A PRACTICAL INTRODUCTION

TO

CHEMISTRY

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BEING THE PRACTICAL INTRODUCTORY COURSE OF WORK IN USE AT CLIFTON COLLEGE

BY

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LATE LECTURER ON CHEMISTRY IN CLIFTON COLLEGE

WITH ILLUSTRATIONS

NEW IMPRESSION

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INTRODUCTION

TO THE THIRD EDITION

WHEN this little book was published in 1885, I stated that it was written partly for the use of my own pupils at Clifton, and partly with the hope that its publication might encourage the introduction of such work elsewhere. It is therefore a source of considerable gratification to me to find that it has been useful to others as well as to myself, and that a third edition of the book is now required.

There can be no doubt that science is of special educational value chiefly in proportion as it leads students to observe accurately, to record their observations correctly, and to think for themselves; and that its full development and usefulness as a part of general education will not be attained until it is better recognised by those who teach and those who examine; that, in the case of very young students, we must expect a less extensive knowledge of facts than is usually demanded at present; and, on the other hand, that we must aim at giving increased powers of observation and description to our pupils, together with some power of using a limited number of facts for the purpose of solving simple practical problems.

In the case of more advanced students, it is and will remain necessary that much, if not indeed most, of what they learn shall be taken on authority, without verification in detail. But if science is ultimately to take that place in education which I believe it is destined to occupy, it is necessary that we shall do all we can to develop in beginners habits of accurate observation and description, and to discourage the too frequent habit of teaching at first by unverified definitions and mere statements of more or less accurately ascertained facts.

I do not doubt that these objects may, to a great extent, be secured in teaching by lectures, though, for reasons not altogether due to teachers, this is not always done at present. But there is no doubt that a better though a slower start can be made by a practical course of quantitative and qualitative experiments—partly because such work awakens a more permanent interest, partly because the details of manipulation keep each subject longer before the minds of the pupils, and therefore secures a more persistent impression, and to some extent also because in the laboratory the duller boys can proceed at the slow pace which suits them best, without keeping back those who are more clever.

In selecting experiments, I have been guided by two considerations, besides those mentioned above. First, that they should be suitable for the young boys who chiefly will have to perform them, and who will have but a limited amount of time to do them in. Secondly, that when completed they shall constitute a body of experience which shall be as valuable as possible when the students pass to lecture classes.

Having very frequently observed that pupils taught by lectures attain only a feeble apprehension of the important part played by the physical properties of substances in chemical operations, I have devoted a chapter to a few very elementary experiments on the relations between solids, liquids, and gases, and in the later chapters I have directed attention constantly to the use made of these differences in experimenting. I did not do so earlier in the course, because I do not find that it is desirable to direct attention to this subject until a little progress has been made.

The system of chemical notation is introduced because, although it was undesirable to dwell too much upon it, yet we find it is advantageous that students should in the first instance study notation in connection with their own experimental work.

In using this book, the lessons should be almost entirely spent in experimenting, the directions given at the beginning of Chapter III. being followed. When an experiment is finished, the boys, who may work in pairs, should each write an account of it. This account should be compared with Part II., and amended; then, and not till then, it should be read and criticised by the teacher. I find that due insistence on the rule that no experiment should be begun till the previous one has been properly described in writing and criticised is of great importance.

When the work to be done is of the nature of a problem, help may be given, especially at first. We always aim, however, at drawing the solutions from the pupils by suitable questions, *and avoid giving direct information as far as possible.*

It is desirable that descriptions of the work done should also be regularly written out of school. This should be done without any help from books, and with no other memoranda than notes of figures relating to quantitative work.

ments to Professor Henry Armstrong, to whom, I believe, elementary teachers are indebted; and also to express my thanks to my colleague, the Rev. E. B. Cook, who has used the book at Clifton for some time past, and has made some suggestions.

W. A. SHENSTONE.

CLIFTON COLLEGE, 1892.

CONTENTS

PART I.

PART II.

This part of the book consists of descriptions of the results of experiments, solutions of the practical problems, &c. The mode of using Part II. is described in the Introduction, p. vii.; and also in Chapter III., p. 15.

APPENDIX.

METRIC WEIGHTS AND MEASURES.

PREFIXES.

Myria—	10,000	( )	1
Kilo—	1000	Deci—	$\frac{1}{10}$
Hecto—	100	Centi—	$\frac{1}{100}$
Deka—	10	Milli—	$\frac{1}{1000}$

Inserting after the hyphen and in the brackets—
(1.) *Metre*, gives the measure of length.
(2.) *Litre*, ,, ,, capacity.
(3.) *Gram*, ,, ,, weight.

LENGTH.

1 Metre = 10 decimetres. (10 dcm.)
= 100 centimetres. (100 cm.)
= 1000 millimetres. (1000 mm.)
1000 Metres = 1 *Kilometre.*

CAPACITY.

1 Litre = 1 cubic decimetre. (1 c.dcm.)
= 1000 cubic centimetres. (1000 c.c.)

WEIGHT.

1 Gram or the weight of 1 c.c. of pure water at 4° C.
= 10 decigrams. (10 dg.)
= 100 centigrams. (100 cg.)
= 1000 milligrams. (1000 mg.)
1000 Grams = 1 *Kilogram.*

ENGLISH EQUIVALENTS.

NEARLY. ACCURATELY

1 Metre = 3 feet $3\frac{3}{8}$ inches = $39{\cdot}37_{079}$ inches.
or $39\frac{3}{8}$ inches.

64 metres = 70 yards (nearly).
25 m.m. = 1 inch (nearly).

1 Kilometre = 1100 yards = $1093{\cdot}63_{31}$ yards.

8 kilometres = 5 miles (roughly).
100 sq. metres = 1 are = rather less than 4 poles.
1000 sq. metres = 1 dekare ,, 1 rood.
10,000 sq. metres = 1 hectare ,, $2\frac{1}{2}$ acres.

1 Litre = $1\frac{3}{4}$ impl. pint = $1{\cdot}76_{0773414}$ pint.
or 35 ounces.

100 litres = 22 gallons (nearly).

1 Gram = $15\frac{1}{2}$ grains = $15{\cdot}43_{23488}$ grains.

28 grams = 1 ounce avoirdupois (roughly).

1 Kilogram = $2\frac{1}{5}$ pounds = 2.20_{46213} pounds.

Metric ton = 1000 kilos = $19\frac{1}{2}$ cwt. (roughly).

CHAPTER I.

CUTTING AND BENDING GLASS—FORMING GLASS APPARATUS BEFORE THE BLOW-PIPE.

Instructions.—*Every student should do the operations described in* 1, 2, 3, 4. *Those in* 5 *and* 6 *may be omitted until it is necessary to perform them.*

1. Cutting Glass Tubes.—The simplest method of cutting a glass tube is to make a sharp scratch with a file across the glass at the point at which it is desired to cut it; then to pull apart the two ends, when it will break clean off. It is important that the file be sharp. In pulling apart the ends the scratch should be held upwards, and the pull should have a downward direction, which will tend to open out the scratch. In the case of a large tube, a scratch will not ensure its breaking clean across. The tube must be filed to some depth, half-way, or even all round it. A good way of breaking a tube is to place the file on the table after scratching the glass, to hold the glass tube above its edge with one hand on each side of the scratch, and to strike the under side of the tube a sharp blow upon the edge of the file, directly beneath the scratch. In this way very even fractures of large and moderately thin tubes may be made. It answers particularly well for removing short ends of tube, not long enough to be grasped. The tube must be held firmly upon the file, and a sharp blow given to the short end with a piece of large tube or a key.

A file whose faces have been ground till they are nearly smooth, so as to leave very finely-serrated edges, will be found useful for cutting glass tubes. Such a file should be used almost as a knife is used for cutting a pencil in halves.

2. Make a scratch with a file, and touch it with the end of a *very small* piece of glass drawn out and heated at the tip to its melting-point. It is important that the heated point of glass be very small, or the fracture is likely to be uneven, or to spread in several directions. Also, it is best to use hot soda glass for starting cracks in tubes of soda glass, and lead glass for doing so in lead glass tubes. If the crack does not pass quite round the tube, you may pull it asunder, as previously described, or you may bring the heated piece of glass with which the crack was started to one end of the crack, and slowly move it (touching the glass) in the required direction; the crack will extend, following the movements of the hot glass. Instead of hot glass, pastils of charcoal are sometimes employed for this purpose. They continue to burn when once lighted, and there is no need to re-heat them from time to time. They should be brought as close to the glass as is possible without touching it, and, when no longer needed, should be extinguished by placing the lighted end under sand, or some other incombustible powder. They must not be wetted.

3. **Bending Glass Tubes.**—The blow-pipe flame is not a suitable source of heat for bending tubes, except in certain cases which will be mentioned in a subsequent paragraph. For small tubes, and those of moderate size, a fish-tail burner, such as is used for purposes of illumi-

nation, will answer best. Use a flame from one to two inches in breadth—from *A* to *A* (Fig. 1), according to the size of the tube which is to be bent. If the length of tube that is heated be less than this, the bend will probably buckle on its concave side.

The tube should be held in the position shown in Fig. 1, supported by the hands on each side. It should be constantly rotated in the flame, that it may be equally heated on all sides. In the figure the hands are represented above the tube, with their backs upwards.

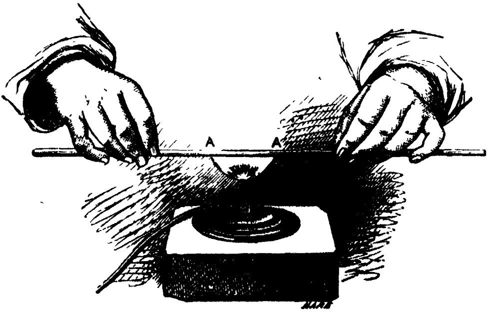

FIG. 1.

A tube can be held equally well from below, the backs of the hands being then directed downwards, and this, I think, is the more frequent habit. It is difficult to say which position of the hands is to be preferred. I lately observed how a tube was held by three skilful amateurs and by a professional glass-blower. All the former held the tube with the hands below it. The latter, however held it from above, as in Fig. 1. He, however, was working with a rather heavy piece of tube, and I am inclined myself to recommend that position in such cases. During a long spell of work the wrist may be rested from time to time by changing the position of the hands.

When the tube has softened, remove it from the flame, and gently bend it to the desired angle. The side of the tube last exposed to the flame will be slightly hotter, and therefore softer, than that which is opposite to it. This hotter side should form the concave side of the bent tube.

FIG. 2.

The exact condition in which the glass is most suitable for bending can only be learned by making a few trials. If it is too soft in consequence of being overheated, the sides will collapse. If, in the endeavour to heat the side *A* of Fig. 2 a little more than *B*, *B* is insufficiently heated, the tube will be likely to break on the convex side. If the bent tube tends to become flattened, and this cannot always be prevented in bending very thin tubes, the fault may be avoided by blowing gently into one end of the tube whilst bending it, for which purpose the other end should be closed beforehand. A tube already flattened may, to some extent, be blown into shape after closing one end and reheating the bent portion, but it is not easy to give it a really good shape.

When making a bend like that in Fig. 2, to secure that the arms of the tube *C* and *D*, and the curve at *B*, shall be in one plane, the tube should be held in a position perpendicular to the body, and brought into the position shown in the figure during bending, by which means it will be found easy to secure a good result.

4. Rounding and Bordering the Ends of Tubes.—After cutting a piece of glass tube in two pieces, the sharp edges left at its ends should be rounded by holding them in a flame for a few moments till the glass begins to melt.

When the end of a tube is to be closed with a cork or stopper, its mouth should be expanded a little, or **bordered.** To do this, heat the end of the tube by rotating it in a blow-pipe flame till it softens, then remove it from the flame; at once introduce a charcoal cone (Fig. 3), and rotate it with gentle pressure against the softened glass till the desired effect is produced. In doing this it is very important that the end of the tube shall be uniformly heated, in order that the enlargement shall be of regular form. If the tube cannot be sufficiently expanded at one operation, it should be re-heated and the process repeated.

FIG. 3.

5. Sealing, that is, closing the ends of tubes, or other openings, in glass apparatus.

In performing this and all the other operations of glass-blowing, the following points must be constantly kept in mind:—

(*a.*) That it is rarely safe to blow glass whilst it is still in the flame. Therefore always remove apparatus from the flame before blowing.

(*b.*) That when heating glass tubes, unless it is specially desired to heat one portion only, the tube must be constantly rotated in the flame to ensure that it shall be uniformly heated, and to prevent the tube or mass of glass from assuming an irregular form.

(*c.*) Always blow gently at first, and slowly increase the force applied till you feel or see the glass giving way. It is a good plan to force the air forward in successive short blasts rather than in one continued stream.

To seal the end of a glass tube (Fig. 4), adjust the flame of a blow-pipe so that it will heat a zone of glass about as broad as the diameter of the tube to be sealed (see *A*, Fig. 4). Hold the tube on each side of the point at which it is to be sealed. Bring the tube gradually into the flame, and heat it with constant rotation, till the glass softens. When the glass begins to thicken, gently

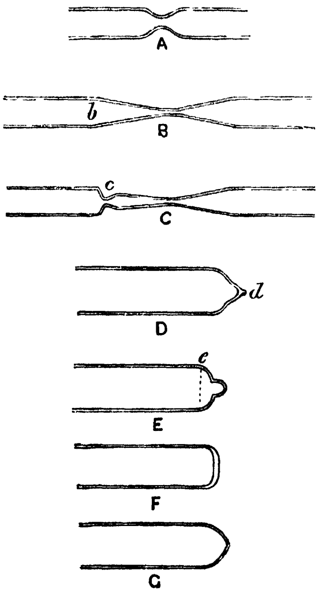

FIG. 4.

pull asunder the two ends, taking care not to pull out the softened glass too much, but to allow the sides to fall together, as shown at *A*. When this has occurred, heat the glass at the narrow part till it melts, and pull asunder the two ends. The closed end should present the appearance shown at *D*. If the glass be drawn out too quickly its thickness will be unduly reduced, and it will present the appearance shown at *B*. In that case apply a pointed flame at *b*, and repeat the previous operation so as to contract the tube as at *c*, taking care not to allow the glass to become much increased or decreased in thickness.

If a considerable mass of glass be left at *d*, it may be removed by heating it to redness, touching it with the pointed end of a cold glass tube, to which it will adhere, and by which it may be pulled away.

When the end of the tube presents the appearance shown in the diagram *D*, and the mass of glass at *d* is small, the small lump that remains must be removed by heating it till it softens, and *gently* blowing with the mouth, so as to round the end and distribute the glass more regularly, as shown in *E*. The whole end, from the dotted line *e*, must then be heated with constant rotation in the flame. If this final heating of the end *e* be done skilfully, the glass will probably collapse and flatten, as at *F*. The end must then be gently blown into the form shown at *G*.

If a flat end to the tube be desired, the tube may be left in the condition shown by *F*, or a thin rounded end may be flattened by pressure on a plate of iron.

If a concave end be wished for, it is only necessary to gently suck air from the tube before the flattened end has become solid.

In order to draw out tubes for sealing close to one end, and thus to avoid waste of material, it is a good plan to heat simultaneously the end of the glass tube *A* which is to be sealed, and one end of a piece of waste tube *E* of about the same diameter, and when they are fused to bring them together as at *D D* (Fig. 5). *E* will then serve as a handle in the subsequent operations on *A*. Such a rough joint as that at *D* must not be allowed to cool too much during the work in hand, or *E* and *A* may separate at an inconvenient moment.

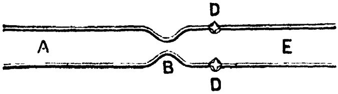

FIG. 5.

The tube *B* of Fig. 10, p. 19, may be made by taking a piece of soft glass tube, one to one and a quarter inch in diameter, and about twelve or fourteen inches long, and heating it at its middle, as in making a jet, only using a larger flame. It must be constantly turned in the flame, and gently pressed towards the melted part, that it may thicken a little. Finally, the two ends must be pulled away from each other till the size of the tube is sufficiently diminished. If the narrow part is not long enough after this is done, you must heat up the thicker tube on either side of the contracted portion, and contract that in a similar manner.

6. Choking, or Contracting the Bore of a Glass Tube.

—If it be not desired to maintain the uniformity of the external dimensions of the tube whilst decreasing the diameter of the bore, the tube may be heated and drawn out as described in the description of sealing tubes on p. 6. This may be done as shown at *A*, *B*, or *C* in Fig. 4, according to the use to which the contracted tube is to be put.

Composition Tube.

In many experiments, instead of glass tubes, composition tube (sold by ironmongers), of the smallest size, may be employed. It does not present so elegant an appearance as glass, but as a good deal of time is saved by its use, it is a good plan to substitute composition pipe for glass tubes when the time available is scanty. Composition pipe should never be used, however, for strong acids or acid gases. Hydrogen, oxygen, water, air, or carbonic acid gas may safely be passed through it, but not solutions of acids, chlorine, &c.

CHAPTER II.

THE BALANCE.

7. A BALANCE suitable for the experiments in this book is shown in the diagram below, together with a diagram which will explain the arrangement of the box of weights.

Such a balance is made by Becker, and costs about 30s.; it is known as Becker's No. 49. A suitable set of weights (No. 37), ranging from 50 grams to 1 centigram, can be obtained for 7s. 6d. A rather better set (No. 29), ranging from 100 grams to 1 millegram, in a box, costs 12s. 6d.

Messrs. Becker are foreign makers. Messrs. Townson and Mercer, of Bishopsgate Street, are their London agents. But most apparatus dealers supply suitable balances at about the same price. Most of the experiments could be made with a less expensive equipment; for instance, with a set of the scales and weights used in dispensing. I would again point out, however, that it is very desirable to encourage accurate work by providing good balances, even if a little time is lost by delay due to having a smaller number of them in the laboratory.

Description of the Balance.

The balance (Fig. 6) consists of a beam *A*, which carries two steel knife-edges at *D*. The beam is suspended by these knife-edges, which, when in action, work upon two steel planes at the top of the pillar *B*. These planes are on a rod, which moves inside *B*, and can be raised and lowered by the handle *C*. The beam carries the two pans *G G*, which are suspended from it by the hooks *E E*. These hang on two knife-edges at the two ends of *A*. As it is impossible to secure that the two ends of the beam and the pans shall be in permanent equilibrium, *A* has at the end *K* a moveable weight *L*, by which they can be adjusted.

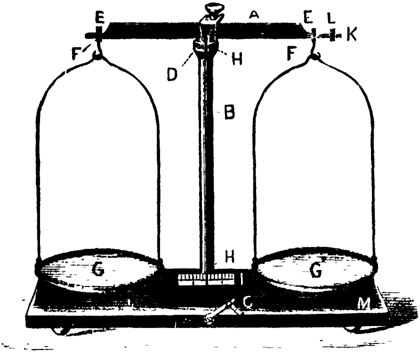

FIG. 6

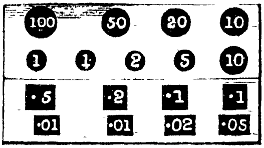

FIG. 7.

To enable the experimenter to follow the movements of the beam with exactness, it carries a pointer *H H*, which moves before a divided scale *I*. When the balance is at rest, the pans are supported on the board *M*, and there is no wear and tear of the knife-edges at *E E*. Similarly the knife-edges at *D*, on which the beam is supported, are not then in action. *C* can be made to lift the rod within *B*, which carries the two steel planes; these, coming under the knife-edges at *D*, raise the beam and pans from their supports and allow free oscillation.

Before reading what follows you should verify the above statements by carefully taking the balance to pieces and putting it together again.

Use of the Balance.

Turn the handle *C*, and observe that the pointer swings to equal distances on each side of the central line of the scale. If it does not do so, adjust the position of *L* till this is attained. Then place the object to be weighed on the pan *G*, and place the largest weight on the pan *G'*. If the weight be too great, remove it, and replace it by the next in size; and if this also be too great, repeat the process until the weight on *G'* is less than the weight of the object. Then add to this weight, which is too small, the next in order. If the two together be too little, add the next, and so on, till the weights are once more too great; when that occurs, remove the weight last added, and put on the next one, leaving that if it be too little, but replacing it by a smaller weight if it be too large. If you proceed in this way with the whole of the weights in order, you will presently find that you have exactly the right weight on the pan *G'*.

Summarised, the above directions are: That you are to add every weight in succession, always removing the *last weight added, if it makes the total too great*, and putting in its place the next weight, till the weights balance the object you are weighing.

8. Reading the Weights.—In this explanation it is assumed that you do not understand decimal fractions.

The weight marked 100 is 100 grams.

The weight marked 20 is 20 grams, and so with the rest of those which have whole numbers upon them.

The weight marked ·5[1] is $\frac{5}{10}$ of a gram.

The weight marked ·2 is $\frac{2}{10}$ of a gram, and so with the others.

The weight marked ·05 is $\frac{5}{100}$ of a gram, and so with the others.

Suppose that the weights required to balance an object are those marked 50, 20, 5, 2, 1, 1, ·5, ·1, ·02, and ·01, proceed as follows :—

First add together the values of the weights which are whole numbers.

Thus 50 + 20 + 5 + 2 + 1 + 1 amount to 79 grams.

Then add up the values of the tenths of grams : ·5 + ·1 produce ·6.

These added to the others make 79·6 grams.

Then add up the values of the hundredths of grams : ·02 and ·01 give ·03. Place the figure 3 after the 6 in the previous statement, and you have 79·63 grams, which shows that the object weighed seventy-nine grams and sixth-three hundredths of a gram.

To learn how to add and subtract decimals, you must consult your teacher, or a book on elementary arithmetic. You will not find they present any difficulty.

When anything is to be weighed, unless it is a single clean fragment, such as a piece of magnesium ribbon, it must not be placed directly on the scale-pan, but must be

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[1] Sometimes, instead of this weight being marked ·5, it is marked 500, which means that it is $\frac{500}{1000}$ of a gram—that is, as you will see, the same thing as $\frac{5}{10}$. The weight marked ·05 above is then marked 50, and stands for $\frac{50}{1000}$ or $\frac{5}{100}$. Therefore you may read the weight marked 500 as ·5, and that marked 50 as ·05.

placed on a watch-glass or small dish, which may be weighed beforehand.

A still better plan is to weigh the watch-glass and the substance, then to remove what is wanted for experiment, and re-weigh the watch-glass with any residue that remains upon it.

Liquids should be weighed in small flasks, or, if they are volatile, in stoppered bottles.

9. Now weigh a shilling, a florin, a penny, a half-penny, a sixpence, a half-crown, and ascertain from your teacher whether your results are correct.[1]

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[1] A collection of weighed coins should be provided for this purpose by the teacher.

CHAPTER III.

BURNING.

Instructions to the Pupil.—In this book you will not be told straight off what is known on this and other subjects. Instead of that, you will be instructed to make certain experiments, and you must try and find out for yourself what the experiments teach you. If you do this earnestly, you will gradually gain the power of making discoveries for yourself, which is much better than being told things. As you may not always be able to think out questions for yourself, especially at first, explanations are given. To help you to avoid seeing the explanations before you have thought over your experiments, they are collected together at the end of the book in Part II.

In working you must proceed as follows:—Suppose that you have completed the experiment of Section **11**, Chapter III., you must next, without the help of the book, write out a careful account of your work in your note-book, a description, that is to say, of what you have done, and what results you have obtained. Then you may look at Section **11**, Chapter III., in Part II., and see if your result agrees with what is stated there; if it does, return to Part I. and proceed with the work of the next section. If they do not agree, you must carefully read through the description of the experiment in Part I. again, to find out in what respects you have failed to follow the directions, and then repeat the experiment. Of course if you have a teacher, you may consult him about your difficulties as they arise; but remember, the great thing is to OVERCOME YOUR OWN DIFFICULTIES. Do not let anxiety to get on quickly lead you to ask for help before you have done your best to master each difficulty for yourself.

In the first two or three experiments more help and explanation are given than afterwards, in order that you may understand what to do more exactly afterwards.

10. Burning.—The truth about burning has not been known for much more than one hundred years. Most things, as you may remember, appear to be almost utterly destroyed when they are burnt. Very little ash is left by a fire after the burning of quite large quantities of coal or wood, for example, and a candle will burn till practically nothing is left. If you search your memory you will probably find it difficult to recall any case of burning in which the ash appears to be at all nearly as great as the body burnt. Chemists, however, are acquainted with such cases. If you obtain a small piece of magnesium wire and burn it, you will find that it leaves a very considerable ash; indeed, so much ash is left in this instance that you will feel uncertain whether the wire or the ash is the greater, unless you test the point by means of your scales and weights. Now this is what the chemists have done. They have collected the products of burning in a number of cases and carefully weighed them, and thus have learnt the truth in these cases.

11. To find how the Weight of Magnesium is Affected by Burning it. (Fig. 8.)

Take a small crucible[1] with a lid, weigh it, then place in it three or four inches of the metal magnesium in

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[1] Some details about apparatus will be found in the Appendix.

the form of thick ribbon, and weigh again. Bend the ribbon so that it will lie across the mouth of the crucible, with one end projecting a little, as in Fig. 8. Light the projecting end *A*, and hold the lid over the crucible loosely whilst the magnesium burns, so that as little smoke may escape as possible. When the ribbon is burnt, and the whole is quite cold, again weigh the crucible with the ash which it contains, placing the lid on the crucible *upside down*, so that the white smoke that has collected upon it may not fall off.

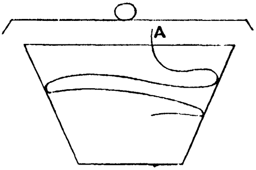

FIG. 8.

The following is the best way of stating the results of such an experiment as that which you have just made :—

A.	Weight of crucible and wire	= 14·76	grams.
	Weight of crucible alone	= 14·20	„
	Weight of wire taken	= 0·56	„
B.	Weight of crucible and ash	= 15·12	„
	Weight of crucible only	= 14·20	„
	Weight of ash	= 0·92	„

A perfect experiment would show that ·56 gram of magnesium produce 0·92 gram of ash. That, in burning, ·56 gram of magnesium gain ·92 − ·56 = ·36 gram of something. Your experiment, however, if successful, will show a gain of weight, but not so much as this.[1] [*Why not?*]

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[1] To assure yourself that the crucible has not altered, clean it with a dry cloth and re-weigh it.

This result suggests two questions :—

(*a.*) *Where does the gain of weight come from?*

(*b.*) *Do things like wood, coal, and candles, which burn and leave little or no ash, also gain weight, or are they really destroyed?*

12. To find where the Gain of Weight in Burning Magnesium comes from.—In the last experiment the probable source of the gain of weight observed seems to be the air. Take a piece of *hard* glass tube (Fig. 9) about half an inch in diameter at the wide part, about as large as a goose-quill at the narrow part, and about six inches long; place inside it a *very little dry red* phosphorus,[1] which is safe to handle if kept away from fire. With the help of a small blowpipe heat the tube at *C* till the glass softens, and draw apart the two ends,[2] keeping them in the flame, taking care to keep the phosphorus away from the hot glass. When the tube is very narrow at *C* let it cool down, and *when cold* cautiously heat the contracted part till it melts, and pull away the ends from *C*. Fix the sealed tube nearly horizontally, with the phosphorus lying at *D*, and heat the end *D* by means of a gas-flame till the tube is full of fumes, and no longer, *taking care not to heat the rest of the tube.* When the tube is again cool, place it, narrow end downwards, in a basin of water and break off the tip.

FIG. 9.

Note exactly what happens. *Find whether your result is correct by comparing it with* 12 (p. 72). Write out

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[1] Magnesium does not catch fire easily enough for this experiment.

[2] See p. 8.

answers to the following questions without the help of Part II., if you can:—

13. Does the air take any part in burning?

Compare your answer with Part II., No. 13 (p. 72).

14. Either compare your result with those of other students, or repeat the experiment, using more phosphorus; and then explain if the air is a simple substance, or if it consists of more than one thing.

Compare your answer with that given in Part II., No. 14 (p. 72).

15. If air is composed of more than one thing, explain how each could be distinguished from the other.

Compare with 15, p. 73.

To find whether a Wax-Candle Gains or Loses Weight when Burnt.

16. So far, your results show that in combustion a constituent of the air is taken up by the burning body. That combustion is not a destruction of the thing burnt, but an addition of something to it. Is this what happens in all cases?

You cannot possibly test every combustible, therefore you cannot answer this question with certainty. You can, however, examine such a case as that of a wax-candle, which will burn and leave little or no residue.

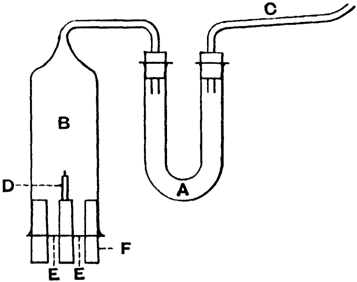

FIG. 10.

(Fig. 10.)—Take a U tube *A*, and by means of a cork with a hole made through it by a file or cork-borer, join to it a tube like *B*, about one inch or rather more in diameter at its widest part, and about the size of a penholder at the narrow end. Attach to the other end of *A* a narrow bent tube *C*, and fix a candle *D* in *B* by means of a cork *F* with several large air-holes *E E* through it. The candle may be joined to *F* by a pin.

N.B.—Select a *very small candle* with as small a wick as possible.—Surround *A* with cold water in a basin, or wrap strips of wet filter paper round it, remove the candle, light it, replace it, and at the same moment suck a stream of air through the apparatus by means of *C*. In *A* you will get a little liquid, as a deposit of dew. It is water. It may be mixed with black soot, if you have not supplied enough air to burn the candle completely.

Now put a little lime-water[1] into *A*, just enough to cover the bend at *A*. Repeat your previous process of burning the candle. The lime-water will turn milky, because a gas is produced by the burning candle, which unites with the lime in the water, and forms a white solid, which is of the nature of chalk. In order to make sure that the substance which acted on the lime-water was produced by the burning candle, and was not in the air, repeat the experiment with fresh lime-water without a burning candle. You must not, however, draw plain air through lime-water too long, because air does contain a little of this gas, which is produced by fires, burning candles, and other causes, so that after a while it will turn lime-water milky. You will find, however, that whilst the air from a burning candle makes the lime-water milky almost at once, natural air only does so after considerable delay.

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[1] Made by shaking some slaked builder's lime with water, allowing the mixture to settle, and decanting the clear liquid. It must be kept in a well-closed bottle.

17. After having made the above experiments and described them in your note-book, endeavour to solve this practical problem.

Given some soda-lime, which is a solid that will take up both water and carbonic acid gas (the gas which acted on the lime-water). To use the apparatus just made and the soda-lime for an experiment, to learn whether the water and carbonic acid gas given by the candle weigh more or less than the candle burnt.

If you can think of a plan, describe your plan in your note-book, and then compare it with that given in 17, Part II. (p. 73). If your plan is like the one in the book, carry it out. If you cannot do this by yourself, you may consult the book (17, p. 73) if you have no teacher, or, if you are working with a teacher, ask him which to adopt.

18. It is very important that you should learn to distinguish what you know of your own experience from what you have been told, and these again from what you infer from known facts.

Thus, you may have read in books that things are not destroyed in burning, but that they combine with the oxygen of the air. You may, of course, believe such a statement, if you trust the books—that is, those who write them. But you must remember that you did not *know* it was true so long as you had simply read it.

Now, however, you *know* that magnesium and wax when burnt give products which weigh more than the substances before they are burnt; and you *know* that phosphorus when burnt in air takes up one part of the air and leaves another part unacted upon. From these facts you may *infer* that other things probably also take up part of the air when they burn, and increase in weight by doing so. But you must not forget that you do not know with certainty that it is so.

19. That Matter is not Created nor Destroyed in Burning and other Chemical Changes.—Lavoisier and other experimenters who have made a great number of experiments on combustion, have always found that things when burnt gain weight by combining with oxygen from the air. So we believe, though we do not know, that other things which have not yet been experimented with also gain weight when they burn, and that the gain of weight is due to their combination with oxygen from the air. As the air cannot be supposed to give up oxygen without losing weight, and as, indeed, whenever the experiment is tried—for it has been tried—it is found that the air loses exactly as much as the candle, or other thing burnt, gains, we further infer that in burning nothing new is ever produced, and nothing is destroyed. In the case of magnesium, for example, the magnesium and the oxygen unite and produce that white ash. If the magnesium gains ten grams, then the air will be found to have lost exactly ten grams—no more and no less—if the experiment is skilfully done, and all loss of the product is avoided.

We do not know that this is a universal truth. But it is known to be true in so many cases that we *believe* it to be a universal truth—that in burning nothing is gained nor lost. The combustible and the oxygen take new forms, but their united mass remains unaltered. Similarly in other chemical changes we have knowledge enough to justify us in believing that matter is never created nor destroyed in such changes. This we may call a law: that matter cannot be created nor destroyed in chemical changes.

20. Air is called a Supporter of Combustion, for candles, gas, wood, &c., will burn in it, whilst substances that will burn in air are termed **combustibles.**

This distinction is often convenient. But consider what it means. Is there really any difference between supporting combustion—which is what we say air does when a candle burns in it—and burning, which is what we call the part played by the candle. At first it may seem that as air could not conceivably burn in the candle, there is a difference. But take the case of coal-gas. Gas is also said to be combustible; air to support its combustion. As the oxygen of the air combines with the gas, and the gas combines with the oxygen, we perceive that the above distinction, though convenient, is artificial; when burning the two gases both do the same thing, each combines with the other.

The distinction we make is, in fact, based upon the accident that the air surrounds a small jet of gas, which by old custom is said to be burnt. Evidently, if the air were turned on at a gas-jet in a room of coal-gas the oxygen of the air and the gas would unite as before. Only we should then say the air was burnt, and that the gas was supporting combustion. You will test the truth of this by the next experiment.

The case of the candle is complicated by the solidity of one of the materials. It is obviously not possible to have a jet of air in an atmosphere of wax. It is none the less true, however, that though we use different words to express the action of the candle and the oxygen of the air in burning, they are actually, from a chemical point of view, acting in the same manner—each is combining with the other.

Of the two constituents of air—oxygen only, which takes part in burning, is the supporter of combustion. Nitrogen, in which you have found that things will not burn, is called a **non-supporter of combustion.**

Nitrogen is a non-supporter of combustion because it will not combine with the components of wood, coal, gas, wax, &c. Therefore, as there is no combination, there is none of the light and heat that accompany those cases of combination to which we apply the terms combustion and burning. To say a gas is a non-supporter of combustion then is to say that it will not combine with ordinary combustibles, or, at least, that if it does so no light nor heat are produced.[1]

21. To find if Air, which is a Supporter of Combustion, will Burn in an Atmosphere of Coal-Gas, which is a Combustible. (Fig. 11.)

Take a lamp-glass *A*, fit a cork carrying two tubes 1, 2, into its wider end. 2 must move easily through the cork, and must be long enough to project at the upper end *B* when pushed forward; join a gas-supply tube to 1, and join a piece of flexible india-rubber tube *T* to 2 at *E;* join the other end of *T* to the tube *D* attached by a cork to a two-necked bottle *F;* fix the long tube with a funnel top *Q* to the other neck of *F* by a cork, and pour as much water into *F* as will cover the end of *Q*.

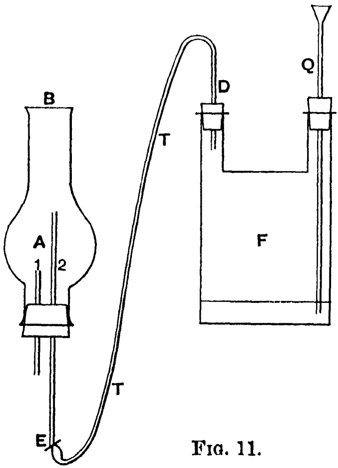

FIG. 11.

Turn on the gas, and when *A* is full, light the gas at

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[1] This subject will be more fully understood when the work of Chapter IV. has been done. Therefore you are advised to re-read 20, after you have finished Chapter IV., and before beginning Chapter V.

B, turn it down to a small flame; move up 2 till its upper end is in the flame at *B*; let a companion pour a gentle stream of water down *Q*, which will send a current of air from *F* out of the end of 2; when this is alight, withdraw 2, so that the flame of burning air is at about the centre of *A*.

Note your result, and after describing your experiment, compare it with 21, *Part II.* (p. 74).

CHAPTER IV.

ELEMENTS, COMPOUNDS, CHEMICAL COMBINATION.

When you burnt phosphorus with air in a sealed tube, a residue of nitrogen was left. Evidently, therefore, air is a more complex substance than nitrogen, since you can get oxygen and nitrogen out of air.

Chemists have discovered that many apparently simple substances are really of compound nature, and it is one of the objects of the science to separate all such bodies into their constituents. Various forces, such as heat and electricity, are used for this purpose.

22. Study of the Action of Heat on Oxide of Mercury, in order to learn whether it is a Simple or a Compound Substance.

Weigh some red oxide of mercury[1] in a strong glass tube[2] *A* (Fig. 12) fitted with a delivery tube *B* by

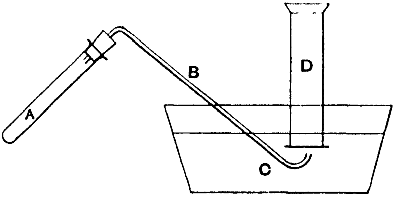

Fig. 12.

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[1] You must use precipitated oxide.

[2] *A* should not be a common test-tube, but should be made of a piece of the infusible tube called *combustion tubing.*

means of a cork; let *B* dip under water in a basin *C*, and let a large test-tube or small cylinder of water *D* be placed over the end of *B*.

Heat the oxide of mercury contained in *A* strongly with a gas or spirit-lamp as long as any remains, and examine the contents of *A* and *D* carefully afterwards. Ascertain whether the contents of *D* support combustion. Then write out an account of your experiment and its results. And express your opinion on this point:—Is mercury oxide a simple substance or a compound substance? If a compound, explain so far as you can how many things you find in it, and what they are.

Compare your account with 22, *Part II.* (p. 75).

23. Elements.—You know now that air and oxide of mercury are compound substances, for each of them can be divided into at least two bodies. In burning, things extract oxygen from air, leaving behind nitrogen. Heat splits oxide of mercury into quicksilver and oxygen gas. Great numbers of common objects, *e.g.*, stones, wood, water, are like these. By suitable experiments two or more substances can be extracted from each of them; and we therefore know them to be compound. But there are about seventy substances which cannot be so divided by any known means. These are called *elements*. We do not know with certainty whether the elements are simple or compound, for things that were once supposed to be elements have been split up into simpler bodies; and it may happen, at some future time, that some of those which we still call elements, and which as far as our knowledge goes at present are elements, will also be proved to be compounds. An element to a chemist is only one of a group of things *which have never yet been decomposed.* Most common objects are compound. The following substances already known to you are elements:—

Silver, iron, gold, lead, quicksilver, tin, copper, magnesium, sodium, potassium, aluminium, zinc, oxygen, nitrogen, carbon (diamond), phosphorus, iodine.

24. The Distinction of Chemical Compounds from Mixtures.—The question here naturally arises, Why is it that oxide of mercury is so very unlike quicksilver, and so very unlike oxygen gas? If these things are simply mixed, why do they not retain their properties to some extent, as sugar does, for example, when you mix it with your food, or as ink does when you dilute it with water? Is not oxide of mercury clearly something more than a mere mixture of mercury and oxygen?

You cannot solve this question easily in the case of quicksilver and oxygen, but you can do so with some other substances—with iron and sulphur, for instance. You may try the effect of mixing these substances when cold, and of putting them together when hot.

To ascertain whether Sulphur and Iron Retain their Properties when Mixed Cold.

Examine iron filings and sulphur respectively by *a*, *b*, *c*, *d*.

Mix some iron filings and sulphur well in a mortar, then examine the product—

(*a.*) With a magnet.
(*b.*) With a magnifying lens.
(*c.*) By shaking in a tube with water and letting the powder settle.
(*d.*) By mixing a little with carbon disulphide, filtering off the liquid, and leaving it to evaporate in a dish.

Write out an account of your results. Compare with Part II., p. 75, *and if wrong repeat the experiment and correct your notes.*

To learn the Action of Hot Sulphur on Hot Iron.

Take a rod of tightly rolled iron gauze about the size of a cedar pencil, heat it as nearly white hot as you can with your blow-pipe flame, or in a furnace, and rub it with a lump of sulphur, letting the drops fall into a basin of water. If this is done properly, you will get a few heavy metallic masses. Powder them in a clean mortar, and examine them as you did the mixture of iron and sulphur. *Compare your results with* 24, α, β, γ.

From the results obtained above you will have perceived that in the first case the sulphur and iron were in no way altered. You could see the particles of each separately. The iron could be attracted from the sulphur by a magnet, and the sulphur could be separated from the iron by carbon disulphide, and, iron being heavier than sulphur, in experiment (*c*) it settled underneath the sulphur. In brief, the iron was still iron, the sulphur was still sulphur. But, after the iron had been in contact with the sulphur at a great heat, you [illegible] very different results. The magnet did not attract any iron from the powder. You could no longer see sulphur and iron separate from each other with the lens. The iron and sulphur did not settle separately from water, and carbon disulphide did not extract any sulphur from the product. In short, there was no longer any sulphur in it, nor any iron. They had united to produce an entirely new body, a *compound* of sulphur and iron (sulphide of iron).

You will now understand what is meant by a *chemical compound*, and how it differs from a *mixture*.

When the constituents of compound substances keep their properties, so that you can separate them again by taking advantage of those properties, they are simply mixed, and such compound substances are called *mixtures*.

When two or more substances are so intimately united that they lose their distinctive properties, and a new substance quite different from either of them is produced, the change is called a *combination*, and the product is called a *compound.*

25. Experiments to ascertain the Influence of Heat and other Conditions on Chemical Action.—The last experiment, in which sulphur and iron combined at a very high temperature, and when one of them (the sulphur) was melted, but did not do so when they were cold and both of them solid, will suggest to you that combination will not take place under all conditions.

After having made the following experiments, draw up a list of results for comparison with Section II. :—

(*a.*) Place some carbon disulphide in a large test-tube or glass jar, cover the mouth with your hand, and shake well to fill the jar with its vapour. Then warm a glass rod and place it in the vapour of the carbon disulphide.

(*b.*) Try to light coal-gas with a similarly warmed rod of glass, with a piece of iron nearly red hot, also with a rod intensely red hot, and with a flame.

(*c.*) Take some carbonate of soda and tartaric acid, and mix them dry in a mortar. Moisten the mixture. Dissolve each of the substances separately in a little water, and mix the solutions.

Describe your results, and compare your notes with 25, *Part II.* (p. 76).

26. *Consider the results obtained in experiments a, b, c of* 25, *and explain, as far as you can from those results, what conditions seem to promote chemical change, and what you have learnt about the conditions under which it will occur. See* 26, p. 77.

CHAPTER V.

ACIDS, ALKALIS, AND SALTS, AND THEIR RELATIONS TO OXIDES.

27. WHEN elements unite with oxygen, the products are named *oxides*. Thus, the white ash left when magnesium is burnt is called oxide of magnesium. Water is also an oxide, and so is the carbonic acid gas of the burning candle. You will learn more about these two oxides later.

A Property of Acids.

Take a little white wine vinegar, add it to some solution of red litmus, and also to some blue litmus solution.[1]

Repeat these experiments with any four substances called acids, *e.g.*, nitric acid, that you can find in the laboratory.

Draw up a list of your results in columns, and compare it with 27, p. 78.

Acid Taken.	Action on Red Litmus.	Action on Blue Litmus.

28. Explain how you would test for acids by red and blue litmus, and compare your answer with 28, p. 78.

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[1] You can make these solutions by steeping some solid litmus in water or very weak alcohol. Divide the liquid which you pour off from the sediment into two parts; to one add a few drops of weak sulphuric acid, to the other add a little solution of sodium hydroxide. You will then have red and blue litmus solutions.

29. A Property of Alkalis.—Repeat the last experiment, using the following: (1) quicklime, (2) slaked lime, (3) sodium hydroxide, (4) magnesium oxide, (5) solution of ammonia. These may conveniently be called *Alkalis.* Draw up a table of results, as before, and compare with 29, p. 78.

30. Explain how you would test with litmus for an alkali, and compare your answer with 30, p. 78, and correct it.

31. *Problem*:—

(*a.*) To make some delicate blue litmus out of red litmus, so that it is a good test for acids (compare with 31 (*a*), p. 79).

(*b.*) To make delicate red litmus from blue litmus, for a test for alkalis (compare with 31 (*b*), p. 79).

32. If you have a teacher, ask which of the acid and alkaline substances that you have been using may be safely tasted,[1] and draw up a table of results, as before, putting together those which blue red litmus, and those which redden blue litmus. Thus:—

Name.	Taste.	Action on Blue Litmus.	Action on Red Litmus.

Compare your table with 32, p. 79, *and correct it.*

33. Metals and Non-Metals.—You already know to some extent what is meant by the term **metal**; iron, silver, gold are good examples of metals. Metals are usually heavy substances which reflect light well when

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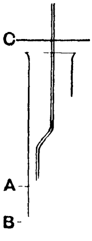
[1] You must be careful never to taste any chemical without assuring yourself by inquiry that it is safe to do so.

polished. They are more or less easily beaten into thin sheets, such as you have seen in gold and silver leaf, or drawn into wire. One of them, quicksilver, is a liquid; all the rest are solids. If you compare sulphur, phosphorus, charcoal, and oxygen with the metals, you will perceive that they are quite different in regard to most of the above qualities. These are called **non-metals.**

Experiment to learn the Behaviour of Oxides of Metals and Non-Metals with Litmus.

34. Burn small portions of the metals, magnesium, sodium, and potassium, in iron spoons, and after adding a little water to the products, test them with red and blue litmus, as before.

Similarly burn small fragments of sulphur, phosphorus, and carbon, and test the products with red and blue litmus. As these last substances will not leave any ash, the best plan is to take a little spoon (A) (Fig. 13) on a long handle,[1] to place this, with the burning substance in it, in a cylinder (B) which contains a little water, and to shake up the gas or solid produced with the water when the burning ceases.



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Draw up a table of before, and with 34, p. 80.

Name.	Action on Red Lit
Oxide of (*here write the name of the substance*).	

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[1] Sold as deflagr

35. When your table is complete and correct, write out accounts of what you have learnt about (*a*) acids, (*b*) alkalis. These accounts must show by what properties you might expect to distinguish acids from alkalis, and also whether you can foretell whether an oxide, when dissolved in water, will give an acid or an alkali, if you know which kind of element produced the oxide.

Compare your account with 35, p. 80.

Experiments to learn the Action of Alkalis and Acids on each other—Salts.

36. Take a little solution of one of the alkalis, say sodium hydroxide with a little litmus added to it, add hydrochloric acid, which probably will be one of the acids with which you have experimented, till the blue colour of the litmus is just destroyed, then drive off the water, either by heating in a basin over a burner, or in a warm oven.

Examine the product as regards taste, action on red
tmus and on blue litmus ; say if it is an acid or an alka-
e body ; or, if it is neither of these, mention any very
mon substance that it in any way resembles.

mpare your notes with 36, p. 80, *and corr*

Now prepare similar preparatio with other acids
lkalis ; for example, with drochloric acid and
um hydroxide, and nitric acid and sodium
and action on litmus of
ole of the chief characters of
led *salts*.

e ready to draw up a tolerably
alkalis, and salts ; make out a
e taste, action on litmus, and
hod of obtaining the members
ps of substances, and compare
81.

CHAPTER VI.

A LAW OF CHEMICAL COMBINATION.

39. Your experiments will have familiarised you with the classification of things into simple and compound bodies, and you ought now to have a clear idea of the distinction of a compound from a mere mixture, and of the fact that nothing is ever created nor destroyed in chemical changes.

The question, therefore, arises, When things unite chemically, do they unite in fixed proportions or in variable proportions?

40. Experiment to learn whether a given Salt is formed from Fixed or Variable Proportions of Acid and Alkali.

Take some strong hydrochloric acid—ten cubic centimetres, let us say—add to it water till the volume is increased to 100 cubic centimetres. Take some sodium hydroxide, and dissolve a weighed quantity in water, so that about three parts (gra[illegible]) are in as much water as will make 100 cubic cent[illegible] f the solution.

(*a.*) Take twenty me [illegible]

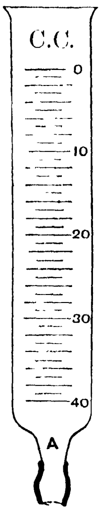
little litmus, [illegible]

[illegible]

(*d.*) Take fifteen measures of either solution and proceed as before.

In any two cases (*e.g.* the first two) put the neutral solutions of salt obtained into weighed basins. Drive off the water by putting the basins in the oven, and then weigh the basins and salt, and calculate how much salt is produced in each case.

Write down the result of each experiment, so that you can compare them, and say what they teach you about the composition of common salt. Remember that in Experiment 36, *Chapter V., you obtained common salt by hydrochloric acid acting with sodium hydroxide. Compare your results with* 40, p. 82.



41. The Burette.—As it is impossible to do the experiments described in 40 well with ordinary measuring glasses, it is better to use the piece of apparatus known to chemists as the burette. (Fig. 13*b*.)

A burette consists of a long piece of glass tube, contracted at one end *A*, open at both ends, and graduated in cubic centimetres or fractions of cubic centimetres. A piece of india-rubber tube *B* is fixed to the narrow end of the tube. This carries a fine jet *C*, and contains a short plug made of glass rod at *B*. To use the burette, fix it by means of a clamp [illegible] retort stand with the jet [illegible] pour the acid or alkaline [illegible] press the india-rubber tube to [illegible] tions, read how much of the liquid you remove at each operation with considerable accuracy.

If you do not care to buy a burette, you can make one out of a piece of glass tube of about 1 centimetre bore and 55 centimetres in length, by drawing out one end and pasting a piece of paper that has been divided into a scale of equal lengths along one side of it.

Such a burette will be sufficient for the experiments described in 40. It is important that the piece of tube employed should be of equal diameter throughout its length. The accuracy of the burette may be tested by filling with water, drawing off its contents in portions of ten divisions into a dish of known weight, and weighing them. If the divisions be of equal value, and if the tube be of uniform bore, you will find that you withdraw nearly equal weights of water at each operation. The quantities of water withdrawn will not be absolutely equal, however, as it is not possible to read the levels of the liquid quite correctly. Differences of even ·2 gram would be quite excusable in the case of a beginner, even after a little practice.

To find the Composition of Silver Oxide.

42. The metal silver forms an oxide which is easily decomposed by heat, like mercury oxide. Verify this by heating a little in a test-tube, and observe that metallic silver is left in the test-tube.

Now, if you can do so, proceed to find whether silver oxide does or does not always contain the same amount of silver in one gram. If you cannot devise a proper experiment, turn to 42, p. 83, and carry out the instructions given there; but, if possible, invent a plan for yourself.

43. Write out what you have learnt about the composition of salts from these experiments. *Compare* p. 83.

Law of Constant Composition.

44. In the experiments you have made upon the composition of silver oxide and common salt, you have had two examples of a general law, known as the Law of Constant Proportions, which, when applied to the composition of compounds, may be stated as follows :—

The same chemical compound always contains the same elements in the same proportions. Thus in one hundred parts of silver oxide you found always ninety-three parts of silver to seven parts of oxygen. This law has not been proved to be true in the case of every known compound. There are far too many of them. It has, however, been proved to hold good for a great many compounds, and *there is no known exception to it.* Therefore we believe it to be a law of nature, and confidently assume its truth in all cases.

The law of constants, as you will presently gather, applies to other changes besides those of combination.

CHAPTER VII.

THE CLASSIFICATION OF CHEMICAL CHANGES.

45. TAKE a little iodine, heat it in a test-tube and observe its behaviour; notice its smell; put a fragment in some chloroform, and observe what happens.

Take a little quicksilver and notice its density, appearance, and the effect of heating it.

Take a few grains of mercury and a rather greater weight of iodine (2 of mercury to 2½ of iodine are the right proportions), rub them together in a mortar, adding a drop or two of spirit, for some time, and describe what you observe in these experiments. Report your result, and try to explain what has taken place between the iodine and mercury.

Compare your account in each case with that given in 45, p. 85.

46. Take a little chlorate of potassium in a test-tube and heat it; if any gas comes off, continue the action till no more gas is produced, even at a red heat.

Examine the gas evolved with a glowing match.

Dissolve the residue, if there is any, in water, and add a drop of solution of silver nitrate to the solution of the residue.

Do the same with a crystal of the original chlorate.

(*a.*) Write out an account of your experiments and results, and compare it with 46 (*a*), p. 86.

(*b.*) Point out the difference between this case of chemical action and the former one (see 46 (*b*), p. 86.

Synthesis, Analysis.

47. The last experiment has directed your attention more particularly to decomposition, a kind of chemical change exactly opposite to the combinations which you studied in your experiments on combustion and in Experiment 45. Chemists term changes such as these **analyses** and **syntheses** respectively. The breaking-up of chlorate of potassium into oxygen and chloride of potassium is an **analysis.** The combination of iodine and mercury is a **synthesis.** The term synthesis comes from Greek words meaning "to put together."

The word analysis also is of Greek origin, and means "breaking up."

48. The following experiment will introduce you to another kind of chemical change. Take a little quicksilver, and dissolve it with the aid of heat in a few drops of nitric acid; dilute the solution of mercury with a little water, drop a piece of sheet copper into part of the diluted solution, keeping another part, and warm gently; observe what happens to the copper, remove it from the liquid, dry it with a piece of filter paper, and cut it into small strips; place these in a very small test-tube; heat them.

Report your observations, and compare them with 48, p. 86.

49. Substitution.—The explanation of these changes appears to be that the quicksilver has, in the first experiment, entered into combination with part of the nitric acid. That the copper has then acted on the compound, turning out the quicksilver and taking its place. This change is called a **substitution.**

The following experiment will explain a case of this kind more fully:—

Take a little weak solution of a compound of copper in water—for instance, of copper sulphate—add to it some solution of ammonia; note the fine blue colour produced, and remember that the production of this blue colour on the addition of solution of ammonia to anything is an indication of the presence of copper in the substance tested.

Now take a crystal or two of nitrate of mercury, dissolve them in weak nitric acid, and treat the solution with scraps of copper. See if the quicksilver is set free by the copper, as before. If so, test the above explanation, *i.e.*, see whether the nitric acid has taken up copper in place of the mercury removed by the action of the copper.

50. State in writing the three modes of chemical action with which you are acquainted, giving any examples you can of each.

Compare your account with that given in 49, p. 87.

51. Allotropy.—Some of the elements can exist in more than one form. The change of an element from one of its forms to another may very properly be regarded as a chemical change, although only a single element takes part in the change. Carbon affords a very good illustration of this phenomenon. It has been found that when pure diamond, black-lead, or soot are burnt in oxygen, the same compound is produced, in each case, viz., oxide of carbon (see p. 33), and that this is the sole product. From this fact it has been concluded that these three very dissimilar substances are all one and the same element, and they are said to be *Allotropic*, forms of carbon.

Phosphorus is another element which exists in more than one form. In this case the two forms are easily convertible into one another, as may be learnt from the following experiments.

Take a little red phosphorus; look at it in the dark. Warm it *gently*. Try if it will dissolve in carbon disulphide or in oil.

Repeat these experiments with a *very* minute piece of common phosphorus; *you must avoid touching this.* Then write an account of your observations, and compare it with 51, p. 87.

52. Action of Heat on Red Phosphorus.—Place *a very little* red phosphorus in a test-tube. Close the test-tube with a loosely fitting cork, and heat the red phosphorus strongly. In doing so take care to keep the upper part of the test-tube cool. When all the red phosphorus has disappeared from the bottom of the tube, and when the tube is quite cold, examine its contents closely. Then break the tube on a plate, and endeavour to make out what has become of the red phosphorus under the influence of heat.

Now compare your work with 52, p. 88, *and correct it.*

CHAPTER VIII.

HYDROGEN AND WATER.

53. PUT a few fragments of zinc into some dilute hydrochloric or sulphuric acid,[1] notice what action occurs, and examine the colour, taste, smell, combustibility, and power of supporting combustion of the gas, if a gas is given off. *Then, after describing your results, compare them with* 53, p. 89, *and correct it.*

54. Explain which kind of chemical action you think has taken place in this last experiment, giving reasons for your opinion.

55. To prepare Hydrogen on a larger scale (Fig. 14).

Place scraps of zinc in *A*, and cover them with water; pour strong sulphuric acid, a little at a time, down the funnel *B* fixed to one neck of the bottle by a cork, till

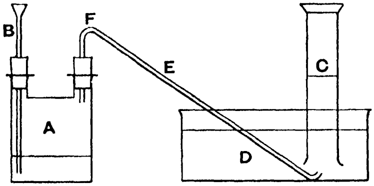


FIG. 14.

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[1] Sulphuric acid is preferable, as the work will be rather less troublesome subsequently if that is employed.

a brisk evolution of gas sets in. The gas may be collected in the jar of water *C* standing in the basin. The delivery-tube *E* may be in two pieces, with a joint of india-rubber tube at *F*.

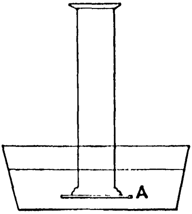

FIG. 15.

When the jar is full of the gas, put a ground-glass plate *A* (Fig. 15) over its mouth whilst still under water; remove the jar of gas from the basin, apply a light to the gas.

Repeat this experiment with another jar of the gas, and if there is no difference between the results in the two cases, do it a third time. *State your results, and explain any difference that you observe, and correct your own account after referring to* 55, p. 89.

56. Find if hydrogen is lighter or heavier than common air. *See* 56, *if necessary.*

57. To obtain the Non-Gaseous Product of the Action of Zinc on Sulphuric Acid, if there be one.

When no more zinc will dissolve, strain the liquid from *A* (55) through a filter paper into a dish, and evaporate the water in an oven till only a little remains. As the liquid cools, you will obtain crystals of a compound of the zinc with that part of the acid which was previously combined with the hydrogen. Keep these crystals for Experiment 59.

The change that takes place when zinc acts on sulphuric acid is as follows:—

When zinc dissolves in hydrochloric acid, it gives hydrogen and zinc chloride; or, if you use sulphuric acid, it gives hydrogen and zinc sulphate. The change will be better understood after reading the following:—

58. Symbols and Chemical Equations.

For the sake of brevity, chemists use a system of symbols for expressing chemical changes.

Thus, instead of "*added to,*" we write +.
Instead of "*produces,*" we write =.
For Zinc, which is an element, we write Zn.
For Hydrogen, which is an element, we write H.

Hydrochloric acid is a compound of two elements, hydrogen and chlorine. The symbol for chlorine is Cl; its compound with hydrogen is written HCl. To explain that zinc acting with hydrochloric acid produces hydrogen, and that the zinc combines with the chlorine, we write :—

$$\underset{\text{Zinc}}{Zn} + \underset{\substack{\text{Hydrochloric}\\ \text{Acid}}}{2\,(HCl)} = \underset{\text{Hydrogen}}{H_2} + \underset{\text{Zinc Chloride.}}{ZnCl_2}$$

A few more examples of these *chemical equations*, as they are called, with a fuller explanation of them, will be given later on. But for a complete account of the subject, you must wait till you attend lectures. The following fact will, however, give you an idea of the value of the method. The symbols are used to express definite quantities of the substances which they represent. Therefore if you gave a chemist a piece of zinc and told him its weight, by the help of the equation written above he could find out exactly how much hydrogen, either by weight or volume, the zinc would produce by acting with the acid.

59. Test the zinc sulphate to find if it is an acid, an alkali, or a salt.[1] Then, according to your result, show that you have a new mode of getting acids, alkalis, or salts. *See* 59, p. 90.

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[1] In order to get rid of the acid liquid adhering to the crystals, put them on filter paper, and press them well between several thicknesses of it. Then throw them into a little methylated spirit, collect again, and when the liquid has drained off, press them once more between filter paper. You will then have them nearly pure and fit to examine.

60. To learn whether the Action of Zinc on Acids, i.e., Substitution, follows the same Law as the Combination of Elements with each other.

Take a glass tube *A* (Fig. 16), about 2·0 *cm.* in diameter, with a hole of about the same diameter at *B*, and of about 150 *c.c.* capacity; close the open end with a cork *D*, and fill *A* with dilute sulphuric acid; close the opening with your thumb, and place the tube in a small basin *C* of dilute acid. Do not take a larger basin for *C* than is necessary.

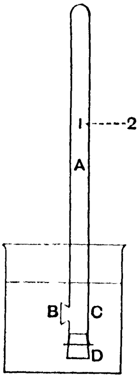

FIG. 16.

Weigh out ·2 gram of zinc as accurately as possible. You will do this most readily by taking a piece slightly above ·2 gram in weight, and rubbing it on a file cautiously so as to wear it down to exactly the right weight. Incline *A* in the direction 1—2, so that you can drop the weighed zinc into *A* through *B*; place *A* in the erect position, and leave it whilst the zinc dissolves. Meanwhile weigh another piece of zinc of equal weight for a second experiment. When all the zinc is dissolved, close *B* with your thumb again, and without letting any water escape, transfer it to a deeper vessel of water; depress the tube *A* in the water so that the level of the liquid is the same inside and outside *A* at *B* (Fig. 17). (If you note carefully what takes place, you will observe a contraction of volume as you do this.) Mark the point *B* with a bit of gummed paper, or better, with an india-rubber ring, and then find what volume of gas you have in the tube.

Use the method given 60 (*a*), p. 91, if you cannot discover how to do it for yourself.

Repeat the experiment, using hydrochloric acid with the ·2 gram of zinc weighed ready for the purpose. Compare your result with that obtained in the first experiment, and say what law the two results seem to be in accordance with. In doing so, remember that for various reasons we never get absolutely accurate results; small errors occur which cannot be avoided. In your case these errors may amount to one part in forty, perhaps, at first; but will become much less as you gain skill in handling apparatus. Then read 60 (*b*), p. 91, *and correct your notes if necessary.*

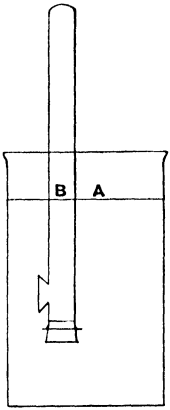

FIG. 17.

61. Oxide of Hydrogen.—Hydrogen gas in burning probably forms an oxide, as other combustibles did in your earlier experiments.

To obtain this oxide, clean and set up the apparatus Fig. 10 made for examining the combustion of a candle. Place a jet of burning hydrogen in the mouth of *B*. (When the air has all been driven out of the apparatus for making hydrogen, it becomes quite safe to light the gas at the mouth of the delivery-tube.) Then if the U tube *A* be cooled as before, a liquid will collect in *A* which you may prove to be water by pouring it on some *dry* copper sulphate, and comparing the effect with that given when common water is put upon dried copper sulphate. Oxide of hydrogen, then, is water.

62. To learn whether the Supporter of Combustion in the Air is really the same Element as that obtained from Oxide of Mercury and Chlorate of Potassium.

You have been told that the part of the air which unites with things when they burn in it is the same substance as the gas called oxygen, which you produced by heating oxide of mercury, and also by heating chlorate of potassium, but you have no evidence of the truth of this from your own experiments at present.

The following experiment will, therefore, be interesting, viz., to endeavour to prepare enough water from hydrogen and oxygen gases to enable you to identify it by the copper sulphate test used in Experiment 61. If hydrogen and oxygen produce water by combining, and if hydrogen and air also produce water by combining, it follows that air contains oxygen. For the same compound always contains the same elements in the same proportions (law of constants). Therefore, if water can be made from hydrogen and oxygen, any air or gas which yields water when hydrogen burns in it must contain oxygen.

Take some chlorate of potassium, powder it, and put it in a test-tube *A* (Fig. 18), to which is fitted a cork with a glass tube, *T*, through it; by means of an india-rubber tube join *T* at *E* to a U tube *G*, containing soda-lime to dry the gases passed through it, and join *G* by another narrow tube *E′*, fitting through a cork to the *hard glass* (combustion) tube *F*, which may be about as large internally as your little finger, six or eight inches long. and should be drawn out at the other end *T*. *F* is to be packed with metallic copper in the form of copper turnings.

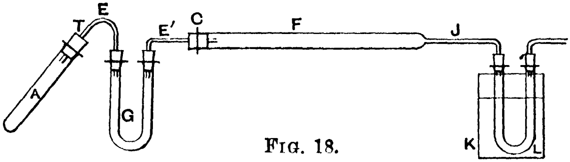

FIG. 18.

Heat the chlorate in *A* so as to send a steady stream of oxygen over the copper, which should be kept hot (a low red heat will do best) by a Bunsen's burner.[1] The copper will soon be coated over with a thick coating of black oxide of copper. *F* must not be heated too near the cork, in order to avoid burning it.

Now detach *A*, *let F get quite cold*, and attach a hydrogen bottle at *E*, from which hydrogen has expelled all the original air (why?). Attach to the end *J* a U tube *L*, and keep this cool by surrounding it with a beaker of cold water, *K*. When hydrogen has escaped in a gentle stream for a few minutes, heat *F* again. A liquid will collect in *L*, and the copper oxide in *F* will be reduced to copper—the hydrogen having taken up the oxygen with which the copper combined in the first part of the experiment. On testing the liquid in *L* with dried sulphate of copper, it will be found to behave just as water does.

Thus we have made hydrogen gas and oxygen gas unite and produce water, by the help of copper, and therefore, since there is a supporter of combustion in the air which also unites with hydrogen and produces water (Experiment 61), we may infer that the supporter of combustion in the air is identical with the oxygen produced by the action of heat on chlorate of potassium.

63. Explain how the same apparatus may be used for finding the proportions, by weight, of hydrogen and oxygen in water. As it will take some time to do, and needs a fairly sensitive balance, you may have to omit this experiment. But if you have time, and a fair balance and weights, do it. If not, write out an account of your ideas on the subject, and compare them with 63, p. 91.

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[1] A very suitable burner for this purpose is made by Townson & Mercer. It is known as Ramsay's burner.

CHAPTER IX.

AIR, ITS COMPOSITION AND USES.

64. (*a.*) WRITE a list of the chief facts you have learnt about oxygen and its compounds. *Compare your account with that given in* 64 (*a.*), p. 93.

(*b.*) From what you know about air, state in writing as nearly as you can whether nitrogen dissolves in water, whether things will burn in pure nitrogen, and what colour, taste, and smell nitrogen has. *Then compare your account with* 64 (*b.*), p. 93, *and correct it.*

Chief Constituents of Air.

65. Your various experiments have already informed you of the two chief constituents of the air, viz., oxygen and nitrogen.

Rain, dew, snow, hail, and the rapid evaporation of water from wet surfaces suggest that water must also be a constituent of the air.

To Verify the Presence of Water in Air.

Take a small flask, rub it quite dry on the outside, put in it some ammonium chloride, and add a little water, or put a mixture of ice and salt in it, and examine its appearance.

State your result, and compare it with 65, p. 93.

66. To examine the Air for Carbonic Acid Gas (Fig. 19).—In Experiment 16, Chapter III., one of the products of the combustion of a candle was a gas which turned a solution of slaked lime (lime-water) milky. You were told that this gas was called carbonic acid gas. As it is produced when some things burn—a candle, for example—it is not unlikely that it may be present in the air.

By a cork *C* fit two narrow tubes 1, 2 to a test-tube *A*, and fill the tube to the level *L* with lime-water. Join the end of 2 by an india-rubber tube at *X* to the narrow glass tube *T*, which is fixed by a cork to the bottle *B*. *B* must have two necks *H J*, and its capacity may be two or three litres; but a smaller bottle may be employed if you have none so large, for it can be detached and refilled several times. *B* must also have a tube fixed by a cork into the neck *J*; and this tube should have a piece of india-rubber tube with a clip *D* upon it.

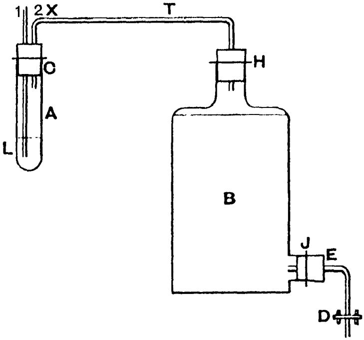

FIG. 19.

Close the clip *D*. Fill *B* with water by the neck *H*, and fix the cork holding the tube *T* to *H*.

Open the clip carefully, that water may flow from

B, then air will enter through *T*, first passing through the lime-water in *A*.[1] Adjust the stream of water flowing from *D*, so that the bubbles can be counted as they pass through the lime-water.

State the result of your experiment, and call attention to any indication that the amount of carbonic acid gas found, if any, is great or small. Then compare your account with 66, p. 94.

67. To learn whether the Oxide of Carbon is identical with Carbonic Acid Gas.—In Experiment 34, Chapter V., you found that carbon (charcoal) when burnt gave an oxide which, when dissolved in water, yielded an acid. The name carbonic acid gas may perhaps already have suggested to you that the acid gas obtained by burning carbon is probably the same substance as the carbonic acid gas of burning candles.

Test the gas from burning carbon to find if this is the case. 34 will perhaps suggest a method, if you cannot think of one without assistance. *Compare your work with* 67, p. 94, *and correct your account if necessary.*

68. To test your Breath for Carbonic Acid Gas.—As breathing is a process necessary for the maintenance of life, it is possible, by finding whether the air we give out is different in any respect from that which we take in, to get some knowledge of the chemistry of the life of a human being. Arrange an experiment to find if there is more carbonic acid gas in the air given out by your lungs than in the air before you inhale it in breathing.

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[1] A bottle fitted up like *B* is frequently used for drawing air through other apparatus. Such an arrangement is called an *aspirator*. If its capacity is found by measuring water into it to a mark on the neck, we can tell what quantity of air is used in any operation, provided that the apparatus is air-tight.

NOTE THAT—it will be sufficient for the purpose if you find that the air in one case renders lime-water turbid much more quickly than in the other. For you will remember, that in the experiment by which you found that air contains carbonic acid gas, you had to pass a great quantity of air through your lime-water in order to get any effect. If the air had been richer in carbonic acid gas, its effect would have been more quickly apparent. The result of such an experiment is not trustworthy, however, except when the differences to be detected are very considerable. *Compare your results with* 68, p. 94, *as usual.*

69. To find if Plants give out any Gas, and if so, to find what the Gas is.—The following experiment is not always easy to carry out in a short time, especially in dull weather; therefore you may not be able to do it in your class-work. In that case you can do it easily enough at home or in your study.

Take a piece of some green plant with two or three leaves—a sprig of mint or peppermint will do as well as anything—place it in a tumbler of water, and bring the tumbler into bright sunlight if possible, or at least into the brightest daylight available; notice what happens, and, with the help of further experiments, find out whether plants give off gases, like animals, and, in case they do so, find out what the gas they emit is. To simplify the problem, you may assume there is only one gas, if you find that any gas is given off.

70. The Usefulness of Plants and Animals to each other.—The experiments you have last made will have shown you that plants and men act oppositely on the air.

Human beings take in oxygen and give off carbonic acid gas, which is formed by the carbon in their bodies combining with the oxygen taken in from the air. It is found that all animals are like human beings in this respect: they give off carbonic acid gas in breathing.

Plants, on the other hand, you have found, give out oxygen gas. It has been discovered that in sunlight the green parts of plants decompose the carbonic acid gas of the air. The oxygen they give off again, as your experiment showed you The carbon is assimilated by the plants. So that plants get at least part of their food from the air.

From these facts it is plain that animals and plants counteract the effects of each other on the atmosphere. Each class fits it for the use of the other. Animals require a supply of oxygen, and are constantly reducing the proportion of that constituent present in the air. They produce carbonic acid gas in their bodies,[1] and by expelling it into the air, are constantly increasing the amount of it there. It has been found that when the proportion of carbonic acid gas rises very much above that which is usually present, air becomes unfit to support animal life. So that animals tend to reduce the proportion of oxygen, which is a necessary for them, and to increase the proportion of carbonic acid gas, which is bad for them, but necessary for plant life.

Plants, on the other hand, tend to increase the proportion of oxygen in the air, and thus minister to the needs of animals. They are using up the supplies of carbonic acid gas, and thus are constantly reducing the proportion present, which also helps to keep the air fit for the use of animals.

It is believed that it is owing to these opposite actions that the proportions of carbonic acid gas and oxygen in the air vary very little, or not at all. But it must be

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[1] See "Physiology Primer," by Professor Michael Foster.

remembered that carbonic acid gas is not only produced by animal life; it is, as you have learnt from your own experiments, produced also by the combustion of carbon (coal is chiefly carbon), and of compounds containing carbon; for example, candles. What we call decay—the rotting away of dead bodies of animals, and of the various parts of plants—is also a carbonic acid gas producing action. For in this process of decay the carbon of the decaying material slowly enters into combination with the oxygen of the air, producing carbonic acid gas. When you think of the quantity of coal and wood burnt on the globe every year, and of the vast amount of vegetable matter left to decay year by year, you will realise that the amount of carbonic acid gas added to the air from these sources must be prodigious.

CHAPTER X.

RELATIONS BETWEEN SOLIDS, LIQUIDS, GASES.

71. To examine the Relations of Ice, Water, and Steam to each other.

Take a lump of ice weighing about half a pound, break it into small pieces. Put them in a glass beaker, and immerse the bulb of a thermometer in the ice. Place the beaker of ice in a warm place, *e.g.*, near a fire, near the drying-oven, but not directly over a naked flame. For want of a better place, you might stand it on a tray of sand, which is placed above a very slight flame, however. Keep the ice and water thoroughly mixed by moving the thermometer constantly during your experiment.

Watch the thermometer, taking note of the temperature indicated at intervals of one, two, or three minutes, so that you make at least half a dozen observations before all the ice melts.

When all the ice has melted, and the temperature has risen two or three degrees above 0°C., place your beaker on a piece of wire gauze over a small flame, and continue to watch and record the temperatures at short intervals of time. Increase the heat applied by degrees, so that the water shall boil within a reasonable period. Continue to make observations of temperature as long after boiling has commenced as may seem wise to you.

Record your observations in two columns, giving the temperatures in one column, and the time at which each observation was made in the other.

If you can do so, explain your results; if not, after assuring yourself of their substantial accuracy, read carefully the explanations given in 71, p. 97.

72. *Problem.*—If 5 grams of water at a temperature of 100°C. are added to 200 grams of cold water, say at 0°C.; and if 5 grams of water in the form of steam are passed into 200 grams of water at 0°C., which will heat the cold water most? In answering this, guide yourself by results of the previous experiment. *For solution see* 72, p. 98.

73. *Problem.*—Find by experiment if steam is a better source of heat than boiling water. *Compare your result with* 73, p. 98.

74. Many other substances resemble water in existing as solid, liquid, and gas; and it is always found that the change of a solid into a liquid, and of a liquid into gas, is accompanied by the disappearance of a quantity of heat, which can be recovered again on reversing the change.

(*a.*) Try if the following liquids will turn into gases, and at what temperature:—Chloroform, acetic acid.

(*b.*) Try if wax and fusible metal will change into liquids, and at what temperatures.

(*c.*) Try if iodine will change when heated.

In each case compare your result with 74, p. 99, *before proceeding.*

75. The Usefulness of Boiling-points and Melting-points to Chemists.—It will interest you to know that pure chemical substances have fixed temperatures, at which they boil, if they are liquids, or melt, if solids, provided that they do melt or boil, for some do not. And that often these melting-points and boiling-points enable us to know if things are pure or impure.

Thus, chloroform, if pure, boils at 61°C. If I had some sold to me which boiled at 55°C., I should know it was not a good article.

Again, if I met with a colourless, tasteless, odourless liquid, which reminded me of water, and found it boiled not at 100°C., but at some higher or lower temperature, I should not believe it to be water. And if I wanted to drink it, I should be very cautious and try small quantities at first. On the other hand, I should know a colourless solid melting at 0°C., or a colourless liquid freezing at 0°C., to be ice or water.

76. Have Gases Weight?—That gases, such as water-gas (steam), have weight, is obvious. A pound of water will, of course, produce a pound of steam. But in the case of gases like hydrogen or common air their weight is less obvious, and deserves some examination.

(*a.*) Can you remember any experiment which proves that any gas, say air, or oxygen, or nitrogen, has sensible weight. *See* 76 (*a.*), p. 101.

(*b.*) Invent, if you can, an experiment for weighing air; if not, consult 76 (*b.*), p. 101.

Compare each result with 76, p. 101, *before proceeding.*

(*c.*) Find the weight of 1000 c.c. of air by the same apparatus as that described in Section II. for finding whether air has weight.

You will learn by-and-by that the volumes occupied by gases vary very much, according to changes of temperature and of pressure. This is a subject with which you will become acquainted in the course of your studies in physics. You must remember, however, that the calculations you have made are therefore only approximately correct. The experiments were introduced chiefly to familiarise you with the fact that the gaseous form of matter is closely related to the solid and liquid forms, and that gases, like solids and liquids, have weight. The studies of chemists have carried our knowledge of the connection between gases and liquids so far, that even the air could now be changed into a liquid by suitable application of cold and compression.

77. Preparation of Pure Water.—The preparation of pure water from ordinary water is a good example of the manner in which we take advantage of changes of physical state in chemistry.

Rain-water, which condenses from the air, is comparatively pure, though it contains dissolved air and a very little dissolved solid matter. But spring-water, which has washed the earth, is sure to be impure.

Evaporate some tap-water in a basin; you will find a solid residue. It consists of several substances which the water has dissolved out of the soil through which it has passed. Sea-water is a very good example of water with dissolved solids in it. And most of the mineral waters used as medicines contain notable quantities of solids dissolved in them.

Suggest a means of getting pure water from sea-water or tap-water, and compare your plan with that in 77, p. 103, which you are to carry out.

78. Show that distilled water is free from dissolved solids. Do this by some method of your own, if you possibly can. *Then compare with* 78, p. 103, *and correct your method or results.*

79. Explain the principle of the process of distilling, and compare your remarks with those at 79, p. 103.

CHAPTER XI.

ACTION OF COMPOUNDS ON COMPOUNDS—SEPARATION OF THE CONSTITUENTS OF MIXTURES FROM EACH OTHER.

80. Action of Compounds on each other.—In the action of copper on nitrate of mercury, and in the substitution of zinc for hydrogen when that metal acts on hydrochloric and other acids, you have had instances of the separation of one of the constituent elements of a compound body, and its replacement by another element.

You will deal with an analogous but more complicated kind of change in the experiments which follow.

Take a little bichloride of mercury, dissolve it in water by warming.

Take a little iodide of potassium and dissolve it also in water.

Use about five parts of the chloride to six of the iodide.

Add the solution of iodide of potassium, drop by drop, to the solution of mercury bichloride.

Collect the precipitate on filter paper,[1] dry it, and heat some of it in a small test-tube. From its red colour, and from its subliming into yellow crystals which turn red when touched after becoming cold, you should be able to say what this substance is. (See 45, p. 39.) And you may assure yourself of the presence of iodine and mercury in it by the following experiments:—

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[1] Preserve the liquid that runs through the filter.

(*a*.) Place a little of the precipitate in a test-tube, add a drop or two of strong nitric acid, warm slightly, dilute with several times its volume of water, drop in a bit of bright copper, and observe the result.

(*b*.) Heat a little of the supposed iodine compound with strong sulphuric acid and a grain or so of manganese dioxide, and observe the result.

Since chloride of mercury and iodide of potassium produce iodide of mercury, it seems to follow that the other two elements—the potassium and chlorine—have also combined, forming potassium chloride, which is the white salt that was left in your tube when you decomposed chlorate of potassium by heat (p. 39).

Test this hypothesis by evaporating the liquid filtered from your iodide of mercury, and heating the residue strongly to drive away any quicksilver salt, in case the proportions of the chemicals you used were not properly adjusted. You will have a white solid residue, which consists of the salt in question. But as you do not yet know any tests for chloride of potassium, you cannot verify this statement.

81. Chemical Symbols and Equations.—You will understand what has happened in the above experiment better if it be expressed by chemical symbols.

The symbol Hg is used by chemists to indicate the metal mercury. Hg not only means mercury, but it means 200 parts of mercury.

Cl similarly means $35\frac{1}{2}$ parts of the element chlorine. In bichloride of mercury, 71 parts of chlorine are in union with 200 parts of mercury, and as 71 is $35\frac{1}{2} \times 2$, we express this by the *formula* $HgCl_2$, which means that 200 parts of mercury are united to twice $35\frac{1}{2}$ parts of chlorine.

The symbol for potassium is K; it indicates 39 parts of potassium; and the symbol for iodine is I, which indicates 127 parts of iodine. When iodine unites with potassium, 127 parts of the former combine with 39 parts of the latter; so writing K for 39 of potassium, and I for 127 of iodine, we get the formula KI for potassium iodide.

Two hundred parts of mercury combine with 127 × 2 parts of iodine in mercury iodide, so its formula is HgI_2, and the formula of chloride of potassium is KCl.

The values 39, 127, &c., express *the relative proportions* in which the elements combine. They may be read as ounces, grams, tons—any weight in fact—but the weight adopted must be used uniformly in any given case.

Thus 200 parts of mercury and 71 parts of chlorine may be taken to mean 200 grains of mercury and 71 grains of chlorine, but may not be taken to mean 200 grains of mercury and 71 pounds of chlorine. If the *combining value* of mercury is taken in grains, so must the value of chlorine be taken in grains. If that of mercury is in pounds, that of chlorine must be in pounds also.[1]

Summarising, we have:—

Iodide of potassium,	formula	KI.
Bichloride of mercury	,,	$HgCl_2$.
Iodide of mercury	,,	HgI_2.
Chloride of potassium	,,	KCl.

K	meaning	39	parts of	potassium.
Hg	,,	200	,,	mercury.
Cl	,,	35½	,,	chlorine.
I	,,	127	,,	iodine.

For convenience in your future work, it is well to mention here that the letter or letters, *e.g.*, H, which represent an element, are termed its *symbol*. Also that the

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[1] Hydrogen has the lowest combining value, so H is made to mean 1 part of hydrogen. The other numbers are based upon this.

weight indicated by the symbol is sometimes called the combining weight, and sometimes the atomic weight. The collections of symbols which represent compounds, *e.g.*, $HgCl_2$ (mercury bichloride), HgI_2 (mercury di-iodide), are termed *formulæ*, and the weights they represent are termed *molecular weights* or formulæ weights.[1]

The following calculation will explain how to find the molecular weight of mercury bichloride from its formula $HgCl_2$:—

$$\begin{array}{lr} Hg = & 200 \\ Cl_2 = (35\tfrac{1}{2} \times 2) = & 71 \\ \hline & 271 \end{array}$$

$HgCl_2$ means 271 parts by weight of mercury bichloride.

If, as before, + is taken to mean *added to*, and if = means *produce*, we may combine the formulæ given above in the following expression, which is called a chemical equation :—

$$HgCl_2 + 2\ KI = HgI_2 + 2\ KCl.$$

which may be read :—Mercury bichloride and potassium iodide produce mercury di-iodide and potassium chloride.

If we add the weights concerned, we have :—

$$\begin{array}{rr rr rr rr} & HgCl_2 + & & 2\ KI = & & HgI_2 + & & 2\ KCl. \\ & 200 & 39 \times 2 = & 78 & & 200 & 39 \times 2 = & 78 \\ 35{\cdot}5 \times 2 = & 71 & 127 \times 2 = & 254 & 127 \times 2 = & 254 & 35{\cdot}5 \times 2 = & 71 \\ \hline & 271 + & & 332 = & & 454 + & & 149 \end{array}$$

From which we learn that 271 parts by weight of mercury bichloride and 332 parts of potassium iodide produce 454 parts of mercury di-iodide and 149 parts of potassium chloride.

As 271 added to 332 = 603, and as 454 added to

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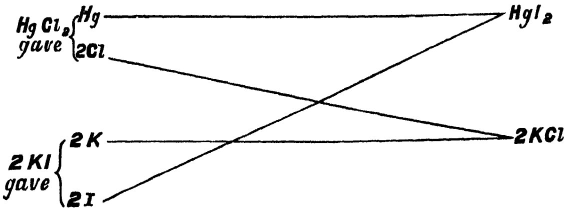
[1] **To understand the theory of this subject, you must refer to "Atomic Theory" in an elementary treatise on chemistry.**

149 = 603, we see that this change obeys the law of the indestructibility of matter; for the weight of the materials taken equals the total weight of the products.

You must remember that the various values which, like these, enable you to know beforehand exactly what proportion of each chemical to use, and what quantity of each of the products you will obtain, are not mere inventions, but are based on experiments. They are, so to speak, memoranda of the results of other people's work.[1]

Returning now to the results of your experiment. You found that the constituents of chloride of mercury and of the iodide of potassium rearranged themselves so that you had the iodine combined with the mercury, and the chlorine with the potassium. Both the compounds concerned may be imagined to have been broken into their constituent elements, which have rearranged themselves. The diagram given below will help you to realise this—



It indicates that the mercury of the mercury bichloride and the iodine of the potassium di-iodide have combined;

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[1] As it is no part of the object of this book to deal with chemical theories, it is not desirable to go further into the origin and meaning of this system of notation, nor of the various terms used, at present—the only object of its introduction here is to enable you to grasp more clearly the kind of chemical action which arises from such experiments as that which we are at present considering. Probably this application of it to your own experiments will help you to acquire a mastery of the system when it comes before you at a later stage of your education.

whilst the chlorine of the mercury bichloride and the potassium of the potassium di-iodide have also entered into combination.

This is called a *double decomposition.* Recollect, however, that you have no direct evidence that this term properly expresses the action that occurs, and that it certainly does not properly express the final result.

82. In the previous lessons you have met with various cases of chemical action. With the aid of your notes make out a list of them, mentioning an example of each. Refer to 82, p. 104, to ascertain if your answer is correct.

83. Separations of the Components of Mixtures.

—In the last experiment you took advantage of the insolubility of iodide of mercury in water to separate it from the chloride of potassium, which is soluble in water. The following experiments will familiarise you with separations based on such physical differences.

At each stage compare your work with Part II., 83, *and correct, or, if really necessary, consult Part II. before you begin.*

(*a.*) Say how you would experiment to find if any substance was, or was not, soluble in water or other solvent.

(*b.*) Find if sand and iodine separately dissolve in spirit of wine, and then from your results see if there is any iodine in the substance A.

(*c.*) Find if sand and ammonium carbonate are volatile when heated.

(*c* 2.) Devise a plan for separating the sand from the ammonium carbonate in B.

(*d.*) Find how much sand there is in ten grams of the sugar C.

(*e.*) Make a strong solution of salt by shaking with cold water. Make a strong solution of salt by boiling with water. Strain off into two test-tubes, and let them stand till the hot solution is cool. Do the same with copper sulphate, and point out in what respects the results differ.

(*f.*) Using the information gained from the results of experiment (*e*), separate the copper sulphate from the mixture of copper sulphate and salt marked E.

(*g.*) Gunpowder contains charcoal, nitre, sulphur. Try to dissolve each substance by itself in water and then in carbon disulphide, stating your results.

(*h.*) Extract some sulphur and some nitre from the specimen of gunpowder marked G.

The experiments made in doing the above exercises will enable you to understand the methods by which chemists separate things from each other, when they are merely mixed, by taking advantage of differences in such properties as solubility,[1] volatility, &c., which are what are known as physical properties.

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[1] Recent discoveries lead one to regard solubility as a physical phenomenon, though cases of solubility are frequently complicated by chemical changes.

CHAPTER XII.

PREPARATION AND PROPERTIES OF CERTAIN IMPORTANT CHEMICALS.

84. In cases of combination, as, for example, when mercury and iodine unite and produce solid iodide of mercury, there is frequently no difficulty in securing the product in a fairly pure state. But in cases of what is called double decomposition, or in decompositions—in fact, whenever there are two or more products—we have to utilise differences in their physical properties in order to obtain either separately from the other.

In the questions and work that follow, you are to particularly notice the physical differences taken advantage of in writing your description of your work.

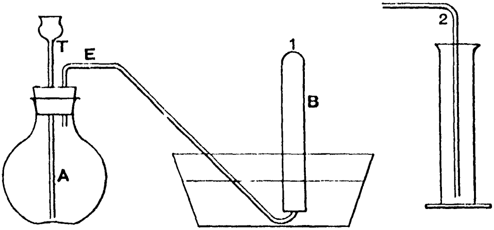

FIG. 20.

Hydrochloric acid.—The liquid you have used under the name of hydrochloric acid is really a solution of hydrochloric acid in water. The acid itself is made in the following way from salt:—Small fragments of salt, obtained by breaking the lumps formed by cooling down melted salt, are put in *A* (Fig. 20), then strong sulphuric acid is poured down the funnel tube *T*, and a little heat applied. When the air has been driven out, collect by any two of these methods:—

(*a.*) Over mercury in a tube, as in (1).

(*b.*) By simply putting the delivery-tube into a cylinder (as 2), and closing its mouth with some cotton wool or a sheet of paper.

(*c.*) By passing a rapid stream of the gas through water in a test-tube, which will not give you the acid itself, but a solution of it.

For obtaining the gas pure, method (*a*) will do best; but in ordinary cases method (*b*) will do.

Chemistry of the process.—Salt is a compound of the metal sodium and chlorine. Na is the symbol for sodium, and NaCl is the formula of sodium chloride.

Sulphuric acid is a compound of sulphur (S), oxygen, and hydrogen; its formula is H_2SO_4. When the acid has acted upon the salt, the products are: hydrochloric acid, which is a compound of hydrogen and chlorine (HCl), and sulphate of sodium (Na_2SO_4), which stays in the flask.

85. (*a.*) Say which kind of chemical action took place in the above experiment, giving an equation, if you can do so, with the help of the above formulæ, and compare with Part II., 85 (*a*).

(*b.*) Explain what physical properties of sodium sulphate and hydrochloric acid are utilised in making hydrochloric acid, and compare your account with Part II., 85 (*b*).

Make the following experiments with the hydrochloric acid. Report your results, explaining, if you can, what happens in each case. *Compare them in each case with* 85, *Part II., before proceeding.*

With the gas:—

(*c.*) Let some escape into the air.

(*d.*) Put a rod moistened with solution of ammonia in it.

(*e.*) Join a tube *A* (Fig. 21) containing a little piece of sodium, *C*, to the delivery-tube at *E* (Fig. 20), and let a slow stream of the acid pass over the metal, which you must warm gently. Ascertain what gas comes off at *B*, what the white residue is, and explain what has happened. Refer to Chap. VIII., No. 53, and Chap. V., No. 36, before attempting your explanation.

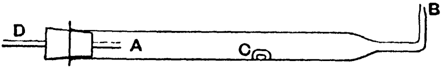

FIG. 21.

With the solution:—

(*f.*) Warm a little of the solution of the gas with manganese dioxide. Observe the colour and smell of the gas given off.

(*g.*) Examine the action of the solution on litmus and on alkalis; also its taste; and in any other way assure yourself that it is like the hydrochloric acid used in your early experiments.

86. To find if Hydrochloric Acid can be produced by combining Hydrogen and Chlorine.

Make some of the gas of Experiment (*f*) (chlorine) in a small flask fitted as for the preparation of hydrochloric acid; collect some in a jar by putting the delivery-tube in it and closing the mouth loosely with paper or cotton wool. Prepare a similar jar of hydrogen. Place the open mouths of the jars of hydrogen and chlorine together, removing the paper cover so that the gases may mix. Note if there is any sign of combination. If not, try to make them combine by lighting them, and observe if the gas produced agrees in any respects with hydrochloric acid. Write an equation for the combination of hydrogen and chlorine if you can, and *compare with* 86, p. 111.

87. Draw up an account of what you have learnt about hydrochloric acid. Point out any respect in which it is different from other acids. *Compare your results with what is given in Part II.*, 87, *and add anything you have omitted.*

88. Chemists sometimes speak of sulphuric acid as a stronger acid than hydrochloric acid, because it sets free hydrochloric acid when it acts upon chlorides, such as common salt, which is chloride of sodium. This property of sulphuric acid, however, appears to be due also to the fact that at the temperature of the experiment hydrochloric acid is a gas, and we find that other acids may also be prepared from their salts in the same way, if they are gases, or even if they are liquids which easily boil.

Thus nitric acid, which has the formula HNO_3,[1] can be produced from nitrate of sodium, $NaNO_3$, by acting upon it with strong sulphuric acid, nitric acid being practically a liquid which will boil at a moderate temperature.

Say what apparatus you will use for making nitric acid, and prepare some. Explain the process, as before, and give the equation if you can, *comparing your account with* 88, p. 112.

89. Carbonic acid gas can also be set free from its salts by other acids.

Prepare some carbonic acid gas from chalk, also from

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[1] What is usually called nitric acid is not represented properly by HNO_3, for there is a good deal of water as well as HNO_3 in it.

sodium carbonate. Prove that the gas is carbonic acid by the usual test, and explain what physical changes are taken advantage of in your experiment.

Prepare some carbonic acid from marble, shells, or lumps of the Clifton rock (all of which contain a compound of this gas, viz., carbonate of calcium) by acting on them with hydrochloric acid.

Collect the gas in jars (*a*) over water, (*b*) without the use of water or other liquid.

Examine its taste, smell, action on litmus solution, and its power of supporting combustion.

90. From these experiments you will have learnt that when we wish to obtain an acid from one of its salts, we may do so by making another acid act upon the salt, and taking advantage of physical differences between the new acid and the new salt to secure the substance wanted.

91. Examine the effect of passing a long-continued stream of the gas through lime-water. *Then see* p. 114.

92. Explain why carbonic acid gas does not support combustion, *and compare your answer with* 92, p. 115.

93. In the experiments just done, the acids have either been gases, or volatile when heated, so they have either come off as carbonic acid gas did, without heat, or they have been driven off by heat, as in the case of nitric acid.

Make a list of all the cases you can remember in which advantage is taken of the fact of one of the products being a gas, in order to separate it from the other. *See* 93, p. 115.

PART II.

CHAPTER III.

BURNING.

11. THERE should be a distinct gain of weight after burning, but probably somewhat less than is shown in the imaginary case set out in Part I.

12. If the experiment has been done skilfully, on opening the tube the water will have rushed into the tube, filling rather less than one-fourth of it. An exact measurement would show that one-fifth of the tube was filled with water.

13. Since the water fills the tube to the extent of one-fifth, we may infer that one-fifth of the air in the tube has been abstracted by the phosphorus, therefore we may believe air *is* taken up by phosphorus when burnt, and that the gain of weight observed in the combustion of magnesium was due to that substance taking up air. And we may further conclude that air, or some part of it, probably unites also with other things when they burn.

14. You will find that though rather different proportions of phosphorus have been used, every one has obtained nearly the same result as yourself, *i.e.*, in every experiment about four-fifths of the air remains over. If you are working by yourself, and repeat your experiment, but use, say, twice as much phosphorus as before, you will find that, notwithstanding that twice as much phosphorus might be expected to consume twice as much air, it leaves as much air in the tube as the smaller quantity did. Therefore you may conclude that although there is nothing in the appearance of air to suggest its compound nature, common air is composed of at least two things, and you may conclude that four-fifths of the air is a gas[1] which will not unite with phosphorus in burning (its name is *nitrogen*), and that one-fifth is a gas which does unite with phosphorus (its name is *oxygen*).

15. Nitrogen and oxygen could be distinguished by trying if phosphorus would burn in them.

17. If your apparatus is too large to weigh on your balance, you must construct a smaller one like it. Having cleaned and dried your apparatus, and cut off *C* just beyond the bend, fill *A* with small lumps of soda-lime, and place a little plug of cotton wool loosely above it at each end, to prevent the current of air from carrying any particles of soda-lime out of the tube. Weigh the whole arrangement, noting its weight in your note-book; then light the candle, replace it very quickly, and by means of a bit of india-rubber tube, previously fixed to *C*, suck air through as before. When a good part of the candle is burnt, stop the current of air and the candle will go out. Let the whole cool down thoroughly, and then weigh again. When your experiment is quite concluded, and you have written your account, see if it agrees with what follows:—(*a.*) as to showing a gain or loss of weight; (*b.*) as to the form in which you express your results.

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[1] You may understand the word gas to mean a substance not solid nor liquid, but still capable of resisting pressure, as air does. Common air is, as you have learnt, a mixture of two airs, or, as we call them, gases. This subject will be considered later more thoroughly.

Weight of apparatus and candle, with water and carbonic acid gas fixed by the soda-lime	.	26·2 grams
Weight of apparatus, candle, and soda-lime	.	25·1 ,,
Gain	. .	1·1 ,,

Showing that the water and carbonic acid gas produced from the burnt portion of the candle, which have been collected by the soda-lime, must weigh 1·1 gram more than the piece of candle burnt, because the apparatus cannot have altered.

NOTE.—In this and all other cases, if your results do not agree with those in the book, you must find out, by thinking over your work and referring to the instructions, in what respect you have not done your experiment properly, and then repeat it. In cases which are too difficult for you, consult the teacher.

21. The air will burn at the mouth of 2 so long as water is poured into *F*.

CHAPTER IV.

ELEMENTS, COMPOUNDS, CHEMICAL COMBINATION.

22. A GAS collects in *D* in some quantity, much more than could be due to the air in *A*. A glowing match-tip, when placed in this gas, bursts into flame. Therefore the gas allows things to burn in it (supports combustion), like the oxygen of the air. This suggests that *perhaps* it is oxygen, only purer than in air, because it is more active.

In *A* there are seen bright drops of quicksilver; there is also a shining ring of quicksilver about half-way up *A*, which easily runs into drops when rubbed with a glass rod or a bit of wood. *The weight of A with this quicksilver is less than that of A with the original red oxide of mercury.* **(Prove this.)**

Therefore mercury oxide must be compound, for when heated it gives quicksilver and also a gas resembling oxygen. It is composed of these two things, possibly also with others which you have not observed in your experiments; for you have not proved that the weight of the oxygen collected exactly corresponds to the loss that the mercury oxide has sustained.

24. (*a.*) In the case of the mixture, the magnet attracts the iron, leaving behind the sulphur.

(*b.*) The lens enables one to see particles of sulphur and particles of iron side by side.

(*c.*) As the powder settles, the iron, being the heavier substance, falls quickly, and forms the lower layer, the sulphur being above it, and for some time partly suspended in the water.

(*d.*) The iron remains untouched by the carbon disulphide; the sulphur dissolves in it. On standing, the liquid disappears, leaving a deposit of sulphur.

(*α.*) The magnet has no attraction for the product, except perhaps for some few stray particles of iron which have not entered into combination.

(*β.*) Seen with a lens, there is no evidence of sulphur and iron particles. The fragments seem all to be of the same kind.

(*γ.*) The whole settles together. There is no separation, except that the larger fragments fall sooner than the smaller.

(*δ.*) Nothing is extracted by the carbon disulphide, for when filtered into a dish it disappears and leaves little or no residue—certainly not more than is left by the original liquid.

25. (*a.*) The vapour will catch fire at the temperature of the warm rod.

(*b.*) The coal-gas will not catch fire at the temperature of the warm rod, nor at that of an iron rod which is below a red heat. But at the temperature of an intensely red-hot rod of iron the gas will catch fire. It also ignites on contact with a flame.

(*c.*) When the dry solids are mixed, there is no action. When water is put upon them, brisk action ensues, a gas being copiously evolved.

When the solutions are mixed, there is a similar result.

26. The results of Experiments (*a*) and (*b*) indicate that the temperatures at which chemical changes occur vary. The oxygen of the air will act upon carbon disulphide at a very moderate temperature, but it will not act upon coal-gas till a much higher temperature is reached. Therefore, in order to see if two substances will combine, or otherwise act upon each other, we must make experiments at various temperatures; and if there is no action at a low temperature, we must examine the effect of a higher temperature.

In connection with this, however, it must not be forgotten that heat breaks up some compounds, *e.g.*, mercury oxide (see p. 26), and that therefore things may be too hot as well as not hot enough to permit of their combining.

From Experiment (*c*) we see that whilst solid tartaric acid has no action on solid carbonate of soda, the presence of water will bring about an action between them. It is a very frequent experience in chemistry that two solids will not act chemically upon each other unless they are in solution, or unless they are heated to a sufficiently high temperature to melt one or both of them, or to bring one or both into the condition of gas. It is thought that this is because two solids do not really touch each other; that they do not come in contact, as a solid and a liquid, two liquids, or again, as a gas and a solid, or two gases do.

The action of the water in the experiment with tartaric acid and carbonate of soda was to enable their particles to come into sufficiently close contact for action to take place between them, by bringing them into a liquid state.

You will find in your subsequent experiments that frequently solutions of solids in water are employed, and not the solids themselves, on account of the fact that solids act upon each other, either not at all, or much less rapidly than when one or both of the acting bodies are in the liquid condition.

CHAPTER V.

ACIDS, ALKALIS, AND SALTS.

27. SUPPOSE that, in addition to vinegar, nitric acid, hydrochloric acid, sulphuric acid, acetic acid were taken. If your observations are correct, your table will stand thus :—

Acid taken.	Action on Red Litmus.	Action on Blue Litmus.
Vinegar . . .	None.	Turns it red.
Nitric acid . . .	"	" "
Hydrochloric acid .	"	" "
Sulphuric acid . .	"	" "
Acetic acid . . .	"	" "

28. The above results suggest that things which are called acids turn blue litmus solution red, and therefore that all substances which turn litmus red are acids. This is not perfectly correct, but it is sufficiently accurate for the present.

29.

Alkali taken.	Action on Red Litmus.	Action on Blue Litmus.
Quicklime . . .	Turns it blue.	None.
Slaked lime . . .	" "	"
Sodium hydroxide .	" "	"
Magnesium oxide .	" "	"
Ammonia . . .	" "	"

30. We may regard things which turn red litmus blue as alkalis. This is not perfectly correct, though it is a very convenient use of the term for the present, and your subsequent experience will show you when it is wrong.

31. (*a.*) Take some solution of red litmus in a small bottle, add to it drop by drop a dilute solution of sodium hydroxide till it turns blue, which will happen suddenly. The solution of sodium hydroxide must be very weak. The ordinary solution should be weakened for this purpose by adding about nine parts of water to one part of the alkaline solution.

(*b.*) Similarly put very dilute sulphuric or hydrochloric acid drop by drop into some blue litmus solution till the last drop reddens it.

If the solutions are properly made, the blue litmus ought to turn red when added to a solution of acid diluted with many times its volume of water; and the red litmus solution should turn blue when a few drops are added to, say, three or four drops of sodium hydroxide solution in a wine-glass of water.

32.

Name.	Taste.	Action on Blue Litmus.	Action on Red Litmus.
Hydrochloric acid .	Sour.	Turns it red.	None.
Nitric acid . .	,,	,, ,,	,,
Sulphuric acid . .	,,	,, ,,	,,
Sodium hydroxide .	Not sour.	None.	Turns it blue.
Quicklime . .	,,	,,	,, ,,
Slaked lime . .	,,	,,	,, ,,
Magnesium oxide .	,,	,,	,, ,,

From this table you will see that all the acids taste sour. The alkalis have a more or less biting taste that is not sour.

34.

Name.	Action on Red Litmus.	Action on Blue Litmus.
Oxide of sodium . .	Turns it blue.	None.
" potassium .	"	"
" magnesium .	"	"
" phosphorus .	None.	Turns it red.
" sulphur . .	"	"
" carbon . .	"	"

35. (*a.*) Acids, you have found, appear to turn blue litmus red, and to have a sour taste. They appear to be produced when oxides of non-metals, such as sulphur and phosphorus, are dissolved in water.

(*b.*) Alkalis, you have found, have a biting but not sour taste. They turn red litmus blue, and, so far as your experiments on magnesium, sodium, and potassium may be trusted, they are formed when metallic oxides are dissolved in water.

36. The substance prepared from hydrochloric acid and sodium hydroxide tastes exactly like common salt; it is neither sour, like acids, nor has it the taste of the alkalis. It is neutral to litmus, *i.e.*, it has no effect either on red or blue litmus solution.

Common salt, which has a similar taste, is also like this substance in having no effect on red or blue litmus.

37. The products of putting together the other pairs of acids and alkalis are all like the salt obtained by the action of hydrochloric acid and sodium hydroxide in their action on litmus and saline taste, and they are called **salts.**

Salts, so far as these experiments teach, therefore, are substances neutral to litmus, with a taste more or less closely resembling that of table-salt, and are produced when acids and alkalis are put together in such proportions that the products have no action on red or blue litmus.

38.

Acids.	Alkalis.	Salts
1. Sour taste.	Biting taste.	Cool taste, or taste like common salt.
2. Redden blue litmus.	No effect on blue litmus.	No effect on blue litmus.
3. No effect on red litmus.	Turn red litmus blue.	No effect on blue litmus.
4. Neutralise alkalis, forming salts.	Neutralise acids, forming salts.	
5. Formed when oxides made by burning non-metals are dissolved in water.	Formed when oxides of metals are dissolved in water.	Formed when acids are neutralised with alkalis.

CHAPTER VI.

A LAW OF CHEMICAL COMBINATION.

40. THE actual figures will depend on the strength of the strong hydrochloric acid used. This ought to contain not less than thirty parts of pure acid to seventy parts of water.

Your results should, however, agree, as the following agree, though you may not get quite such accurate results.

Suppose that—

(*a*.) 20 measures of acid solution were taken, and required $21\frac{4}{5}$ measures of the sodium hydroxide solution.

(*b*.) 20 measures of acid solution required 22 measures of the sodium hydroxide solution.

(*c*.) 10 measures of acid solution required $10\frac{4}{5}$ measures of sodium hydroxide solution.

(20 measures would have taken $10\frac{4}{5} \times 2 = 21\frac{3}{5}$ measures.)

(*d*.) 15 measures of acid solution required $16\frac{1}{2}$ measures of the sodium hydroxide solution.

(Then 10 would have required $16\frac{1}{2} \div \frac{2}{3} = 11$.
And 20 would have required 22.)

Thus 20 measures of the hydrochloric acid required $21\frac{4}{5}$ measures of sodium hydroxide solution in Experiment (*a*), 22 in Experiment (*b*), $21\frac{3}{5}$ in Experiment (*c*), and 22 in Experiment (*d*). That is, the proportion of alkali to acid required in forming salt is constant, if you allow for unavoidable errors in making the experiments.

In the two experiments in which you weigh the salt produced, you will find that the quantities of salt produced, if (*a*) and (*b*) are taken, will be practically equal; but that if the quantities of salt produced in the other experiments are weighed, they will be in proportion to the amounts of acid taken. You will obtain only half as much salt from (*c*) as from the quantities used in (*a*) or (*b*).

42. Take a hard glass tube, weigh it, introduce a little oxide of silver (1·0 gram), then heat it, cautiously at first, finally as strongly as possible, keeping the tube in a nearly horizontal position; when white silver remains, cool and weigh the tube with the silver, and calculate what weight of silver you have obtained from 1·0 gram of the oxide.

Repeat this experiment exactly in every respect, but use another specimen of silver oxide. Write down what the two results, taken together, appear to indicate. Then compare with the following:—

If you have done the experiments carefully, you will get ·93 gram of silver from 1·0 gram of the oxide in each case. But in practice, if you find either ·92 or ·93 or ·94 gram of silver, it will be good work.

These results show that both specimens of silver oxide contain the same amount of silver in proportion to oxygen, *i.e.*, the composition of silver oxide appears to be constant.

43. One learns from Experiment 40 that any fixed quantity of hydrochloric acid requires a constant quantity of sodium hydroxide to neutralise it in forming salt, and that if the quantity of acid taken is less in any proportion, the quantity of alkali required is less in exactly the same proportion. And by drying and weighing the salt produced from equal quantities of acid and alkali, we find that the amount of salt produced is in proportion to the acid and alkali used. From which we may infer that probably the composition of common salt is constant, as the same weight of the salt comes from the same quantities of the same acid and alkali. It has not been shown, however, that the salt was the only product in this case, and in fact it is not the only product.

Similarly, Experiment 42 indicates that silver oxide has constant composition. In this case you may be even more certain than in the other, as you found equal weights of silver in equal quantities of oxide by direct experiment.

CHAPTER VII.

CLASSIFICATION OF CHEMICAL CHANGES.

45. The iodine is in metallic-looking fragments; it has a faint odour; when heated, it gives off violet fumes until it has all disappeared. The fumes condense in bright particles on the cool upper part of the tube. (*This is termed subliming.*)

Quicksilver is a bright, white, heavy liquid, which, when heated, boils; it condenses upon the cool upper part of the tube in tiny drops, which through a lens are seen to be quicksilver. It boils, in fact, like water, giving off quicksilver steam, which condenses again to liquid quicksilver, just as steam condenses to water.

When rubbed with iodine and spirit for some time till dry, the drops of quicksilver disappear, and the iodine also is no longer separately visible, even with the aid of a lens. Instead of the mercury and iodine taken, there is a dullish-red powder. This suggests that these two have **combined** and produced a new substance (*iodide of mercury*). To test this, see if it has any of the properties of iodine or mercury; for example, you will find that when heated in a tube it gives little or no violet fume, if it has been well mixed; that it will not give a sublimate of glittering crystals of iodine, nor any drops of liquid quicksilver. But it sublimes in crystals, which are yellow at first, and afterwards turn red. Again, the product when put into chloroform will not dissolve, as iodine does. It will remain quite unacted on by the chloroform. If a little iodine should remain in the free state, which is possible, this will dissolve; but the residue, when treated with pure chloroform, will be unattacked. Again, it is not liquid, and has not the bright metallic appearance or other characters of mercury. Since, then, the product is quite different from both mercury and iodine, it is evident that the new body is a chemical compound of the mercury and iodine.

46. (*a.*) The solid first melts, then seems to boil, giving off a gas which is probably oxygen, because it has no taste nor smell nor colour, and causes a glowing match to burst into flame, as oxygen gas did in a former experiment After a while a residue of white solid remains, which will give off no more gas. This, when dissolved in water, gives a white precipitate with a solution of silver nitrate in water. As the original chlorate does not give any precipitate with solution of silver nitrate, the residue left, after driving off the oxygen by heat, is evidently a new body. (Its name is chloride of potassium.) So that heat has split the chlorate of potassium into two new things, chloride of potassium and oxygen gas.

(*b.*) The chemical change in this case is exactly the reverse of that in the experiment with iodine and mercury. The iodine and mercury **combined to form a single new substance.** Potassium chlorate, on the other hand, **was broken up by heat into two simpler bodies.** The attraction between its parts was overcome by the action of the heat.

48. The copper becomes silver-like when in the mercurial solution. When dried and heated in a test-tube, the mercury is driven from the copper and condenses in tiny drops on the cold upper part of the tube. If these droplets are rubbed with a bit of wood, they run together into larger drops.

49. You will find that, as before, quicksilver is deposited on the copper; and if, when a good deal of the quicksilver has been deposited, you pour off the solution into another test-tube and test for copper with solution of ammonia, you will find that the ammonia produces a fine blue colouration, showing that some of the copper has taken the place of the mercury in the solution.

50. You have met with three modes of chemical action.

(*a.*) The union of simple things to form more complex things, as in the combination of iodine and quicksilver, and in burning. This is chemical combination (*synthesis*).

(*b.*) The separation of compound things into more simple things, as in the separation of oxygen and chloride of potassium from chlorate of potassium by heating, and in the decomposition of mercury oxide by heat (p. 26). When decomposition can be carried no further, the products are called *elements*. Thus the oxygen produced in this case is an element, for it cannot be further split up. But the chloride of potassium is not an element, for it can be separated into simpler substances.

(*c.*) The replacement of one element in a compound by another, as in the last experiment, where copper and nitrate of mercury *produce* mercury and nitrate of copper, the two metals changing places. This is called *substitution*—the copper being substituted for the mercury in the compound.

51. The red phosphorus is a dark opaque powder, without odour, not easily ignited, insoluble in sulphide of carbon, and in oil, and not visible in the dark. Common phosphorus, on the other hand, is a translucent, wax-like solid, soluble in carbon disulphide. It is visible in the dark. It ignites when touched with a slightly warm rod, and, in short, is in many respects quite unlike phosphorus.

52. After heating red phosphorus you will find on the sides of the test-tube an incrustation consisting of a soft, transparent solid, which exactly resembles common phos phorus. It is luminous in the dark. It readily ignites at a low temperature, and is soluble in carbon disulphide. It has, indeed, all the properties of common phosphorus, and is exceedingly unlike red phosphorus in many respects. Yet it was made from red phosphorus by the influence of heat alone, and can therefore contain no other element than that of which red phosphorus is composed. The two things, though so different in their qualities, are yet mutually convertible the one into the other. They are evidently *allotropic* forms of the element phosphorus.

CHAPTER VIII.

HYDROGEN AND WATER.

53. BUBBLES are given off at the surface of the zinc, and rise through the liquid, giving it the appearance of boiling. The gas is free from colour, and has not much taste or smell.[1] A glowing match thrust into it is extinguished, so it does not support combustion. If a lighted match is brought near the gas, however, it catches fire, and burns with a flame that gives little or no light. This gas is hydrogen.

54. As all the zinc disappears except a few black flakes of a substance not at all like zinc (these are due to impurities in the zinc), and hydrogen is produced, and as zinc is one of the elements, and therefore cannot contain hydrogen, it appears that hydrogen is a part of the acid, and that it is turned out of the acid by the zinc. So this is a case of *substitution.*

55. When a light is brought to the gas it explodes with a very high note. When the experiment is repeated, if *C* (Fig. 14) be nearly as capacious as *A*, the gas will burn quietly from the mouth downwards with a pale blue flame, but if *A* be more capacious than *C*, it may very likely explode again, only with less violence.

The explanation of this is that hydrogen gas, like wax, magnesium, and other combustibles, requires oxygen for combustion. The gas which first comes off is an intimate

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[1] It will have no taste nor smell if made from pure zinc and acid.

mixture of hydrogen with some of the air originally in *A*; this mixture contains all that is necessary for combustion, which takes place, therefore, suddenly throughout the whole mass of gas; hence the explosion. In the later experiment, when the gas gave a very slight explosion at the mouth of the jar, and then burnt quietly with a pale flame running down the jar, there was pure or nearly pure hydrogen, which could only burn at its surface as the air reached it.

56. Fill two jars with hydrogen gas, hold one of them mouth downwards with its lid off for half a minute. In order to keep it steady, a good plan is to let the edge of the jar touch the table at one point, but not all round. Then bring a light to its mouth. The gas will explode, showing that hydrogen is not heavier than air; for if heavier, it would have fallen out of the jar. Place the second cylinder mouth upwards without its lid for the same length of time—a good plan is to do both experiments at once—then bring a light to it, as before; no explosion or action will follow, for all the hydrogen will have escaped. Therefore hydrogen is lighter than air, for it has risen into the air from an open jar.

If you try, you will find that you can collect hydrogen in a jar without a basin of water, by putting the delivery-tube into the jar held with its mouth downwards. This is *upwards displacement* of air. Much of the gas is lost, but the method is sometimes used.

59. Unless you have your litmus too delicate, so that the trace of acid still adhering to the crystals (which it is not easy to get rid of completely) turns it red, you will find that these crystals are neutral to litmus, therefore you may class the substance as a salt.[1] So that a salt can

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[1] All neutral bodies are not salts. But a neutral body produced in this way may be taken to be a salt.

be made by a metal turning out the hydrogen of an acid and taking its place, as well as by neutralising an alkali with an acid. Note that in this case a metal acts on the acid instead of the oxide produced by burning a metal. The methods are, therefore, related to each other.

60. (*a.*) Fill one of your measuring cylinders with water. And after emptying *A*, pour in water from the measure till it just reaches the mark. That is, till it just occupies the space previously occupied by the hydrogen. Then observe how much water has been removed from the measure, and you will know what volume of hydrogen there was in the tube.

(*b.*) Your results should agree closely; each should give 69 *c.c.* of hydrogen, *i.e.*, in each case ·2 gram of zinc will have taken the place of 69 *c.c.* by measure of hydrogen gas.[1] This seems to be a new case of the Law of Constants. You have found that equal weights of the same metal (zinc) replace equal measures of hydrogen when acting upon different acids, just as previously you found that substances act on each other to form new compounds in constant proportions.

If this holds good in other cases of replacement, the law of constant proportions may be expressed thus:—

The proportions in which any two elements will combine with each other to form the same compound, or replace each other, are constant.

63. In the apparatus of Fig. 18 *G* serves to dry the gas before it enters *F*, so that no water from either of the gases used shall enter the apparatus and confuse your results. If, after oxidising the copper in *F*, the tube and oxide of copper are cooled and weighed, and if the tube

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[1] Whether you obtain 69 *c.c.*, or rather more or less, will depend upon the purity of the zinc you have. If possible, you should get a little pure zinc.

and the copper left in it are again weighed after the hydrogen has robbed the copper oxide of its oxygen, you will know how much oxygen has been yielded by the copper oxide to the hydrogen.

To find how much water this oxygen will yield, put some soda-lime, which you know to be a good absorbent of water, in *L*. Weigh the tube of soda-lime, and use it, instead of the plain tube, in the experiment in which you find the loss of oxygen from the copper oxide in *F*. At the end of the experiment weigh *L*, after drying the outside of it. The gain of weight will give the amount of water produced by the oxygen given up by the copper oxide and the hydrogen it has combined with.

As water contains only oxygen and hydrogen, if you deduct the weight of oxygen used from the weight of the water formed, you will have the amount of hydrogen in the water.

If two or three experiments are made, and the mean result is calculated, you will find there is about eight times as much of oxygen by weight as of hydrogen in water.

CHAPTER IX.

AIR, ITS COMPOSITION AND USES.

64. (*a.*) OXYGEN is the part of the air which combines with other substances when they burn in air.

It is made—

(*a.*) By heating oxide of mercury.

(*b.*) By heating chlorate of potassium.

It can be collected in jars over water, therefore it does not dissolve in water.

It has no colour, taste, nor smell.

Things burn in it very brightly, forming oxides.

Facts about the compounds of oxygen :—

The oxides of metals turn red litmus solution blue.

The oxides of non-metals turn blue litmus solution red.

Water is an oxide of hydrogen.

64. (*b.*) One knows that air can be divided into two parts by burning phosphorus in it. There is the oxygen, which combines with the phosphorus, and the residue, which is chiefly composed of nitrogen.

Nitrogen must be a very inactive gas, for it takes no part in burning except to weaken the effect of the oxygen, which supports combustion less in air than when pure. As air is without taste, smell, or colour, and does not dissolve in water, it seems likely that nitrogen, which makes four-fifths of the air, is colourless, tasteless, odourless, and insoluble in water.

65. The flask will quickly be coated with dew, or, in case the room or place you work in is cold, with ice. That the liquid really is water you must prove by the copper sulphate test. If you touch the flask you will find that it is quite cold. The low temperature of the flask is caused by the solution of the solid ammonium chloride in the water, and the dew condensed on the outside of the flask must consist of water condensed from the state of steam in the air.

66. At first you will notice nothing, but after a time the lime-water will become turbid, showing that there is some carbonic acid gas in the air. As the precipitate forms very gradually, however, we may infer that the quantity is not great.

It has been found that it does not amount to more than one or two parts of carbonic acid gas in five thousand parts of air. This expressed in figures shows that $\frac{1}{5000}$ or $\frac{2}{5000}$ of air is carbonic acid gas.

67. Place a piece of charcoal in one of the spoons used in 34, Chapter V., fixing the charcoal in its place by a wire if necessary. Put a little lime-water in the bottom of a cylinder. Light the carbon by holding it in a flame. When it is lighted, place it above the lime-water in the cylinder, and let it burn there for a few minutes; remove it, place a ground-glass cover over the mouth of the cylinder, and shake up so as to wash the air in the cylinder well with the lime-water.

The lime-water will be rendered turbid, as in previous experiments in which carbonic acid gas has acted on lime-water. Therefore carbon in burning produces carbonic acid gas.

68. Take the test-tube fitted up as Fig. 22. Put a little lime-water in it so that it may come above the level of the end of *A*.

(1.) *Draw* air through *B*, taking care that no moisture gets into the tube from your mouth. If no turbidity is observed in the lime-water in half a minute or so, stop. If turbidity is observed, note what time elapsed before it first becomes visible.

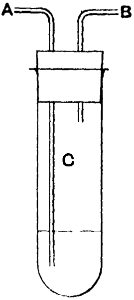

FIG. 22.

(2.) Blow air from your lungs through *A* in a gentle stream, and note how soon the air turns the lime-water milky. You will find that it does so almost directly, whilst air does not have any effect for a long while. Therefore the air you give out from your lungs contains more carbonic acid gas than the air you take in, so that you produce oxide of carbon in your body. As carbon when burning gives out heat, you may infer that either partly or altogether the temperature of your body is kept up by the union of the carbon of your body (which is derived from your food) with the oxygen of the air which you inhale.

69. If you watch the leaves under the water, you will observe that small bubbles form on the leaves, more particularly on their undersides. They gradually grow, detach themselves, and rise to the surface, quite a steady, though a very slow, stream of them. Fill a small test-tube with water, and close it with your thumb, and place it mouth downwards in the tumbler of water. You will be able to collect these bubbles if you notice which are about to rise, and have the collecting-tube ready for them at the right moment. To find what gas it is, you may try any tests you know of when you have partly filled your tube with it. When you have nothing to guide you in selecting your tests, but have to select one at a hazard, it is best to begin with the easiest tests. For instance, to place a glowing match in the gas. If you do this, you will find that the gas you have collected is oxygen—at least, that it is a gas which, like oxygen, causes the glowing piece of wood to burst into flame. For the

present you may conveniently take this quality as a sufficient indication that the gas is oxygen.

If you close the tube quickly after testing the gas with a glowing match—which you may do by fixing the match to a cork, and closing the tube, not too tightly, with the cork immediately after the match enters the tube—there will be carbonic acid gas left in the tube, after the match has ceased to burn, in case there was oxygen there. By adding a little lime-water after the match and tube have cooled down, closing the tube with your finger, and agitating it so as to bring the gas and lime-water well into contact, you will be able to detect carbonic acid, and so assure yourself of the nature of the gas from your plant. Carbonic acid gas is a compound of carbon and oxygen. The charred match-tip consists of carbon, which can only form carbonic acid by combining with oxygen, so that oxygen was the gas supplied by the plant.

CHAPTER X.

SOLIDS, LIQUIDS, GASES.

71. YOUR results should be such as are given in the following table. The exact temperatures at which ice is found to melt and water to boil will not be quite the same as those given perhaps, for thermometers are rarely made which give temperatures quite accurately :—

I. Time.	II. Temp.	
11·0 a.m.	0°C.	
11·5 ,,	0°C.	
11·10 ,,	0°C.	
11·15 ,,	0°C.	
11·20 ,,	0·5° or ½°C.	Very little ice left.
11·25 ,	1·0°C.	,, ,,
11·30 ,,	2·0°C.	
11·35 ,,	3·0°C.	The rise of temperature will only proceed at an increasing rate if you turn up the gas a little every few minutes.
11·40 ,,	5·0°C.	
11·45 ,,	10·0°C.	
11·50 ,,	20·0°C.	
11·55 ,,	40·0°C.	
12·0 ,,	70 0°C.	
12·5 ,,	100·0°C.	Water boiling all this time.
12·10 ,,	100·0°C.	
12·15 ,,	100·0°C.	
12·20 ,,	100·0°C.	
12·25 ,,	100·0°C.	
12·30 ,,	100·0°C.	

Or the table may indicate the periods of time allowed to elapse between the separate observations, *e.g.*, after five minutes, after ten minutes, after fifteen minutes, and so on.

Explanation (*a*.) So long as any quantity of ice remained in the beaker the thermometer did not rise.[1] The temperature began to rise, however, so soon as all the ice was gone, and continued to do so till it reached 100°C. The explanation must be that the heat you were supplying to the melting ice was used up in melting the ice instead of heating it. Ice in melting seems to take up heat.

(*b*.) You will also have observed that during the change of water into steam the thermometer kept steadily at 100°C. (or some temperature near to that, according to the accuracy of your thermometer). As you had a considerable flame supplying heat to the water, it appears that the change of water into steam is also accompanied by a considerable absorption of heat.

72. The answer depends on this: is the heat that is lost when water is converted into steam reproduced when the steam, on passing into cold water, is condensed again? If so, the steam will have the most effect, as it will supply as much heat as water at 100°C., plus the heat absorbed during its change into steam.

73. *To find if it is correct that steam, though at the same temperature as boiling water, is a better source of heat.*

This can be done by taking a tube fitted up like *A* in Fig. 18, p. 48, with some water in it, driving steam from *A* into 200 grams of water at 0°C. in a beaker, and noting the rise of temperature. The weight of the whole being known, the amount of steam added is found by weighing

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[1] Unless you are very skilful, it is probable that when only a few small lumps of ice remain the thermometer will begin to rise gradually.

the beaker of water again after the experiment, and a simple calculation will show what temperature would be produced by 5 grams of steam.

To find the effect of 5 grams of water at 100°C. Take a tube with water in it, heat it to boiling; then add some of it, stirring well, to a beaker containing 200 grams of water at 0°C., the total weight of which has been noted Re-weigh the vessel after the addition of the hot water, and from the rise of temperature and gain of weight produced calculate the effect that 5 grams of water at 100°C. would have.

As it is some trouble to weigh water at 0°C., for it collects dew, weigh it at ordinary temperature, then cool down by surrounding the vessel with ice. Or use the water at ordinary temperature, for it is only necessary to notice the *difference* between the final temperature and the initial temperature.

There are certain sources of error in this method of working. But as a means of assuring yourself that a great deal of heat is taken up by water when it is changed into steam it is sufficient.

Your results ought to show that the effect of 5 grams of steam is about six times as great as the effect of 5 grams of water at 100° C.

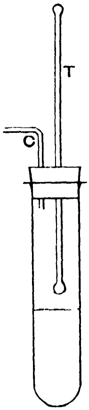

FIG. 23.

74. (*a.*) (Fig. 23.) To try both substances with one apparatus, arrange a test-tube with a cork carrying a thermometer *T*, and a tube *C* to let off the steam. The bulb of *T* should be, as in the diagram, above the liquid, for the temperature of a vapour is slightly more constant than that of its liquid.

Results:—

The chloroform will boil and give off vapour. Continue watching till the thermometer gets as hot as the vapour, which will have occurred when the mercury ceases to rise, and you will find that its boiling-point is 61°C.

Similarly you will find that acetic acid changes into steam, or gas, at a fixed temperature. But what that temperature is depends on the quality of the acid. Your teacher, who will know what acid you use, will be able to tell you its boiling-point.

(*b.*) This may be done by putting a fragment of the substance to be melted in a very narrow test-tube, and placing that in a bath of water with a thermometer in it. A good plan is to tie the tube containing the substance to be melted to the thermometer. Warm the water gradually; keep stirring with the thermometer, and watch your substance; directly it begins to melt, note the temperature. If you do a rough experiment first, heating up quickly, and then repeat the experiment more carefully when you know within a few degrees at what temperature the substance will melt, you will probably get rather better results. If water will not give a sufficiently high temperature to melt the solid, some other liquid, such as hot oil, or even melted lead, may be used.

Your results will depend on the specimens and their purity. Your teacher will test them beforehand, and tell you if your observations are correct.

(*c.*) Iodine will be found first to melt, then to turn into a splendid purple gas. If you do the experiment in a dry flask, closed with a cotton-wool plug, the effect is very fine. Little crystals will collect on the cooler parts of the flask. This, as was previously stated, is sublimation.

76. (*a.*) Since magnesium wire gained weight when burnt in air, and since the gain of weight was said to be due to the union of the magnesium with oxygen gas, it follows that oxygen gas has weight.

(*b.*) You will only be able to do this if you have a balance which is suitable. Either it must be large enough to hold a flask of some size, say 250 *c.c.*, and turn with ·01 gram; or, if it will only carry a smaller flask, it must be more delicate in proportion. Provided that your balance is suitable, you may proceed as follows. Take a flask *A*, fit to it an india-rubber cork *C*, having a glass tube *T* passing through it; attach a piece of india-rubber tube to *T*, securely binding it on with fine wire, and have a clamp at *D* on the india-rubber tube, or let *T* have a glass stop-cock upon it. It is best to have a flask which is perfectly globular, as it is less likely to break under reduction of pressure.

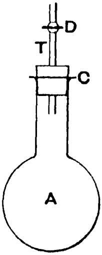

FIG. 24.

Process.—Open *D*, and suck as much air as you can out of *A* with your mouth, or if you work in a laboratory possessing any kind of air-pump, exhaust *A* with the air-pump. Close *D* securely, place the apparatus on a balance, and counterpoise it exactly with weights.

Open *D*, air will rush in, as you will hear, and the weights which balanced the exhausted flask will no longer be sufficient to balance the flask with the air that has entered it.

Therefore air has weight.

(*c.*) Weigh the flask first full of air, then exhaust it as before, and weigh again. Your results might be such as the following:—

Weight of the flask and air . .	125·13 grams
,, ,, with less air .	125·06 ,,
	·07 gram

Then open *D*, holding the end of the tube under water, and measure the water which runs in to take the place of the air you extracted. Suppose it measures 60 *c.c.*

Then 60 *c.c.* weigh 0·7 gram. Therefore 1000 *c.c.* would weigh ·07 × $\frac{100}{6}$ = 1·17 gram. This is not very far from 1·29 gram, the true weight.

The accuracy of your result will depend partly on the scales you use, partly on the care you take.

It is well to do three or four experiments, and to take the average of the results. You will probably have some too high and some too low, and the errors will correct each other. The greater the number of your experiments, the nearer your average will be to the truth.

For example, suppose you had a poor balance and obtained these results:—

1. 1000 *c.c.* of air were found to weigh	1·1 gram
2. ,, ,, ,,	1·0 ,,
3. ,, ,, ,,	1·3 ,,
4. ,, ,, ,,	1·2 ,,
5. ,, ,, ,,	1·4 ,,
6. ,, ,, ,,	1·3 ,,
7. ,, ,, ,,	1·3 ,,
8. ,, ,, ,,	1·4 ,,
Result of eight experiments . .	10·0 grams
Average	$\frac{10{\cdot}0}{8}$ = 1·25 gram

This method of avoiding the effect of accidental errors is very frequently employed.

77. Take a glass retort *A* (Fig. 25), and pour some salt water into it by one of the long-necked funnels called thistle funnels. Support it on a stand *S* by means of a ring *R*, and let its neck pass into a flask *B*. Heat the water in *A* till it boils slowly, and collect the condensed steam in *B*. The product is called distilled water. *B* may advantageously stand in a basin of cold water, or a tap of cold water may play upon it. This is distilling.

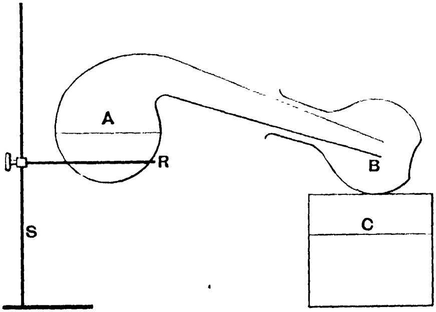

FIG. 25.

78. When boiled to dryness in a dish, no solid residue is left.

79. When heated, the water turns into steam, which, being partly cooled down by the neck of the retort, and partly by the cool flask, returns to the condition of liquid water. The solids, however, which heat does not turn into gases, remain behind in the retort *A*.

CHAPTER XI.

ACTION OF COMPOUNDS ON COMPOUNDS, ETC.

80. IT is red iodide of mercury.

82. (*a.*) Combination, as when hydrogen unites with oxygen, producing water.

(*b.*) Decomposition of a compound substance, either into its elements, or into simpler compounds, as when oxide of mercury is heated and splits into the elements oxygen and mercury. And when chlorate of potassium is decomposed into chloride of potassium (a compound) and oxygen.

(*c.*) Replacement or substitution, as when zinc acts on hydrochloric acid, sets free the hydrogen, and takes its place; and when copper in a similar way takes the place of quicksilver.

(*d.*) So-called double decomposition, as in the precipitation of iodide of mercury.

(*e.*) The change of a substance into a new body, without the adding of anything to it, or abstracting of anything from it. For example, when red phosphorus is changed by heat into common phosphorus.

83. (*a.*) The most obvious plan is to shake a very small quantity of the solid with the liquid, and observe whether it disappears, leaving a clear liquid, as sugar does in water.

Try this—

> By putting sugar in water.
>
> By putting a little calcium sulphate into water. In this case, first put as much calcium sulphate as will lie on a sixpence into a test-tube half full of water. It will apparently *not* dissolve. But suppose it is not very soluble; suppose only one-hundredth part of what you took has dissolved?

Evidently this plan will only succeed for things that are rather freely soluble, like sugar. Therefore, in such cases as that of calcium sulphate, when the first experiment leaves you in doubt, you may be guided by the following considerations:—

Does the solid supposed to be dissolving impart any colour to the liquid? If it does, you may infer that it is more or less soluble.

> Put a fragment of iodine in some spirit of wine to see an example of such change of colour.

If there is no change of colour, you cannot infer that solution has not taken place. Pure sugar, for example, does not give a coloured solution in water.

When you can observe neither the disappearance of a considerable amount of the solid, nor any development of colour, you may apply the following less easy but more certain method:—

> After agitating the solid and liquid together for some time, with or without heat, according to circumstances, filter a few drops into a dish and evaporate the solution in an oven. If the solid has dissolved in the liquid, it will be left behind in the dish when the water has evaporated. This may be tested by filtering the liquid from the calcium sulphate of your former experiment, and comparing

the residue left after evaporation with that given by pure (*i.e.*, distilled) water. You will find that *some* calcium sulphate has dissolved. Then add the sulphate in very small portions to some water, and you will find you can even *see* it dissolve, if you are very careful.

(*b.*) Sand will not dissolve, for it neither disappears nor colours the spirit, nor is there any residue if the liquid is strained off and evaporated.

The iodine does dissolve, for it colours the spirit brown.

Therefore, if the mixture is warmed with spirit repeatedly as long as it colours the spirit, the two will be separated.

For the answer to *A*, apply to your teacher.

(*c.*) If a particle of each is heated in a very small test-tube, the sand will remain unaltered in the tube.

The ammonium carbonate, however, will sublime, *i.e.* turn into gas, volatilising and condensing on the cool upper part of the tube.

(*c*2.) If the mixture *B* is heated in a tube, it will separate into its two constituents. The sand will remain in the heated part of the tube, the ammonium salt will collect above on the cooler part. This mode of separation is often practised.

(*d.*) Take a known quantity of the sugar by the following method. Weigh a beaker (suppose it weighs 15 grams), add some of the sugar and weigh again (suppose they weigh 17½ grams).

Weight of beaker and sugar	**17½**	**grams**
" " only	**15**	**"**
Sugar taken .	**2½**	**grams**

Treat the weighed portion with water.

When the sugar is dissolved in the water by gentle warming (it is well to take a good quantity of water), filter off the solution, and treat the residue with water several times, each time filtering the solution obtained through the same filter paper. Then spread the filter paper out flat, and wash any sand on it back into the beaker by pouring water over it, let it settle, pour off as much water as you can without losing any sand, evaporate one drop of this water in a basin to see that there is no sugar in it; and if the result shows that your sand is free from sugar, let the whole dry and weigh again. Suppose it to weigh $15\frac{3}{4}$ grams. Then :—

Beaker and sand weigh	$15\frac{3}{4}$	grams
„ only . . .	15	„
Sand weighs .	$\frac{3}{4}$	gram

As $2\frac{1}{2}$ grams of *C* were taken, $2\frac{1}{2}$ grams contain $\frac{3}{4}$ of a gram of sand; and 10 grams, which is four times $2\frac{1}{2}$, will contain 3 grams. If 10 grams of the mixture were carefully weighed out at first, the need of a calculation would be avoided.

(*e.*) With common salt there is no difference, or practically no difference, between the two results. With copper sulphate there is this difference: that the hot solution deposits blue crystals as it cools, but the cold does not do so. From which it may be inferred that copper sulphate is more soluble in hot than in cold water, but that common salt is not more soluble in hot than in cold water.

(*f.*) Make a hot solution of the mixture and cool it. For hot water will not take up more common salt than cold, as you have just seen, whilst it will take up more of the copper salt. Hence, on cooling the solution, crystals of copper sulphate will form, leaving behind all the salt, with only part of the copper sulphate dissolved in the water.

(*g.*) *Results* :—

Charcoal dissolves in neither.
Nitre ,, water only.
Sulphur ,, carbon disulphide only.

(*h.*) Agitate the gunpowder with water, filter off the liquid, and treat the residue with water again, adding the second solution to the first; then dry the solid residue in the oven. Meanwhile evaporate the solution of nitre.

When the residue from which the nitre has been extracted is dry, extract it with *cold* carbon disulphide; filter off the solution from the carbon, and let it evaporate in *a fume closet*—the residue will be sulphur. If you leave it to evaporate in a test-tube with a plug of cotton wool, you will get one or more large crystals of sulphur.

CHAPTER XII.

PREPARATION AND PROPERTIES OF CERTAIN IMPORTANT CHEMICALS.

85. (*a.*) PUTTING the formulæ to make an equation, we have—

$$NaCl + H_2SO_4 = HCl + Na_2SO_4.$$

But NaCl on one side of the equation cannot give Na_2SO_4 nor can H_2SO_4, give HCl, so it must be written—

$$2NaCl + H_2SO_4 = 2HCl + Na_2SO_4.$$

We see that both compounds are decomposed, and their parts rearrange themselves; so that it is a case of so-called double decomposition.

(*b.*) The products, hydrochloric acid and sodium sulphate, are separated by taking advantage of the fact that hydrochloric acid is a gas and escapes from the flask. It is soluble in water. Therefore it is collected over the liquid quicksilver instead of water.

(*c.*) Dense fumes are given in the air. This is caused by the readiness with which this gas dissolves in water. It acts upon the water vapour in the air, and the two gases condense to a cloud of minute drops of solution of hydrochloric acid in water. The invisible gases become visible through the physical difference between them and their liquid product.

(*d.*) A copious cloud of *solid* white fumes forms; they begin near the glass rod, extending till the jar is more or less full of them.

Here again we are able to see the results of a chemical change, in consequence of a physical difference. Two invisible gases in uniting have produced a solid, visible substance.

This is a case of combination. The hydrochloric acid and the ammonia have combined; the solid fumes are called ammonium chloride. NH_3 is the formula of ammonia, which is composed of nitrogen and hydrogen. The combination is expressed by the following equation :—

$$HCl + NH_3 = NH_4Cl.$$

(*e.*) As sodium is a metal, and as in the earlier experiments you have found that acids when acted on by metals produce hydrogen, you will have done wisely to try first if the gas is combustible. You will find from the result that it is hydrogen.

The reference given in Chap. V., which relates to the formation of salt from hydrochloric acid and hydroxide of sodium, may suggest to you that salt is likely to have been formed. The taste of a substance does not give any certain knowledge of its nature, as a rule, but is a guide when it is safe to taste. In this case, if a fragment of the *white solid* is tasted, [N.B.—*In tasting it, you must take great care not to get any of the metal into your mouth*] it will be found to resemble salt.

Sodium acting on hydrochloric acid has set free hydrogen, taking its place. It is a case of substitution or replacement, as this equation will help you to understand :—

$$Na + HCl = NaCl + H.$$[1]

(*f*.) In this experiment you will have a green, evil-smelling gas produced. It is *chlorine*—the element which, by combining with hydrogen, forms hydrochloric acid.

(*g*.) You will find that in smell, taste, action on litmus, and power of neutralising alkali, also in producing the green gas, when warmed with manganese dioxide, your solution of hydrochloric acid and the purchased acid are alike. You must test all these points practically, and draw up a table of results, thus :—

Action of HCl Solution made by myself.	Action of bought HCl Solution.

86. These gases will give no evidence of combining, unless direct sunlight should come to them. In that case they may combine explosively. If a lighted taper is brought near to either jar, however, there will be a flash of flame and an explosion, the green colour will

---

[1] For reasons which it is not desirable to explain at present, this should be written—

$$Na_2 + 2HCl = 2NaCl = H_2$$

disappear, and fumes like those given by hydrochloric acid in air will be formed. The hydrogen and chlorine have combined—

$$H + Cl = HCl,$$

or more properly,

$$H_2 + Cl_2 = 2HCl.$$

The production of heat, or light, together with change of property (for your gas is no longer green, and no longer smells of chlorine after the explosion, and it has gained the power of fuming in air), are indications that a chemical change has taken place.

87. You have found that hydrochloric acid is a compound of hydrogen and chlorine, both by combining those two elements and by separating them from the acid. *There is no oxygen in it.* All the other acids of your own preparation contained oxygen, for they were made by dissolving the oxides of non-metals in water. This is an important point, as it shows that your definition of an acid (see p. 81) will not include all acids, for it will not include this acid. You have also found that hydrochloric acid, like other acids, is sour, turns blue litmus red, and neutralises alkalis; that a metal (sodium) will turn out its hydrogen, and that some of its chlorine can be set free by the action of manganese dioxide; that it is very soluble in water, and fumes in air, and as you can collect it over quicksilver, that it has no action on quicksilver.

88. As the product is said in Part I. to be a liquid and to boil, the apparatus used for purifying water will be suitable (Fig. 25, p. 103). Place the sodium nitrate in the dry retort *A*, and by means of a funnel with a long neck add some strong sulphuric acid to it, attach a collecting flask as before, and place the retort over a burner on a stand *S;* heat the materials you have placed in *A*, and nitric acid will pass into *B*, which should stand in a basin of cold water.

The equation which expresses the change is—

$$NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3.$$

As each compound is broken up, this is another case of double decomposition.

The physical differences taken advantage of are that nitric acid is a liquid which boils, and therefore passes off into *B*, whilst sodium sulphate is a solid which will not boil, and so remains in the retort. If too much either of acid or of salt be taken, the excess will stay in the retort, as they are not volatile at the temperature at which the nitric acid boils.

89. As it is a gas, you may simply add the liquid acid to the solid you use in a flask or tube. A gas will be evolved which will render a drop of lime-water held in it on the end of a glass rod milky; it is therefore carbonic acid gas.

In setting free the carbonic acid gas, you take advantage of the fact that the oxide of carbon is a gas, and so separates itself at once from the other materials, which are liquids or solids.

The action of the gas on lime-water will be understood by the help of this equation and explanation :—

Lime-water contains a compound of a metal, calcium, with hydrogen and oxygen, called calcium hydroxide, CaH_2O_2. When the oxide of carbon, CO_2, acts on this, carbonate of calcium, $CaCO_3$, is formed together with water :—

$$CaH_2O_2 + CO_2 = CaCO_3 + H_2O.$$

Now the calcium hydroxide dissolves in water, and is invisible; but carbonate of calcium, $CaCO_3$, will not dissolve in water, and therefore as soon as it is formed it is *precipitated*, and the solid particles suspended in the water make it turbid.

(*a*.) You may put your materials in *A* of the apparatus (Fig. 14), and collect it over water, as you did in the case of hydrogen (p. 43).

(*b*.) First find if the gas is heavier or lighter than air by the method previously used in experiments on gases.

Then collect it by either upward or downward displacement, according to your result.

See how long it will stay in a jar with its mouth open, and placed upward or downward, as may be best.

It will be found to have no smell, and to have an acid taste, to turn blue litmus solution red, to extinguish a light, and to be heavier than air.

91. When a rapid stream of carbonic acid is passed through lime-water, it first renders the lime-water turbid, as in previous experiments, but afterwards the solid dissolves up again.

Why is this?

When all the lime in the lime-water is used up, sc that there is no more to combine with the carbonic acid gas, may not the gas dissolve in the water, and the solution thus formed dissolve the carbonate of calcium?

Test this explanation by warming some of the clea solution just made in a tube fitted like *A* (Fig. 18), and passing the steam and any gas that may come off int some more lime-water in a flask or tube. Observe th result, draw your conclusion, and compare with wha follows.

Result.—Boiling sets in quickly, and the gas which comes off is evidently carbonic acid gas, as well as steam for the lime-water it is passed into is made turbid by it When the boiling has continued for some time, the sediment forms in *A* again. This must be because there is no carbonic acid gas left in the solution ; so we may conclude that the explanation given of the re-solution of the precipitate by excess of carbonic acid gas was correct.

92. As burning is the combination of oxygen from the air with the body burnt, we should not expect carbonic acid gas to support combustion, for it does not contain free oxygen, but combined oxygen — oxygen that has already taken its part in burning.

93. This has been done in preparing oxygen, hydrogen, chlorine, carbonic acid gas, and hydrochloric acid.

APPENDIX

LISTS OF NECESSARY APPARATUS AND CHEMICALS.

THE following lists of apparatus and chemicals have been carefully compiled, and I think will be found to contain all that is necessary for the work described.

List **A.** includes apparatus for general use.

List **B.** includes apparatus which each of the pupils, if they work at all at equal rates, and are all at the same stage, will require. In my experience, after the first few weeks, there is a certain degree of inequality in the rate of progress, so that it is not necessary to provide for every boy doing the same work at the same time. And as it is profitable to let them work in pairs, it is only necessary to provide fifteen sets of apparatus for thirty students.

In a few important cases I state what provision of apparatus I have found sufficient.

The expense of the necessary apparatus for a class of thirty boys, including such balances and drying-ovens as I describe, should not much exceed £50. By using inferior balances, and a commoner drying-chamber, this might be considerably reduced. Good scales are particularly desirable, however, as they encourage careful work in the quantitative experiments.

Besides the items on the lists, working-benches, with gas and water, are needed, a few re-agent bottles, and, if possible, a fume-closet.

List A.

Balance and weights. I find one balance to every six boys sufficient.

Drying-oven, warmed by hot water, internal area, say 14 in. ×

10 in. It may be made to supply distilled water, which is a convenience when much is not wanted.

Earthenware pneumatic trough (about one to every four boys).

Mouth blow-pipe, to fix on Bunsen burner, for heating glass tubes, &c. Two would be desirable.

A Herapath blow-pipe with foot-bellows is also of great use. Those made by Mr. Fletcher of Warrington are satisfactory.

Two or three sets of cork-borers, three in a set.

A few round and triangular files.

About twelve yards of small black india-rubber tube.

A few dozen medium-sized test-tubes (5 × $\frac{5}{8}$ and 6 × $\frac{3}{4}$).

Small test-tube stands.

Six small magnets.

Six small lenses.

A few square feet of medium iron gauze.

A few square feet of rather fine iron gauze.

A few pounds of glass rod.

Half a dozen sets of wooden blocks.

Ten or twelve pounds of small glass tube for bending.

Some *small* composition pipe.

Ten pounds of soda glass tube, half an inch to one inch in diameter.

Five pounds of rather thin hard glass tube of the same sizes.

[These are for making the tubes described on pages 8, 26, 37, 48. Such tubes can be obtained from dealers in apparatus at small cost, but they can very easily be made at still less cost. A few words on making such articles of glass are given, for the benefit of those who need that help, in Appendix II.]

List B.

English-clay assay crucibles and lids.
Bunsen's burners with roses.
U-tubes, 4 in. (about two for each).
Mixed corks.
Lamp-glasses, 5 in. long.
Wolff's bottles, 10 oz.
Thistle funnels.
*Measuring cylinders, 200 c.c. capacity.
*Measuring cylinders, 25 c.c. capacity.
Flasks, 16 oz., 10 oz., 4 oz.
Beakers of deep form, 8 oz.

*Ramsay's burners.
Two-necked bottles.
Thermometers, marking 300°C.
Small tin trays for holding hot sand.
Retort-stands and rings, 15 in. (one for each pair of boys).
Gas cylinders, 11 in. high (two each).
*Mortars (4 in. diameter) and pestles.
Round plates of ground glass, 4 in. diameter.
*Iron spoons.
*Deflagrating spoons.
Evaporating basins, 3½ in. diameter, two or three dozen.
*Beehive stands.
Clamps for retort-stands (one each).
Screw or spring clips.
Retorts, 8 oz.
Small glass funnels.
Fine copper wire.
Globular flasks for Fig. 24, p. 101.
Burettes.

* These being in use for a short while only at a time, need not be provided quite so plentifully as the other articles should be.

INDEX

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