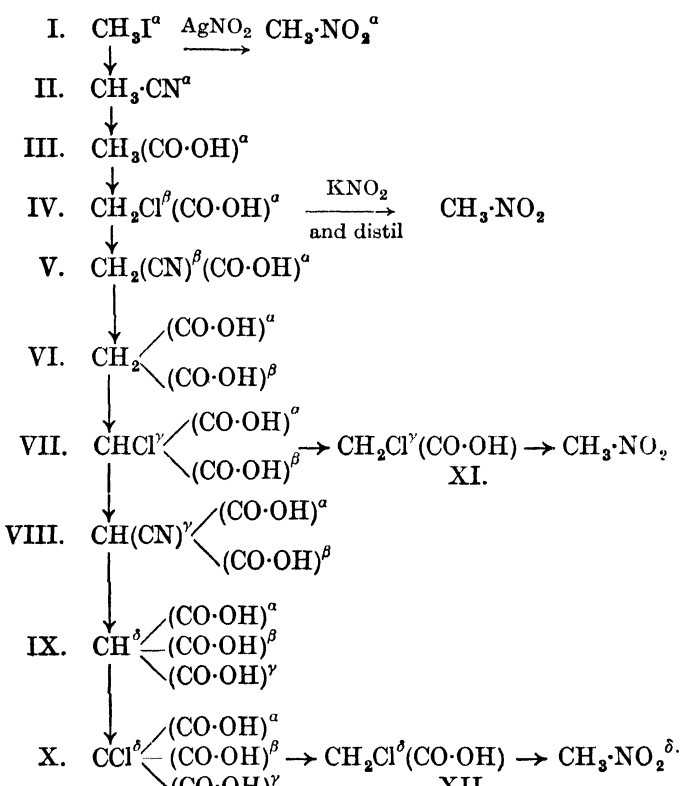
(3) A portion of the above $CH_2Cl^{\beta}(CO{\cdot}OH)^{\alpha}$ was converted into cyanoacetic acid V, which was hydrolysed (§§ 211, 225) to malonic acid VI, which must be $CH_2\begin{cases}CO{\cdot}OH^{\alpha}\\CO{\cdot}OH^{\beta}\end{cases}$. By chlorinating this a compound is obtained, in which a *third* hydrogen atom, which we term H^{γ}, is replaced. This chloromalonic acid VII, $CHCl^{\gamma}\begin{cases}CO{\cdot}OH^{\alpha}\\CO{\cdot}OH^{\beta}\end{cases}$, when dry-distilled gives chloroacetic acid XI (*cf.* § 211)

[1] Also methyl cyanide: details are not given here.

which must be $CH_2Cl^{\gamma}(CO{\cdot}OH)$. This, when treated with potassium nitrite and hydrolysed, as in (2) above, gives a third nitromethane, $CH_3{\cdot}NO_2{}^{\gamma}$.

(4) The same process as is set out in (3) above is repeated with the chloromalonic acid. This is converted into cyanomalonic acid VIII, which on hydrolysis gives methanetricarboxylic acid IX. This is chlorinated to monochloromethanetricarboxylic acid X, which when dry-distilled gives a chloroacetic acid XII, $CH_2Cl^{\delta}(CO{\cdot}OH)$, which when treated with potassium nitrite and hydrolysed gives $CH_3{\cdot}NO_2{}^{\delta}$, the fourth nitromethane.

In this way four nitromethanes are obtained, the $-NO_2$ group being attached to a different valency bond of the carbon atom in the original methyl iodide. All four nitromethanes are identical, and the four valency bonds are therefore equal in strength and, presumably symmetrically distributed.



APPENDIX II

ENZYMES

Characteristics of Enzymes.—Most of the chemical reactions which occur in the animal or plant are brought about by the catalytic action of minute quantities of substances known as enzymes.

The chief facts generally accepted about these enzymes are the following:—

(1) They are colloidal in character and are either proteins or combinations of proteins with an active group. The reagents which precipitate proteins do the same to enzymes, which, like proteins, are destroyed or altered by heating to 60—80° C.

(2) They are true catalysts and cause the transformation of many thousand times their weight of material. Like inorganic catalysts, they catalyse a reversible reaction in both directions. Thus a *lipase*, which causes fats to be split into fatty acids and glycerol, will also cause the recombination of glycerol and fatty acids.

(3) They are remarkably specific in their action. A particular enzyme will as a rule bring about the hydrolysis or oxidation of only one substance or a small group of closely related substances. Herein lies the chief difference of their mode of action from that of inorganic catalysts which are not usually so specific in their action.

(4) Owing to their colloidal character, it is very doubtful if any enzyme has been obtained in a pure state.

Classification of Enzymes.—Enzymes are classified according to the type of reaction they catalyse, and the table on page 570 indicates the chief classes of enzyme.

Methods of Purifying Enzymes.—The plant or animal material is totally disintegrated—mere breaking of the cell-wall is not enough—by grinding it with kieselguhr or by other similar means. The mass is then filtered through unglazed porcelain (by the aid of pressure) and a liquid containing no solid particles results. This contains the enzyme and all the soluble constituents of the cell-juice. The usual procedure for purification is to absorb the enzyme by shaking with a solid colloid such as gelatinous alumina or kaolin. The enzyme is taken up by this and may be removed from it by treatment with dilute acids and alkalis. The progress of the purification can only be judged by testing the catalytic activity of samples of the purified material. After several adsorptions a product of an activity three hundred to as much as three thousand times that of the original

Class.	Reactions catalysed.	Sub-division.	Reactions catalysed.	Typical examples and function in organism.
Esterases	Hydrolysis of esters.	ESTERASES	Hydrolysis of lower esters.	LIVER ESTERASE.
		LIPASES	Hydrolysis of fats.	PANCREAS LIPASE: digestion of fats by animals.
				RICINUS LIPASE: Breaks up the oil in the castor-oil bean on germination.
Proteases	Hydrolysis of proteins.	TRUE PROTEASES	Hydrolysis of proteins.	PEPSIN: Converts proteins into peptones in stomach.
				TRYPSIN: Converts proteins to amino-acids in intestine.
		PEPTIDASES	Hydrolysis of peptides.	EREPSIN: Converts peptides formed in stomach into amino-acids.
Aminoacylases	Hydrolysis of amino-acids and amides.	—	—	UREASE: Converts urea into ammonium carbonate.
Carbohydrases	Hydrolysis of carbohydrates	HEXOSIDASES	Conversion of glucosides and disaccharides into monosaccharides	SACCHARASE: Inverts cane-sugar; found in yeast and many plants.
				MALTASE: Converts maltose into *d*-glucose; found in yeast.
				EMULSIN: Splits up amygdalin (§ 273).
		POLYASES	Hydrolysis of polysaccharides.	AMYLASE (DIASTASE): Splits starch into maltose. Contained in pancreatic ferments, seeds, etc.
Carboxylases	Split off CO_2 from acids	—	—	CARBOXYLASE: Decomposes pyruvates to acetaldehyde and carbon dioxide (§ 301b).
Oxydases	Causing oxidation.	—	—	TYROSINASE: Forms black pigments by oxidising tyrosine (§ 609).
Peroxidases	Oxidation by H_2O_2.	—	—	BLOOD CATALASE: Use doubtful, see § 475.

material may be reached. No true criterion of purity for enzymes exists.

Precipitation methods have also been used. Thus the addition of acetone to the cell-juice of yeast precipitates 'zymase,' a mixture of several enzymes with alien protein material. The adsorption method is more adaptable and efficient.

Chemical Composition of the Enzymes.—As yet no enzyme has been identified as a chemical individual. They seem to show a distinct resemblance to the proteins and as ordinarily obtained are certainly colloid. A school of thought exists which considers that enzymes are not actual chemical individuals, but are merely protoplasm in a particular state of colloidal dispersion. These views are now not widely supported.

If an advance in chemical technique ever allows of the purification and synthesis of enzymes, an entirely new field will be opened to the activity of the organic chemist, for their specific action, taking place at low temperatures, would render them particularly valuable for the study of such complex and unstable compounds as the proteins.

APPENDIX III

CHIEF COAL-TAR PRODUCTS

Benzene

- Hexahydrobenzene
- Chlorobenzene
- Nitrobenzene
- Aniline
  - Acetanilide
  - Phenylhydrazine
  - Azo-dyes
  - Triphenylmethane dyes
  - Indigo
- Benzidine—Azo-dyes
- Benzene-sulphonic acids
- Maleic anhydride
- Phenols
- Succinic acid

Phenol

- Salicylic acid
- Phenetole & Anisole
- Picric acid
- Azo-dyes
- Aspirin
- Phenetidine & Anisidine—Azo-dyes
- Explosives

Cresols

- Disinfectants

Toluene

- Nitrotoluenes
- Toluidines
  - Azo-dyes
  - Triphenylmethane dyes
- Cresols
- Trinitrotoluene
- Benzyl chloride
- Benzal chloride
- Benzotrichloride
- Benzyl compounds
- Benzaldehyde
- Benzoic acid—Benzoyl compounds

Xylene

- Xylidines
- Azo-dyes

Naphthalene

- Phthalic acid / anhydride
- Phthalein dyes
- Naphthols
- Naphthylamines
- Azo-dyes

Anthracene

- Anthraquinone
- Alizarin and related dyes

PETROLEUM PRODUCTS

Natural gas

- Methane
- Methyl alcohol
  - Methyl compounds
  - Formaldehyde
  - Methylanilines

Petroleum

- Paraffin hydrocarbons
- Polymethylene hydrocarbons

PRODUCTS OF SYNTHESES FROM INORGANIC MATTER

Carbon

Calcium carbide—Acetylene—Acetaldehyde—Acetic acid

Carbon monoxide — Carbonyl chloride — Urethanes; Urea; Certain ketones

Carbon dioxide — Urea — Ureides

Cyanides — Thiocyanates; Cyanates; Nitriles — Acids

Carbon disulphide — Carbon tetrachloride; Mustard oils; Xanthates — Viscose rayon

PLANT PRODUCTS

Sugars

Amyl alcohol — Amyl nitrite; Amyl acetate

Ethyl alcohol — Ethylene—Glycols; Ether; Ethyl compounds in general; Acetic acid

Lactic acid

Citric acid

Butyric acid

Starch

Starch esters

Dextrins — Adhesives

Maize

Furfural and glycols — Chlorinated ethers, etc. (non-inflammable solvents)

Wood

Oxalic acid — Formic acid

Acetic acid — Acetic anhydride and acetyl compounds; Acetone — Chloroform

Methyl alcohol — Methyl compounds; Formaldehyde — Artificial resins; Methylanilines — Dyes

Cellulose — Nitrocellulose — Explosives; Cellulose acetates — Artificial silk

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Fruits

Tartaric acid

Citric acid

Oils and Fats

Soaps

Glycerol — Allyl compounds; Propyl compounds; Nitroglycerol

Essential Oils

Esters — Acids

Terpenes (Camphor, turpentine, etc.)

Resins	Soaps Terpenes		
Miscellaneous	Alkaloids Anthocyanins Tannins	Gallic acid	Pyrogallol

ANIMAL PRODUCTS

Connective tissue—Gelatin		
Other proteins	Amino-acids	
Fat	Soaps	
	Glycerol	Allyl compounds Propyl compounds Nitroglycerol—Explosives
Milk	Casein	(Distempers, artificial leather and ivory)
	Lactose	Galactose
Bones	Gelatin	
	Bone oil	Pyrrole Pyridine, etc.
Miscellaneous	Uric acid and the Purines	

ANSWERS TO NUMERICAL AND SOME OTHER PROBLEMS

Ch. I. (2) $C_{10}H_8$.
(3) CH_4N_2O.
(4) $C_5H_{11}Cl$.
(5) V.D. 77·6: M.W. 155.
(6) $C_{10}H_6Cl_2$.

Ch. II. (1) (a) No, (b) No, (c) Yes, (d) No.
(2) Two.
(4) $CH_3{\cdot}CH_2{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3$: $C(CH_3)_4$: $CH_3{\cdot}CH(CH_3)_3$: *n*-butane : *iso*-pentane *or* ethyldimethylmethane : ethyltrimethylmethane.

Ch. III. (9) $CH_3{\cdot}CH(OH){\cdot}CH_2{\cdot}CH_3$: $C_2H_5{\cdot}C(OH)(CH_3)_2$: $CH_3{\cdot}CH(OH){\cdot}CH_3$: $CH_3{\cdot}C(OH){\cdot}(C_2H_5)_2$: *sec.*-butyl alcohol : *iso*-butyl alcohol : *tert.*-butyl alcohol (or trimethylcarbinol) : normal propyl alcohol.

Ch. IV. (3) C_3H_7Br : Yes. $(CH_3)_2CHBr$ and $CH_3{\cdot}CH_2{\cdot}CH_2Br$.
(4) M.W. 156 : C_2H_5I.
(8) CH_2I_2 : $CH_3{\cdot}CCl_2{\cdot}CH_3$: $CH_2Cl{\cdot}CH_2Cl$: $CH_3{\cdot}CHCl_2$: $CHBr_3$: *iso*-propyl chloride : ethyl bromide : $\alpha\alpha$-dibromopropane : iodoform : hexachlorethane.

Ch. VII. $C_2H_5{\cdot}O{\cdot}CO{\cdot}H$: $CH_3{\cdot}O{\cdot}CO{\cdot}CH_3$: $C_2H_5{\cdot}HSO_4$: $C_5H_{11}{\cdot}O{\cdot}NO$.

Ch. VIII. (1) $CH_3{\cdot}CH_2{\cdot}CH_2{\cdot}CH_2OH$: $(CH_3)_2CH{\cdot}CH_2OH$: $C_2H_5{\cdot}CH(OH)CH_3$: $(CH_3)_3C{\cdot}OH$: $C_2H_5{\cdot}O{\cdot}C_2H_5$: $CH_3{\cdot}O{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3$: $CH_3{\cdot}O{\cdot}CH(CH_3)_2$.
(6) (a) 8·18 g. (b) 9·60 g.

Ch. X. (10) $CH_3{\cdot}CO{\cdot}NH_2$.

Ch. XIII. (3) $CH_3{\cdot}CH_2{\cdot}CH : CH{\cdot}CH_3$; $CH_3{\cdot}CH_2{\cdot}CH_2{\cdot}CH : CH_2$; $(CH_3)_2CH{\cdot}CH : CH_2(CH_3)_2C : CH{\cdot}CH_3$; $CH_3{\cdot}CH_2{\cdot}C(CH)_3 : CH_2$.
(8) Two.

Ch. XV. (6) Succinic acid.

Ch. XVI. (6) $NH_2(CH_2)_2{\cdot}COOH$.

Ch. XX. (7) 2·01 per cent. urea.
(8) 1·125 per cent. urea.

Ch. XXIX. (3) One.

INDEX

Figures in italics indicate the chief reference where two or more are given.

Prefixes usually printed in italics (*o-*, *m-*, *p-*, *iso-*, *sec-*, *tert-*) and Greek letters are neglected in indexing. Thus "*iso*Phthalic acid" follows "Phthaleins" in the index.

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