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CHEMICAL WARFARE

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By

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FOREWORD

Curt Wachtel organized the pharmacological section of the Kaiser Wilhelm Institute during the World War. He supervised all the installations necessary for testing more than three hundred toxic gases on thousands of animals and was in charge of research on gas intoxications. He served as instructor at the Military School of Noxious Gases. In addition he assured the service of the military physician which comported the first observations of the effect of war gases on men and of the chronic intoxications and subjective experiences on those engaged in the manufacture, testing and handling of war gases.

FRITZ HABER.

Dr. Curt Wachtel completed his medical and chemical studies at the Universities of Berlin, Greifswald and Freiburg. He engaged in research work at the Robert Koch Institute (Berlin), Institute of Hygiene (Freiburg), Kaiser Wilhelm Institute of Physical and Electrochemistry (Berlin) and the Institute of Pharmacology (Breslau). He was the founder and director of the Institute of Industrial Hygiene and Professional Diseases (Berlin).

Subsequent to the World War, Dr. Wachtel made a survey of noxious gases in England, France, Russia and the United States. In Russia, after the Franco-Soviet Pact was signed, he served as Professor at the Central Institute of Medical Chemistry and acted as Consultant to the Civil Air Defense. Today he is a resident of the United States and has written this book in the hope that it will be helpful to the military of his adopted country.

H. BENNETT

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INTRODUCTION

OF ALL the weapons of modern war, gases aim most exclusively at the wholesale annihilation of human individuals. For this reason chemical warfare is a problem of most direct concern to the people. Citizens of free countries who are responsible for themselves desire to know and should receive all the information which is necessary to deal with this problem. On the other hand chemical warfare is a highly specialized branch of applied science ; physical, chemical, physiological, tactical, technical, economic and political factors are involved.

Only a rational consideration of all issues can lead towards a reasonable solution of the problem. It is the purpose of this book to present this information to the reader in a form that is comprehensible not only to chemists, physicians, engineers and military experts, but also to the laymen who are the prospective individual victims of the war gases. Fortunately the average standard of education in the United States is so high that not only college graduates but everybody who has passed public and high school has at least some knowledge of physics and chemistry. Even if not every technical term is familiar to every reader, I trust that every one will be able to understand the principal issues which are derived from the problems of more technical character.

I also hope that the coordinated presentation of technical, medical and military problems involved will contribute to the mutual understanding between the experts in so different fields who cooperate in the development of chemical warfare.

The reader of this book will certainly understand that even

in a field that requires so specialized scientific knowledge as chemical warfare does, the final decisions always rest with the people who control the government under democratic constitutions. If the people resign their duty or right of control, because they are indifferent or too lazy to make the mental effort toward the full understanding of the problem, they will encourage the uncontrolled dictatorship of administration experts who, in the France and England of 1938, felt satisfied with a state of preparedness in the field of chemical warfare that would not have been adequate in 1918.

There seemed to be nobody in England before the outbreak of the present war who was able to oppose with scientific knowledge such disastrous conceptions of England's military situation. These ideas were widely spread by the writings of many authors; and the teaching that nothing but defense would be necessary, left England equipped with fifty million gas masks against the tons of explosives ready to destroy the property and war industries of the British Islands.

A more fateful misunderstanding of the potentialities of chemical warfare can scarcely be imagined. Nobody will plead that it is sufficient for defense against air attacks to hide underground. One has to have airplanes for counter attacks. Equally gas masks are not enough. The enemy must know that he will suffer from the same kinds of weapons which he applies.

The threat of chemical warfare from the enemies of Britain charged a tremendous economic burden on the British people and delayed other measures that could have been more effective in counter attacks.

In a war that is allegedly directed against "plutocratic" governments the weapons which destroy property are used

in the first place. Only in a later stage of war, when it becomes apparent that no people want to be left at the mercy of the victor after the destruction of their national means of production, only then the people themselves will be attacked with the specific casualty weapons of war gases. This is only one of the reasons for the fact that gas has not been used in the initial stage of the second World War. Mustard gas was used by the Italians in 1936 against the unprotected Abyssinians during the Ethiopian campaign. It will certainly be used in a later stage of war, when the political and tactical situation so requires.

While this volume is devoted to the advance of general understanding for chemical warfare, it shall be confined to the concrete facts. Emotional approach can only be harmful and blind the people and governments against the essential issues. A people trembling from fear of imagined future horror and a government kept in fear that the people will lose their nerve at any decisive moment cannot make plans as logically and coolly as is required. Any public writer who stirs the emotions and fears of the people for the sake of sensation acts for the advantage of the enemy. It is, for instance, possible to magnify the dangers arising from contact with mustard gas. In fact, mortality and permanent disabilities after mustard gas are very low.

This volume will certainly not unduly minimize the dangers which originate from gases against troops or civil populations. It attempts a correct evaluation of individual gases and of chemical warfare as a whole. It emphasizes the value of preparedness for gas attack. If any prospective enemy knows that he will risk effective counter attacks, he will think it over twice, before he opens the valves of his gas cylinders against this people. This conception of gas warfare is the only practical pacifism that counts.

Preparedness requires superiority of chemical production. Does this country possess this superiority today? During the years 1915–1918 Germany and Austria used in the battlefield a total of..... 66,400 tons of toxic gases. The Allies, including France, Britain, the United States, Russia and Italy, used all together only ..... 57,800 tons

It is still more informative to compare the World War figures for the industrially most advanced power of the World, the United States of America, with those of the most backward country, Czarist Russia. Russia used in battle..... 5,200 tons of toxic gases, which was almost 5 times the amount of gases used in battle by the United States Expeditionary Forces, recorded as only 1,100 tons

The problem thus exposed is simply that: Will the Allies, and especially the United States of America, today be able to excel any group of possible enemies in both the qualitative and quantitative production of war chemicals?

While chemical industries in some countries are rather centralized, the American chemical industry is divided in a great number of individual enterprises. Will they be well enough organized in time for war production?

The nationwide planning of chemical production in Germany has been complete since 1916. Will it be equally possible in democratic countries to obtain the same result or will planning here be confined to a listing of production capacities according to the interests of individual companies? Certainly the resources of the American petroleum industry alone would be sufficient to produce such an amount of incendiaries that the rest of the world could be set afire at

once. But will there be enough guns and airplanes and shipping facilities to have this ammunition at the places, where it is needed, at the time, when it is needed?

Will there be enough aluminum to produce thermite for incendiary bombs, if the American aluminum industry does not produce enough aluminum for airplanes, while production is limited by lack of power and by international agreements on prices and production?

This list of questions could be continued indefinitely. It is obvious that such problems cannot be solved by the Chemical Warfare Service if government, congress and public opinion, which is the people, do not come to its aid.

Such problems cannot be solved by scientific discussion. They were solved for Germany in the past by the cooperation of a great independent scientist, Fritz Haber, and a great industrial leader, Carl Duisberg. With reference to chapter 3 we may conclude that the scientist served the national interest of his country more successfully.

We may also learn from past experience that the superior quality of gas weapons on one side may outweigh the superior quantity on the other side. Superior quality of organization may do the same. Superior quality of training and equipment may equally be worth thousands of tons of gases on the other side. But far superior quantity of production may well frustrate the highest degree of quality, if it is not combined with a certain minimum of quantity. This can be learned from the final issue of the gas warfare efforts of the Central Powers in 1918.

Material superiority always depends upon the ability and initiative of men. There would be no mass production in America without a Henry Ford. There would have been no superiority in chemical warfare in Germany without a Fritz Haber. Nor could anything like that ever be accom-

plished without the cooperation of well trained chemists, engineers and skilled labor.

Only careful advance planning of material and human resources of a nation, combined with the correct scientific evaluation of all factors can solve such problems.

Will there be men in the right places who are able to correctly evaluate future developments? Chemical warfare preparedness of Britain and the United States, according to recent published field manuals is well adapted to what was correct in 1918. No future development is envisaged in these official government publications which regulate the training of the armed forces of Great Britain and the United States in 1940.

There will be new gases. The Intelligence services should know all about them. But if they fail,[2] scientific imagination should anticipate what can be expected, if the prospective adversary possesses at least a mediocre knowledge of chemistry and toxicology. There is no word in all the government regulations which would disclose the slightest degree of preparedness for future possible developments.

It has been proven that every detail of chemical warfare is important by itself and in connection with the entirety of national defense. An American expert on military problems recently made the following statement: The French defeat did not come from any single internal failure nor from any new and secret weapon developed by the German high command. It was rather the sum of a great number of reasons,

[2] A number of details were never published by the German scientists; some details are not known, some are not correctly understood by the scientists of the other countries. As a result gases may still be used on the one side which were discarded as ineffective on the basis of research on the other side.

each apparently insignificant in itself, but in toto utterly disastrous.[3] Every detail, "each apparently insignificant in itself" counts heavily in chemical warfare. The coordination of chemical warfare with other weapons of army, navy and air force is most important. Everybody who knows which obstacles may originate from the bureaucratic attitude of big and small units in a modern army also knows that no army in the world is free from this evil and that a long and careful preparation is needed in the years of peace to eliminate factors of this kind through education of staffs, individual officers and the troops towards mutual understanding and cooperation. The well functioning of a good chemical warfare service depends upon such "apparently insignificant details."

As in the past, gases will be used in the future against human life and human efficiency. We stand only in the beginning of this development. The fact that more than twenty years between two World Wars have not yet brought forth visible new developments of gas warfare does not prove that there will be no further advance. In fact we observe a peculiar contradiction. Laymen fear, expect or predict fantastic effects of future gases in which the expert cannot believe. Experts on the other hand predict that nothing new will appear, that nothing has been invented. They go so far as to say that certain gases of the last World War were so perfect that nothing superior to them can be found.[4]

Experts of all belligerent nations said so and apparently believe so. But must this be true? Certainly not. Experts in all fields of science make so many public declarations that are just completely forgotten or proved wrong after

[3] U. S. Capt. C. R. Kutz, Army Ordnance, Vol. 21, p. 242 (1940).
[4] Kendall, Breathe freely! Appleton, New York (1938).
Meyer, Les gaz de combat. Paris (1938).

a very short time, sometimes weeks, seldom more than two years. This is especially the case in the field of medical chemistry. Unfailing remedies against pneumonia change about every two years. Still patients die from pneumonia and the unfailing remedy of today will certainly be forgotten in 1943.

The result of such bad habits on the part of the professional men in the field of medical chemistry is that laymen have lost belief in predictions of experts. They still fear that, in spite of the conforming attitude of the experts in chemical warfare, something unforseen may happen.

Surprise is still possible, if one of the belligerent powers organizes, or has organized, research in this field under the direction of intelligent men.

In modern warfare misleading scientific opinions are sometimes intentionally spread, in order to disarm the future adversary or to prevent his preparedness. The most prominent scientists of one country may be ordered to systematically build up misleading conceptions which are accepted by the more harmless scientists of the other country, long before both become belligerent. To believe in the impossibility of any progress in chemical warfare may be convenient to job holders who have no ideas of their own. The same pattern is used in a larger field, nations who persecute pacifists at home subsidize pacifist movements in the country of the prospective enemy.

Are American scientists in the field of Chemical Warfare immune against infections of this kind? Still, very recently the French and British were not.

Where it does not appear feasible to spread misleading opinions in a more general way, other procedures are used to confuse the minds of the people and experts and to

harass or delay defense measures by undermining activities. Private international connections between scientists are largely exploited to build up false reputations for inefficient scientists and to undermine the confidence in truly capable persons. Mediocre people are frequently invited to lecture at international scientific meetings and made members of all kinds of international committees, while the real experts are neglected. By such ways the less capable chemists of some countries won the personal reputation which made them the leading men in chemical warfare of their country and kept out of activity the more able men who are, in addition, actively discredited by all kinds of personal blackmailing or otherwise. No ruse is too base, if it helps to prevent an able scientist from using his knowledge for the defense of his country.

There is only one defense against the active confusion of the minds: perfect scientific training combined with absolute moral integrity. The best strategist will not be perfect and not know what can be accomplished by chemical weapons in the battlefield, if he has not thoroughly studied this specialty. Men who believe in the impossibility of scientific and technical progress, who believe in "ignorabimus," in "we shall not know," do not belong at the head of a modern army.

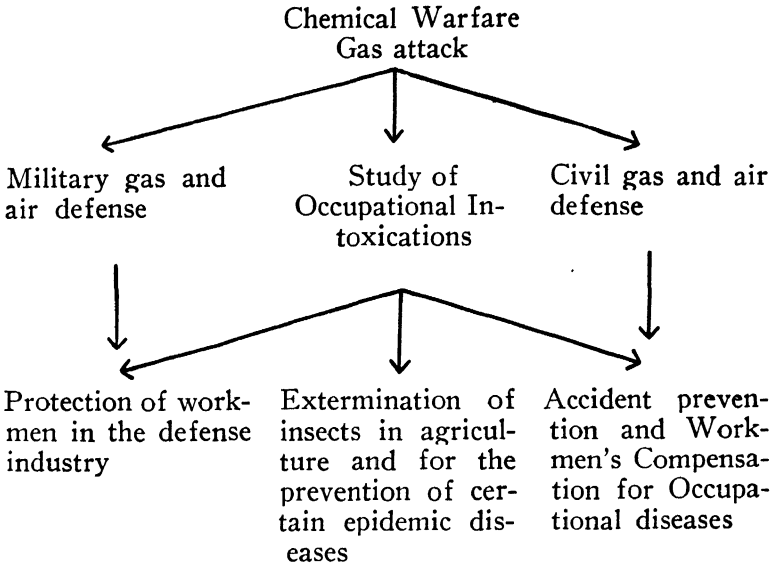
CHAPTER I:

THE IDEA OF CHEMICAL WARFARE.

Chemical Warfare and Peacetime Science.

The gas attack is the main problem of study and research in the field of chemical warfare.

During the World War, the occurrence of frequent occupational intoxications and accidents in the manufacture of noxious gases demonstrated the close connection between the research on war gases, industrial hygiene and safety problems. Along with the development of gas warfare and the introduction of a great number of various gases for use at the front it could be proved that some of the same gases that were highly effective in the destruction of human health and life could with equal success be used for the extermination of noxious insects such as lice carrying the germs of typhus. Hydrogen cyanide was also largely used in agriculture for the extermination of insects. Later, chlorpicrin was applied in Central Asia and the Caucasus mountains for the extermination of the fleas of certain ratlike squirrels that had been the cause of endemic plague in these countries for centuries. Thus, public welfare has well profited from the study of the war gases. The following table illustrates the various fields of scientific research which have developed in close connection with or in consequence to the research on war gases:



In this way, the study of noxious gases has been and still is an ever-flowing source of scientific knowledge and practical progress in so many different fields. Indeed, the historical development in most countries has followed the course as indicated in the table above. Only in a very few states of this country were occupational diseases included in Workmen's Compensation Laws before 1916. In most European countries and in most of the states of this country, compensation laws were enforced after the first World War. There can be no doubt that the occurrence of mass intoxications through chemical warfare has opened the eyes of many for the need of compensation for the victims of peacetime intoxications in industry, just as the growth of accident insurance mainly resulted from the occurrence of mass accidents in railroad catastrophes.[1]

Scientific institutes for the study of industrial intoxica-

[1] Stewart & Holbrook, "Let Them Live." New York (1938).

tions were founded immediately after the World War in Soviet Russia and Italy. Later, the author of this book founded the first institute of industrial hygiene and occupational diseases in Germany, where his war gas experience was thus made useful to protect the workers in peace time.

At a time, when the entire civilized world is again threatened with death and destruction from chemical poisons and explosives, it may be useful to remember and review the rôle which science once played in this field. A science guilty of creating the means of immeasurable destruction and human suffering may be considered more than fully exculpated through the great contributions to public hygiene and welfare which resulted from the same research on war gases. Certainly many more lives have been saved through these and other accomplishments resulting from the war time study of gas attack than were sacrificed by the latter during the World War.

The destinies of the men behind the gas, the fates of the nameless victims of the same gases, the tragedies of the genius and of the common man are inseparably interwoven in the history of chemical warfare and in the general history of our time.

No man, however small and limited his part may seem to be, can isolate himself from the rest of society. Nor can any one escape for himself the destiny of our society. Even the most specialized technical problem, such as chemical warfare, does not permit its students isolation. Unfortunately, the unavoidable need for military secrecy is frequently the cause of isolation of the chemical warfare services.

Military secrecy may easily be abused to protect the responsible officials against criticism of their mistakes or omissions. Lack of preparedness has been the tragic re-

sult of such abusive "isolationism" in England, France and elsewhere so far. The tragedies of men behind the gas and the tragedies of the peoples are again inseparably interwoven. The history of chemical warfare reflects the tragic conflict of our time, the simultaneity of annihilation and regeneration of social order, of the destruction and rebirth of nations, of physical, moral and spiritual death and resurrection of millions of individuals.

Poisons As War Weapons

It is remarkable that the use of poisons for war was in no case suggested by a physician. It is beyond doubt, that no individual poison for gas attack was introduced on the German side at the suggestion of a physician.

The principal idea of chemical warfare originated in the brains of chemists and engineers. Toxicologists were only later called in for collaboration.

Of course, the idea of intentional killing of human beings must be very strange to every physician, who has taken the oath of Hippocrates. A physician is, however, also a citizen of his country, and, when drafted into the army for service in wartime, he also swears to be loyal to his country and even to sacrifice his life, if this be necessary. If such a physician, on account of his special training and experience, is called to do pharmacological research for the purpose of discovering the most effective poisons for gas attack, he is indeed confronted with conflicting duties.

Whatever an individual physician may decide to do, depends upon the circumstances and upon his conscience. If he places first the obligation towards his country, he should be as much respected by the rest of the people as the man who wants first to be loyal to his physician's oath.

The use of poison against enemies is very old. That part of medicine which deals with poisons is called pharmacology. The ancient word also means sorcery or witchcraft. The poison of the sorcerer was not always used to kill but also to make victims insane. The same effect was accomplished by hypnotic suggestion and fascination. Those, who had such knowledge, kept it secret and became the political and spiritual leaders of the people. In ancient times the pharmacologist was not only the medicine-man, but also the priest. We may learn about the personal union between medicine-man and priesthood from the Bible. Moses had learned his magic powers from the Egyptian priests who had brought him up and educated him.

As in Egypt, the priests kept medical knowledge and experience as their secret in all ancient civilizations and ruled through this knowledge. The ancient Goddess Hecate and her daughters Medea and Circe were worshipped as poisoners and sorceresses. Their deeds and misdeeds inspired the greatest poets of all times. Thus the myth of poison becomes familiar to the youth of our time.

With the aid of Medea's poison, Jason conquered a country and kingdom for himself. The use of poison for military and political conquest by brutal force or artful trickery accomplished political deeds in Greek mythology, in Shakespeare's Hamlet or Macbeth, in the Papal State of the Borgias, — to mention only a few examples.

In historical times, poisons were frequently used as weapons. About 200 B.C. the leader of an army of the State of Carthage won a victory by means of poison. After he had met the enemy for the first time, he retreated, in order to create the impression that he was afraid of the enemy. He left in his camp great quantities of wine that was poisoned with mandragora, a toxic root with narcotic

effect. The enemy took the camp, drank the wine, and was killed during narcotic sleep by the returning soldiers of Maharbal.[2]

Hannibal won a naval battle against King Eumenes of Pergamon in this way: venomous snakes were collected and put into earthen vessels which were thrown onto the ships of the enemy. The snakes brought such confusion among the enemy sailors as to insure their defeat.[3]

The Roman historian Aelian justified the use of poison for defense in war by the fact that nature had armed certain animals with poisonous secretions and that wasps moistened their strings with the poison of dead vipers.[4]

The Poisoning of Drinking Water.

The poisoning of the water supply is a very old military measure that has always been attempted by such means as the scientific knowledge of the time and the conditions of the special case admitted. This purpose can be accomplished by the use of chemical poisons or by poisonous plants and drugs and also by throwing the carcasses of animals or corpses of men into the rivers or wells. The latter procedure is a primitive but rather effective method of bacteriological warfare and has always been in practical use.

Though we mention a small number of historical records, we must not overlook that much superstition concerning the effects of poison has always been and still is in the mind of laymen and physicians who are not specialists in pharmacology.

[2] Frontinus, Stratagematicon, lib. V and VIII.

[3] Iustini, Historiae Philipicae, lib. XXXII, cap. IV.

[4] Lewin, Gifte in der Weltgeschichte, p. 559. Berlin (1920).

During the Boer War the British believed that the Boers had poisoned the wells with potassium cyanide. Even the British medical staff believed this and recommended antidotes which would help against cases of poisoning. The physicians of that time should have known that a person who absorbs a fatal dose of cyanide dies almost immediately, so that no aid could come in time. If a person absorbs less than the fatal dose, he recovers without the aid of a physician.

A more successful use of poison in ancient times was made about 600 B.C. The great legislator of the Athenians, Solon, ordered many roots of helleborus thrown into the small river, Pleisthenes, from which the beleaguered enemy drew his water supply. The poison produced violent diarrhœa, thus weakening the defense and causing the defeat of the people of Kirrha.[5]

At the time of the crusades many poisonings of water supplies are reported. In 1155 Kaiser Frederick Barbarossa besieged the Italian town of Tortona and conquered the place by poisoning its water supply with animal carcasses and corpses in decay. He also added to the water burning torches made from tar and sulfur. The resulting formation of sulfuric acid and tar products made the water undrinkable.[6]

Poisoning of water supply by organic matter in decay is scientifically equivalent to the use of chemical poisons. As has been mentioned above, this method produces the additional danger of infections, especially of typhoid fever, dysentery, cholera and others according to local and climatic conditions.

[5] Lewin, L. C., p. 536, Pausanias, Graeciae descriptio, lib. X, cap. XXXVII.

[6] Lewin, L. C., p. 541, Otto Frisingensis. De gestis Friderici, lib. II, cap. VII.

During the American civil war, in July, 1863, General Johnston retreated from Vicksburg. General Sherman, the commander of the Northern Army who followed the retreating troops of Johnston, found the carcasses of pigs and sheep in the ponds and lakes.

W. T. Sherman[7] reports: "Johnston had marched rapidly, and in retreating had caused cattle, hogs and sheep, to be driven into the ponds of water and there shot down; so we had to haul their dead and stinking carcasses out to use the water." It is remarkable that in American military literature this method of poisoning water supplies is considered permissible in wartime.[8]

Poisoned Projectiles

Projectiles carrying poisons have been in use throughout the ancient world, not only among the peoples of the Orient but also in the Western countries among the Celts, the Gauls, the Belgians and others. An entire literature has been published about the *arrow poisons* which are the predecessors of the modern gas shells. Just like the modern gas shells, arrow poisons may be classified as irritant poisons which cause local inflammation and as poisons which cause a general intoxication.

Without going into detail I wish to remind the reader of the fact that certain poisonous plants are perhaps more dangerous than any of the chemical poisons now used. A certain variety of aconite is used as arrow poison in many parts of India and China. It is said to be far more toxic than the varieties of aconite occurring elsewhere.. The dose attached to one arrow is said to be sufficient to kill an elephant. The

[7] Memoirs, vol. 1, p. 331. New York (1875).

[8] Spaight, War Rights on Land, p. 83. London (1911).

same poison is used for bear hunting on the island of Sacchalin. The poison paralyzes the respiration.

It is very possible that in a future more advanced stage of development, chemical warfare may return to such complicated organic compounds as aconite, as soon as it is possible to manufacture them in sufficient quantities and to construct shells in which the organic compound would not be destroyed by the explosion of the shell. Just as the poisoned arrow was the climax of the shooting technique before the invention of fire-arms, so the poisoned shell represents the climax of our modern war technique. Although aconite represents the arrow poisons which *paralyze the respiration,* there are other poisons more widely used which *act on the heart* of the victim. Throughout Asia and Africa, there are in use many poisons of this group which are also applied—like strophanthus—for the medical treatment of heart failure. Many Europeans have lost their lives through such arrows.

Another group of arrow poisons *causes convulsions.* Plants containing strychnine and the poisons of certain snakes and insects, widely used throughout the Old World, belong to this group of arrow poisons.

Natives of New Guinea and Australia, where other poisons are not in use, dip their arrows into decaying carcasses just as, according to Aristotle, the ancient Scythians dipped their arrows into a mixture of human blood and snakes in decay.

The most famous poison in America is curare which was brought to Europe by Sir Walter Raleigh in 1595. It is still in use among the natives of the Amazon and Orinoco rivers, in French Guinea, Rio Negro and elsewhere.

Let us not be hypocritical! Not only natives of the black and primitive countries used poisons for war. Germanic tribes used poisoned arrows for centuries. The Vandals

and others also used poisoned arrows. Such weapons were in common use during the 13th century. Remember Hamlet's duel and Beowulf's. During the 15th century surgical literature discusses thoroughly the treatment of injuries caused by poisoned projectiles.

Soon after the invention of fire-arms poisoned bullets or projectiles were used. The attempts may appear sometimes very primitive. At least the fact that such attempts were undertaken again and again, proves that the evil thought was there and has been alive at all times.

There are formulas for mixtures of gunpowder and various poisons recorded from the 16th to 18th centuries. Arsenic, mercuric sublimate, auripigment, even lead compounds were recommended, and also vegetable poisons, such as belladonna, mandragora, helleborus, strychnos seeds and many more.

Certainly, all these compounds are destroyed by the explosion of the gun powder, forming rather ineffective products. Even if we consider the limited chemical knowledge that, for centuries, was directed at alchemical aims, the search for the alkahest, the panacea and the transmutation of base metals into gold, the beginning of scientific physics and chemistry can be dated back to the 17th century. Still this scientific knowledge was not widely spread and so dilettantic formulas as mentioned above were recommended and used as late as the beginning of the 18th century.

These facts prove that the generals did not want to learn from the scientists at that time. Even during the World War the generals were sometimes hesitant to follow the advice of the most distinguished professors of chemistry.

It was considered more practical for the early development of gas warfare to put the professors of chemistry into the uniforms of soldiers and officers which however did not make

them true warriors or military experts. At times, teams were formed by the coordination of professional or reserve army officers and professional chemists drafted into the army. When the persons so allied were intelligent and tactful, the teams worked well, otherwise the results were rather ludicrous.

Some improvements concerning the technical training of personnel may have been attained in the armies of various countries. It remains to be seen to what extent scientific and military training are compatible. The soldier's education for precise, strict and straight statements and the scientist's more problematic approach are too frequently not easily united in the same person.

Gas And Fire

The use of gases and vapors in warfare is very old. The smoke of green wood was used very early in history, in order to drive out men or animals from caves or nests. Later, resins, pitch and mineral products, as sulfur and arsenic were added to such smokes. This has been recorded in the history of the Assyrians, the Chinese, the Greeks and other peoples.

Thukydides reports that the Spartans, in the battles of Platææ and Belium, during the Peloponesian War, 431—404 B.C., used smoke containing arsenic for attack. Plutarch reports in the vita of Quintus Sertorius that he used an ash-like sand, in the war against the Charakitanes in Spain, which was driven with the wind, thus causing cough and blindness and defeat within two days. In 187 B.C., according to Polybius, 22nd Book, 11th Chapter, the people of Ambrajia, besieged by the Romans, produced smoke from a barrel, filled with fine feathers and glowing coals to drive out the Romans from the mines.

According to Kallinikos, the Greek fire that was in use during the Middle Ages up to about the year 1000 A.D., contained petroleum, pitch, resins and sulfur. Fioravanti of Bononia made stench bombs from an oil that was distilled from turpentine, sulfur, asafœtida, human feces and blood.

Other recommendations, of a more modern character, were made by Leonardo da Vinci, Leibniz and Johann Rudolf Glauber (1604-1668). Glauber used a preparation made from turpentine and nitric acid to make incendiary bombs and smoke shells.

In 1701, Charles XII, King of Sweden, used an artificial fog in his war against the Russians to force his way over the Duna River.

The French pharmacist, Lefortier, in Sèvres, constructed an "obus asphyxiant et incendiaire" in 1830, but this invention was not applied in practice.

The General Pilissier used smoke from green wood against the Kabyls in Ouled Ria in 1845 and suffocated the whole tribe in this way. He was recalled by the French Government on account of this massacre.

In 1855, the British War Department examined shells, containing cacodyl and cacodyl oxide combined with self-inflammable liquid. The British General Dundonald, at the same time, proposed the use of vapors of sulfur dioxide during the seige of Sebastopol, but the Government refused the proposition.

Modern chemical warfare begins with the German gas attack at Ypres on April 22nd, 1915, when 5,700 cylinders, filled with chlorine gas, were blown against the Allied front. This first gas attack of the World War was, at the same time, the most effective one of the entire War, because it met the Allied Armies both unprepared and unprotected. It has been assumed by military experts of the Allied Armies that

this attack might have decided the War, if the German High Command had immediately exploited its success. The German High Command, under General von Falkenhayn, did not have the imagination or foresight to see the potentialities of this new means of warfare and admitted it only as an experiment without providing sufficient reserves in the case that it proved successful. Only later, Hindenburg and Ludendorff proved to have a better understanding of modern chemical warfare, but it was already too late, as the Allied Armies, by this time, were equipped with adequate protective means.

Fire has always been one of the main weapons in war throughout history. It was inseparable from smoke, as long as the modern methods of production of artificial fogs were unknown. Therefore, the effects of fire and smoke are frequently combined in old-time weapons. Such was the case with the famous Greek fire. The composition of this device was carefully kept secret in Constantinople for 400 years. Then the Mohammedans succeeded, by espionage, to learn its secret. Its action resulted in fires and smoke containing carbon monoxide.

When Acron was besieged in 1289, three hundred catapults threw Greek fire into the town, until it was entirely burned down. Many inhabitants were asphyxiated by the smokes formed.[9]

The difference between this method of warfare and the use of modern incendiary bombs is not great. The idea was then the same as it is today. The use of modern flame throwers is not very different from the old-time habit of pouring boiling oil on the aggressors of a beleaguered place.

The idea of chemical warfare has remained unchanged

[9] **Lewin, Gifte in der Weltgeschichte, p. 678, Berlin (1920).**

throughout history. Only the technical means are progressive.

Explosives

Since the invention of gunpowder, explosive gases have always threatened the defender and the aggressor alike. The explosion of picric acid produces gases containing 61.05% carbon monoxide. Trinitritoluol, one of the most widely used explosives, produces by its explosion a gas mixture containing 57.01% carbon monoxide. Dynamite forms 34% carbon monoxide. These effects of explosive shells have been investigated and the results of this research were published for the first time as early as 1909 by the great German pharmacologist Lewin.[10] Neither the German nor the Allied admiralties, however, were ready to draw practical consequences for the protection of their sailors. They learned only by the experience in the first naval battles of the World War. Not only sailors, but also a great number of high ranking naval officers paid with their lives for their unwillingness to learn from science what science had offered to them.

The enemy shells, hitting and exploding inside the vessels formed explosive gases that contained such amounts of carbon monoxide, as mentioned above, in addition to carbon dioxide and nitrous fumes. The gas mixtures which are highly toxic could not escape from the hermetically closed rooms. The gases, therefore, seeped through pipes which connected the rooms, where they exploded, with the rooms of the commanders in the armed towers. These officers, not aware of the danger, inhaled the gases, fell sick and died from the concentrated carbon monoxide gas mixtures.

[10] **Lewin and Poppenberg, Archiv für experimentelle Pathologie und Pharmakologie, vol. 60, p. 433 (1909)—Zeitschrift für das gesamte Scheiss-und Sprengstoffwesen (1910).**

After these battles only, did the admiraltics call for help of the scientists. The ordinary gas masks did not protect against carbon monoxide. A special filter, giving such protection, was developed for the use of the navy.

Under special circumstances, therefore, explosive shells may also form asphyxiant and toxic gases. The action of these gases—especially when the poison takes place in closed rooms—may be more important than the explosive effect. It is, therefore, difficult to define the borderline between gas ammunition and explosive shells. Indeed, international conferences did not succeed in finding a satisfactory definition.

The idea of chemical warfare is consequently not separable from modern war technique. Only a very few of the poisons used in chemical warfare are gases or vapors, most of them are liquids or solids at ordinary temperature. It would be, therefore more correct to use the term "Chemical Warfare" instead of the more popular "Gas Warfare". Explosives, incendiary bombs, artificial fogs, etc., may develop gases of poisonous character. Chemical warfare includes all the hazards resulting from manifold causes. The reader will also understand that chemical warfare is not an invention of the last World War, not an invention of one nation, but it has been developed throughout history along with the progress of chemistry and other sciences.

The Idea And The Law

The logic of the lawyer is based on definitions. As no exact definition can be established of the term "chemical warfare", "gas warfare", "gas attack" etc., the lawmakers have been unable so far to arrive at the enforcement of internationally accepted or respected laws. The subject, therefore, can be discussed very briefly.

On August 27, 1675 an agreement was reached in Strassburg between the German and French Armies. Article 57 of

this agreement decrees that no side should use poisoned bullets. Wherever such weapons would be found, the person thus convicted should be severely punished by his own superiors.

This is the first international agreement in modern history through which the use of poisoned weapons is prohibited.[11]

In more recent times, the International Conferences in Petersburg (Russia), Brussels (Belgium), and the Hague (Holland) in 1899 and 1907 reached agreements prohibiting the use of poisons or poisoned weapons.

It was said by a military expert in England in 1911: "It is certain that no civilized power would allow its troops to use poison today.[12] No comment is needed.

Article 171 of the treaty of Versailles contains the statement that the use, production or import of asphyxiant, poisonous or similar gases as well as liquids, products and procedures, are prohibited.

The confidence in international treaties was nevertheless below zero at all times. All "civilized" countries, their general staffs and armies, prepared for gas attack and defense as well.

[11] Lewin. Gifte in der Weltgeschichte, p. 563, Berlin (1920).
[12] Spaight, War Rights on Land, p. 85, London (1911).

CHAPTER II

THE MEN BEHIND THE GAS

How I Came To Know Them.

When I first met Fritz Haber on a Sunday morning in the courtyard of his Kaiser Wilhelm Institute of Physical and Electrochemistry, there was not much time lost with introductory formal talk. Almost immediately, he confronted me with physiological problems that puzzled him. Experiments with animals had been made already. But it had happened too frequently that those rabbits or cats which had been exposed to higher doses of gases survived, while other animals exposed to smaller doses of the same gases, under seemingly identical conditions, were fatally poisoned.

This was, indeed,one of the principal difficulties connected with such experiments. When the technical details of this problem are discussed in chapter VI, the reader will understand, how much work on the part of physicians and chemists had to be done to elaborate all the physical, chemical and biological factors involved and to find a rather definite answer to this very complex problem.

I was, then, a young physician at the beginning of my career, to be exact, 25 years old. Spurred on by Haber's fascinating, commanding personality I felt I had to answer this question in a constructive way which would lead, directly and without a detour to the practical solution. I made an outline of the experiments and research that should be made for the solution of this complex problem. I also asked for

the laboratories, equipment and physicians, chemists, zoologists, technicians and other personnel which were needed for the purpose. Haber agreed and signed an order that gave me authority to build up the pharmacological section of the Kaiser Wilhelm Institute which was organized in such a way that problems could be solved within one week which would have taken at least half a year for the average university institute. This was accomplished immediately.

In the following years this work brought me in close contact with the leading pharmacologists and chemists of Germany whom I learned to know as scientists and human characters.

Such was my introduction into the world of poisonous gases.

For the duration of the World War I was fascinated by the sphinx like complexity of this peculiar branch of science. My military rank was that of first lieutenant, my next superior was the "Royal Prussian Captain" Professor Fritz Haber, Chief of the Chemical Section of the War Ministry. His only superiors were the Minister of War and the Commanders of the German Army, the General Field Marshals Hindenburg and Ludendorff.

After the World War I devoted my experience and further studies to the subject of noxious gases in peace time, for the benefit and welfare of workers in industry. Yet, after about 15 years of such activity, when I arrived in Paris, France, the French were much more interested in my war time experience than in industrial hygiene and occupational diseases.

After the Franco-Soviet Pact was initiated by Mr. Laval's visit to Moscow in 1935, my friends in Paris induced their new Ally, the Soviet Government to invite me, under very

flattering conditions, to come to Moscow as an adviser to the Russian Government for civil air defense. When I arrived there, in July, 1935, I was received, just like before in Paris; somebody said: "Here comes the gas man!"

Nor could I escape this reputation, when I returned two years later in Paris and then to London.

I cannot admit that it was my fault that so much more attention was paid to my studies of chemical warfare and so little to the problems of noxious gases in industry.

In a time like this gas warfare seems, indeed, more interesting than industrial hygiene to many people. On my return from Russia, in Stockholm, the Swedish newspaper men who came to interview me wanted to hear all about war problems and Russian preparedness for war, while I was at that time, much more interested in a thorough study of social and public welfare conditions in Sweden.

After that, when I came to London, I was again drawn into many conversations on gas warfare. There were no questions on industrial diseases. Englishmen seemed to know all about the latter, but only wished to discuss chemical warfare with me.

Fritz Haber

In 1914, the German Armies marched through Belgium into the heart of France. There was no rest between marching and fighting for weeks. The Battle of the Marne was won by the Allies. Again without rest both the Allied and German Armies marched day and night, until they dug deep into the French soil along the 500 mile line for the four years of the war of trenches to come.

France was deeply shaken by the events that saved her definitely from further invasion. The German people had

not the slightest idea of the fact that at that time they had already lost the World War. They lived on for four more years in that state of exultation that was caused by their trust in reported conquests and made them believe in final victory.

Only a small number of staff officers of the Army General Head Quarters were slightly worried by the complete lack of artillery ammunition. The infantry was without defense against the French and British artillery shellings, as the German guns were unable to reply. In the beginning, there was a harmless explanation at hand: the German advance and retreat had been so fast that ammunition supplies could not follow at the same pace. Every morning every single battery of field guns and howitzers had to count the shells they had and to report the number to the higher staffs. Twenty, fifty or a hundred shells at hand for a battery of six field guns was considered an ample supply at that time.

Had the French attacked the German lines at that time, the entire German artillery would have been silent after five minutes of firing. There was neither economic understanding nor technical comprehension on the part of the Allied leaders. Else the World War could have been brought to an end with a complete defeat of the Germans in December 1914.

Only a few German generals knew of the highly critical situation. There was iron and steel in abundance, but there were no explosives. Nitrates, ordinarily imported from Chile were lacking completely. None of the economic experts of the Reich had expected that modern war tactics would exhaust the stocks of ammunition in so short a time. There was plenty of nitrogen in the air of the atmosphere, but there was only one man in the world who knew how this

nitrogen of the air could be used to produce the explosives that would frustrate the early victory of the Allies.

This man, Fritz Haber, at that time, was experimenting in his laboratory in peaceful Dahlem, a western residential suburb of Berlin, where the research institutes of the Kaiser Wilhelm Society were located. Only a very few of his peace time assistants remained with him. The others had gone to the army. Neither in Germany nor elsewhere did the people realize the tremendous service this man gave to his country, until a heavy explosion shattered the quiet institute and tore off the arm of one of Fritz Haber's most able collaborators. Thus the people learned that this place of scientific research had brought forth the new process, how to make nitrate and modern explosives from the inexhaustible and omnipresent supply of nitrogen in the atmosphere.

With the efficiency that is characteristic of the scientific mind, factories were immediately developed and ammunition began to flow again into the empty camps of the German Army at the Western front. The now world famous Leuna factories were developed and Germany saw this plant growing from month to month.

Less than twenty years later, the man who saved his country from early defeat in the World War through the same process that provided the agriculture of all countries of the world with the most effective artificial fertilizers had to leave his country, because his dead parents were Jewish. He died in exile only a short time later.

While the Western front at the end of the year 1914 enjoyed the relative quiet that followed the battle of the Marne, the minds of the men in the trenches again began to function more normally. A thought that apparently was in the air flashed through thousands of brains belonging to chemists

then serving as soldiers in both armies: irritant and poisonous gases should be used to fight and defeat the enemy.

About at the same time, hundreds of letters from such chemists in the trenches poured into the War Ministries of Berlin, Paris and London, suggesting the use of chemicals for war.

The idea was striking. However, the military experts behind both lines did not fully understand its importance. Only a few outstanding scientists in each country took up the idea and began to experiment, some of them on their own initiative and responsibility.

Not much result came from these scattered efforts. The French used small rifles and hand grenades filled with insufficient quantities of irritant gases that were about of the same size and had about the same effect as have the tear gas bombs still used by police.

For the second time, Fritz Haber came to the aid of his country. He prepared the first and, up to date, the most effective gas attack in the military history of the world.

The scientific atmosphere of pre-war Berlin was characterized by the presence of great physicists and chemists, some of them the greatest not only of our time but of all times. Only a few of the names may be mentioned: van't Hoff, Nernst, Planck, Einstein, Emil Fischer, Richard Willstaedter, Frank, Freundlich, Carl Neuberg, Fritz Haber. The scientific meetings of the physical and chemical associations in pre-World War Berlin under the leadership and control of such minds are unforgettable for everyone who took part and was able to follow the ideas of the most advanced geniuses of our time.

Not infrequently, Haber discussed problems in these meetings. He presented his ideas in a splendid way, yet spoke

and presented his suggestions or thoughts like a teaching professor or philosophical thinker. A short time later, however, when he was confronted with the problems of war and nationwide planning of chemical production, his personality grew in a miraculous way. He always remained the same natural human being, but his personal superiority grew immensely, his genius always perceivable to sensitive persons became more impressive even for the average man, the spiritual distance between this man and ordinary people became more apparent, his commanding authority required undisputed respect. When Napoleon Bonaparte met Goethe, he said: "Voilà un homme!" This was my impression, when I met Haber again for the first time after the outbreak of the war.

When Haber prepared, planned and directed the first great history-making gas attack at Ypres (Belgium), he was a non-commissioned officer, not even a lieutenant in the Kaiser's Army. It was a fundamental break of the tradition, when after Ypres, the Kaiser appointed Haber a captain. Even the princes of the ruling house of Hohenzollern had to pass through the regular scale of advancement from lieutenant to first lieutenant and captain. Haber was probably the only case in the history of the Prussian Army that a non-commissioned officer of the reserve was directly promoted to captain and director of a section of the German War Department, its Chemical Section.

France

During the World War, the French Chemical Warfare research was highly efficient. This record is too well known to need discussion. It seems that after the World War, French scientific and military circles became satisfied

with themselves to such an extent that further progress was impossible.

When I came to France after the World War I felt that, like everything in France, the atmosphere in which the French scientists lived and worked was different from that of Germany. No more than other Frenchmen, would scientists have violated the sacred rite of undisturbed lunch time. There was not too much emotional interest in work. Everything was done with the coolness of logic. The Fatherland was highly important to some of the scientists, only when this attitude was helpful to the individual at the same time.

One of the Paris professors was interested in a special method which I had developed but not yet published. He explained to me that French editors, patriotic as they were, could not well give their space to a German scientist. Therefore, he would like for the benefit of science to publish my method in his name and to pay me for leaving the authorship to him.

However, there were, in the same city of Paris, other Frenchmen, who were honest patriots. One, professor L., editor of a scientific periodical, invited me to write a paper and published it without feeling that this was not compatible with his patriotism.

When I visited Paris again, after my return from Russia (in 1937), this professor had disappeared from his laboratories at the Conservatoire des Arts et Métiers. He was now chief of the cabinet of one of the ministries. He was young vigorous and ambitious, highly talented and an open character. He had accomplished valuable work in his field, but in spite of his personal energy, his institute was almost deserted as were most scientific laboratories I visited in Paris.

At that time French laboratories were quiet, somewhat depressing by their emptiness and lack of life. They could not stand comparison with the businesslike correctness of British institutions nor with the overcrowded laboratories in Russian research institutes.

The same unemotional approach which I met among the French scientists was characteristic of French generals and officers in charge of gas warfare and air defense. There was no noticeable progressive work. In 1937 it was still an open question, whether civil air defense would definitely be controlled by the Air Ministry or the War Ministry. Everybody admitted that a decision should be made quickly, because the danger was imminent. Somebody suggested that the prime minister should be urged to make a decision on this problem immediately, but the General in the Air Ministry was in no hurry and was in a rather resigned mood. There was a cool atmosphere, almost a lack of interest as far as the emergency situation of the country was concerned. Opportunism in personal matters prevailed. I saw only confusion. I was not a bit astonished, when friends wrote me from Paris, a year later, that it was impossible for them to buy a gas mask at any price in all Paris. For this reason alone, they felt relieved, when Daladier brought his "peace in our time" back from Munich. The lack of preparedness, cool, reserved lack of interest in common affairs combined with personal opportunism, were all too apparent in the field of French gas warfare and civil air defense. As conditions were the same in other fields, the decline of democracy was the only thing for which there was any preparedness.

A Frenchman who had been all over Europe as an attaché and in other diplomatic positions, expressed the same opinion, when he said to me in Paris: "I know my country-

men. I can also compare them with other peoples. They do not want war for any cause, but they will readily give their lives only, if and when they are threatened by loss of money and property. They will die for their money."

Then, in 1937, I saw the foreshadows of the tragic fate of democratic France, the most humane people of Europe. I felt, it was time to leave that continent for good.

Soviet Russia

During the World War, Russia was surprisingly efficient in the field of gas warfare. The men who served the army of the Czar disappeared from view after the Bolshevik revolution. New men have grown up. Some of them are nationally or even internationally known as outstanding scientists in their fields. I may mention Professor S. W. Anitchkoff, director of the Military Academy in Leningrad. The names of others and the men themselves are kept secret under Russian regulations.

When I wanted to see the manager of a factory, where air filters, for the use in the ventiliation systems of air-raid shelters are made, I could get no information at all. Finally, when I insisted, I was informed that I could not see this factory on account of the regulations for military secrecy.

I suggested that the manager of this factory should come to see me, but this was not possible either. Russian regulations demand that the seat of the factory, the name of the manager and other employes should be kept secret. The manager is not allowed to see strangers. The factory is known only by a number without indication of its location. Letters and orders are simply addressed to factory number and not only arrive, but the orders are also executed. I was never admitted to see the manager of this factory, but

I received the filters which are manufactured there. They are correct imitations of American models and are marked as such. Under these circumstances it is still more difficult to understand the reason for this secrecy. I mention this experience, because it characterizes to some extent the Russian atmosphere in the field of chemical warfare and air defense.

There is materially, mentally and morally more preparedness for gas warfare and air defense in Russia than elsewhere. A tremendous organization "Ossiaviachim" possesses numerous research institutes and training centres under the direction of military and scientific experts. The Russian people are, at least, *gas-conscious,* more so than the French and English were, when they entered the war.

So numerous are the men behind the gas in Russia that I cannot mention individuals. Only a few can be outstanding, of course. One may meet among them the same types as elsewhere: the routine-man, the talkative "wise-cracker," the scientific clerk as well as the creative personality.

It may be of interest to mention an outstanding general of the Russian army who was in charge of chemical warfare and air defense for the entire army and territory of the Soviet Union, until he died in 1936. He had been an officer in the General Staff of the army of the Czar. After the revolution he became a loyal officer of the new government. He was loyal and he was efficient in his field.

He did his best to make the military and civil air defense of the Soviet Union a strong weapon. The military aspects of gas warfare belonged to his domain. His name was Kamenieff; the same name as the old revolutionary Kamenieff who had been sentenced to death as a traitor by a Stalinist court.

Both Kamenieffs, the revolutionary, convicted of treason, and the general, died in the same August night in 1936. The revolutionary was executed, the general Kamenieff was said to have died of natural causes in his bed. He was given a state funeral. Stalin, Molotoff, Voroshiloff and other members of the government personally carried the coffin of the former Czarist officer through the streets of Moscow, flanked by the silent crowds.

General Kamenieff was a real soldier. He loved his country, Russia, no matter by whom it was ruled. Shortly before his death he had carried through a general inspection of the gas defense of the Soviet Union and submitted his judgments and criticisms to the Council of Peoples Commissars which corresponds to the inner cabinet under the presidency of the prime minister in other countries. He introduced methods and procedures into the Russian military and civil air defense which are worthy of being followed elsewhere. They will be discussed in detail in my next book that deals with civil air defense. His fate represents another of the personal tragedies suffered by men behind the gas.

Great Britain

In Britain, the research in gas warfare had fallen into the hands of outstanding scientists and men of genius. During the World War, technical and physiological research brought excellent results in Britain. The British gas mask and the box respirator were among the best gas protection devices. The British Intelligence Service helped the scientists efficiently, as can be proved by the following experience: laboratory research on the first mask-penetrating gas was going on in Berlin in 1916. Only a small number of

scientists, exclusively chemists of the laboratories concerned, knew about it. The first few experimental shells were tested on the manœuvering field of Döberitz near Berlin, when a messenger brought a small package from General Head Quarters at the Western Front. The package contained a little capsule filled with filter paper and was adapted to use with the British box respirator. This device guaranteed full protection against the new mask-penetrating gas of the Germans and had already been many months at the British front, before the first German shell with mask-penetrating gas was used.

This example may be sufficient proof that the men behind the gas in Britain were at least alert. Sir Joseph Barcroft and J. B. S. Haldane are internationally famous for their research in the physiology of respiration. When I met other scientists and army officers in London in 1937, I noticed some confusion in the minds of Englishmen, just as there was in Paris. The interconnection here between military preparedness, business and personal profiteering takes place, however, in a nobler or cleaner atmosphere. The British industry that specializes in devices for divers and safety appliances for the fleet, mines, etc., is more than 150 years old, lives up to a respectable tradition and is, therefore, a most stable industry. Consequently the gas masks for the army, navy and civil population were ready in time, not as in France.

I do not wish to quote the names of the men with whom I discussed gas warfare and air defense in various countries during the years preceding this war. Many, or perhaps all of them, are still alive and in official positions. Some of these very frank conversations were certainly not intended for publication, but were all the more characteristic of the situation.

I may say, however, that I discussed the great efficiency of German "Blitzkrieg" methods with military experts in London in 1937 and found that even among them there was much confusion of minds; also there was not the slightest idea of what was to come. I was seriously and sincerely asked to write a book explaining that civil air defense is too expensive to be borne by a nation if it is carried through in a complete and thorough way. I could not agree with this and I still do not.

Omitting certain details which would permit identification of the person in question, I may mention another conversation which I had with a British officer of high rank.

This gentleman had been engaged in certain specified research in Britain similar to one with which I was loosely connected in Germany; both during the World War. I acknowledged in our conversation that I considered the British method of investigation more practical in this special problem, and he was pleased with my opinion. Certainly with no other intention than to tell me something he thought I would like to hear, he explained to me his opinion that Englishmen had greater sympathy for the Germans than for the French. Too frequently in the past the French had been enemies of Britain. "Now," he said, "we are allied to them for nothing but the idea of democracy."

This confession was certainly frank. It would have shocked me more deeply, had I not learned—only a few weeks earlier, in Paris—that certain groups of Frenchmen had similarly unpleasant opinions about their British Allies.

United States of America

The men who were responsible for chemical warfare in this country during the World War are well known, so that not much need be said regarding the United States, where the men behind the gas were free to report their own records.

The chief of the Chemical Warfare Service in Washington was Major-General Amos A. Fries. He wrote, together with West, a book on chemical warfare. The medical aspects of chemical warfare have been published by Colonel Edward Bright Vedder; and a book on noxious gases was written by Dr. Yandell Henderson, Professor of applied physiology at Yale University, who was in charge of the United States war gas investigations during the World War.

In addition, Henderson wrote a volume of personal memoirs in which he discusses the human side of the science of gas. There is indeed no need for additional discussion of the men behind the gas in this country. They have presented themselves and their records quite openly and clearly.

Not much has been published in this country about further progress in the field of chemical warfare since the World War. One may wish to believe that chemical warfare is, in the United States, at least as far advanced as it is in European countries.

It is reasonable that military secrecy should be preserved in a field of military importance like this. The only criticism, however, that may be justified, is this: Publications on first aid and medical research concerning war gas intoxications should not be restricted, so that American physicians should be well prepared to come to the aid of gassed Americans in case of war.

The United States Gas Warfare Service has taken care of this task very well. The regulations are better than those of other countries.[1] I have seen their translation into the Russian language printed in Russia, to be used by the air-raid precaution service of the Red Army. The original regulations,[2] are, however, not available for American physicians. It seems, they are kept secret in our own country.

[1] While I was in Moscow, I had the opportunity of discussing with experts of the Russian Government the usefulness of these regulations in comparison with those of other countries.

[2] The A.R.P. Dept. of Great Britain has published regulations on the "Medical Treatment of Gas Casualties", 145 pages, London, (1937).

CHAPTER III:
PSYCHOLOGICAL, SOCIAL AND ECONOMIC ASPECTS

Psychological Aspects

The onrolling cloud of suffocating fumes forcing the French to retire from the trenches near Langemarck on April 22, 1915, the day which is usually considered as the beginning of modern chemical warfare, created surprise. horror and death. This event stirred the imagination of men very deeply because it caught the Allied troops entirely unprepared. The code of honor of the medieval knights forbade the killing of an unprepared or unarmed adversary. Humanity respects unwritten laws of honesty, even during a pitiless war. Yet surprise is, and always has been, the most effective means of attack that every general or soldier would use, whenever possible. Gas attacks lost much of their horror, after gas protection was perfected. Still the fear of surprise in chemical warfare remains and frightens the professional general all the more, the less he knows about chemical science.

General Weygand says: "Chemical warfare always exposes us to one main danger: the technical surprise, the discovery of a new gas which would penetrate the gas masks. It would, indeed, create for the armed forces and the civil population of a country, thus surprised, a dramatic situation, such as existed in April, 1915 for the troops which, without any protective devices, were ex-

posed to the action of the first wave of chlorine. . . . The only way to be, in a minimum of time prepared for defense against a surprise of this kind as well as to riposte against an adversary who would take the guilty initiative, is to work out in advance all the problems concerning chemical warfare." [1]

Chemists or physicians are not extraordinarily frightened by a new poison, because they are familiar with hazards of this kind. Generals are not, or, at least, were not so during the first World War. They were, however, well familiar with firearms of all descriptions. For this reason alone, army men had less fear of the fatal and crippling power of gun shells than of the insidious gas clouds. This kind of feeling has been preserved in a great part of our population. Yet, in a country, where every citizen is provided with protective masks and shelter, no undue fear of gas is reasonable.

It is an experience of the World War and of more recent wars that terror is less effective in actual warfare. Narratives and pictures of horror, of actually experienced horror, surpass the effect of the event itself. During the fight itself or, while we give first aid to the victims of battle, while we are exposed to bombing or war gas, our minds are directed to the immediate need for protection or help. Higher feelings are repressed through the needs of the moment. Every war veteran who took part in battles and afterwards read the descriptions of these events in books knows it. Hate and pity are silent in actual warfare. For these reasons all the people of bombed London have become soldiers; not only the men, but women and children as well. Terror as a weapon of war is ineffective.

[1] **André Meyer, Gaz de combat. Paris (1938).**

False sentiments may be stirred in peace time through ridiculous nonsense written by ignorant zealots. With the first hour of warfare these sentiments are scattered into thin air.

Preparedness based on the knowledge and scientific understanding of the possible dangers from gas warfare is all that is needed to deprive the threat of terror of its effectiveness.

Social Aspects of Chemical Warfare

The social effects of chemical warfare are only part of the social effects of war in general and especially of total war.

There are some useful effects of chemical warfare. It has been mentioned that a strong impetus toward industrial safety and compensation of occupational intoxications originated from the research on chemical warfare during and after the first World War. Toxic gases are used to fight noxious insects in agriculture and for the prevention of contagious diseases. Science itself is neutral; it equally serves the aims of the good and the evil. The scientist is devoted to science. The people and government determine, whether science should be used for destruction, defense or construction. The scientist devotes his service to his people and government and is not primarily responsible for the use to which the government puts his scientific achievements. True scientific research is not done with a view to material profit or public reward. Research for the sake of science and cultural progress and for spiritual advance of humanity only were our aims, before the search for profit became all powerful.

War Casualties Through Gas

The direct social effects of chemical warfare mainly concern the fates of the victims of gases: fatalities, temporary or permanent disability and compensation for such effects.

The statistics on the total casualties through gas are less complete and conclusive than the statistics on fatalities. It can be assumed that the total casualties through gas poisoning on both sides during the World War, including the injured and dead exceeded 1,000,000

The total fatalities through gases were only 30,000

The total casualties due to all weapons including gas and including all nations which participated in the first World War are estimated at about 35,000,000

This figure includes the dead 10,500,000

The casualties suffered by the principal belligerents and caused through the use of all weapons were as follows:

United States	262,000
Gt. Britain	2,978,674
France	5,693,000
Germany	6,055,000

The social effect of the losses caused through gas casualties alone may appear relatively small, if one compares the figures of gas casualties and fatalities of the first World War with the civil accidents which occurred in the one year, 1939-1940, in the United States. Here we had more people killed in one year in accidents at home than were killed through gas in four years in all belligerent nations together. The same must be said of our highway fatalities. In the one year 1939-1940 three times as many Americans were killed in farm accidents as died through gas in 1917-1918 in

the battlefields and in the hospitals. The number of American accidents during the year 1939-1940 exceeds by far the total casualties which any one army suffered from all weapons during the four years of the World War.[2]

The total losses through gas are recorded as follows

for the United States	75,000
Gt. Britain	180,981
France	190,000
Germany	78,000

The following figures include those who were killed in action or died in hospitals from gas poisoning:

United States (1917-1918)	1,399
Gt. Britain (in 1914-1918)	6,080
France (in 1914-1918)	8,000
Germany (only in 1918)	1,755

The percentages of those who died through gas in proportion to the total number of gas casualties are the following:

United States (only in hospitals)	1.73%
Gt. Britain	3.35%
France	4.2 %
Germany (only in 1918)	3.0 %

The percentage of those who died from injuries caused through weapons of all kinds in proportion to the total number of casualties are estimated at between ..... 24-30%.

There can be no doubt that the comparison between these

[2] The Annual Report of the American Red Cross for the year July 1, 1939 to June 30, 1940 records the total United States accidents 8,800,000
including fatalities ..... total 93,000
through automobile accidents 32,600
through accidents at home 32,000
through farm accidents 4,200
Quoted from New York Times, November 3, 1940.

figures, mortality through gas, 1.73-4.2%, mortality through all other weapons, 24-30%, proves that gas is the most humane weapon ever used so far.

The number of gas poisonings, requiring hospitalization, in the American Expeditionary Force during the first World War was 70,552. These cases were caused by various gases in the following proportions:

Gas	*Officers*	*Enlisted Men*	*Total*
Chlorine	31	1,812	1,843
Phosgene	409	6,425	6,834
Arsine	31	546	577
Mustard gas	883	26,828	27,111
Irritant poisons of unknown composition	1,249	32,338	33,587
Total	2,603	67,949	70,552 [3]

The total mobilized forces of the United States during the World War were 4,355,000

The French, British and German armies fought in many war theatres, where very little or no gas at all was used. For this reason it is not possible to consider the figures for gas casualties in relation to the number of total casualties or to the number of mobilized men. Exact figures have been published by the American Warfare Service for periods during which the amounts of gas and explosive munition and of casualties are established reliable statistics.

Permanent Disabilities

It is of great social importance that permanent disabilities caused by gas poisoning are far less numerous than those caused by other weapons, epidemics and other causes.

As the mortality of gas poisoning is only about one tenth of the mortality caused through other weapons, the pensions paid to dependents of those killed by gas are accordingly few.

[3] Hanslan, l. c., p. 214.

Among the permanent disabilities caused by gas poisoning the following are the most frequently found: emphysema of the lungs, chronic bronchitis, asthma, bronchiectasies, cardiac disturbances.

Tuberculosis cannot be caused by gas poisoning but only by infection with the Koch bacilli. However, latent tuberculosis may be reactivated by intercurrent gas poisonings. Such cases must be infrequent, because persons with latent or quiescent tuberculosis are not drafted into the army; if it does occur, it can occur only through a mistake. If gases are used against civil populations, this problem will become one of the first order. It cannot be denied that in certain cases the organism of a person is weakened by gassing so that the patient may be infected with tuberculosis after having suffered gas poisoning.

Among 70,552 American cases of gas poisoning, medical examinations revealed the presence of tuberculosis as a late sequela in only . . . . . 173 cases
This is in 0.24%
Achard in France examined 3,535 cases of gas poisoning and found late tuberculosis in only . . . . . 6 cases

Such are the results of some careful investigations. Equally in Britain, France, the United States, and Germany permanent disabilities of all kinds have been found to be very infrequent after gas poisoning.

In spite of such authoritative statements, there remains some doubt in the mind of both laymen and physician as to the correctness of these findings.

It is certainly safe beyond any doubt that there are and must be far less permanent disabilities after gassing than other mechanical injuries. There can be no losses of limbs, no crippled victims through gas. Even mustard gas has caused only a very small number of cases with permanent

blindness. Fire arms cause both total or partial blindness in far greater proportions than do gases.

On the other hand, about one-half of the gassed World War veterans of the United States claimed subjective complaints in medical examinations, three years after the armistice of 1918. Yet there were no objective findings. No compensations or pensions are paid for such cases nor are they included in statistics as cases with permanent disabilities.

However, both laymen and physicians alike know very well that there are many symptoms in all kinds of diseases which cannot at all — or sometimes only with the greatest difficulty — be objectively proven by medical examinations.

There can be no doubt that in a number of gassed persons a decrease of physical fitness and efficiency and a loss of resistance to physical, chemical or bacteriological exposures result in a permanent sequel which cannot be objectively diagnosed by any kind of medical examination.

In March, 1917, I submitted to the Medical Department of the German War Ministry a report about the "evaluation of war gases with respect to their faculty to cause chronic disabilities." This report was never allowed to be published. Not only post mortem findings in experimental animals and human autopsies of gas victims, but also clinical statements by physicians of gas hospitals and gas regiments served as basis for this study. Such clinical reports made it certain that in a number of cases gas poisoning had caused a decrease of physical efficiency for which no objective clinical symptoms could be found. Problems of this kind will be discussed in greater detail in the chapters dealing with the medical aspects of chemical warfare.

The figures mentioned so far prove the following statements:

1. The mortality of men injured by shells, firearms, explosives and all weapons other than gas was about ten times as high as the mortality through gas during the World War.
2. The mortality through gas was about the same or at least of the same magnitude on both sides.
3. The mortality through gas poisoning in the American army was the lowest of all belligerents. This can be explained partly by the fact that the figure refers only to cases treated in hospitals, but it can also be assumed that the American medical service was more efficient than that of other nations. It is explained elsewhere that the fate of the gassed individual largely depends upon an adequate system of transportation.

The American means of transport for wounded and gassed men were superior to the vehicles of other armies, not only during the World War, but also eighteen years later. While I was in Russia, I attended an army inspection, the purpose of which was to establish standards for the transport of gassed soldiers. The Russian Government had brought and assembled on a manœuvering field near Moscow original models of army ambulances from various countries.

As a result of this inspection it was obvious to everyone and also acknowledged by both the chief of the medical corps of the Red Army, General Baranoff, and the chief of the civil public health administration, Peoples' Commissar Kaminski, that American type ambulances were most practical and most worthy to be used in the Soviet Army and also in civil air defense.

4. When America entered the first World War, more than one-fourth of the German artillery ammunition was gas. Accordingly, more than one-fourth of the losses was due to gas, namely ..... 75,000.

About three-fourths were due to other injuries ..... 233,097.
Yet the number of men who died because of gas were only 1,399
equal to about 1/36 of those who died from other weapons ..... 50,475.

If war casualties and fatalitiees caused by gas poisoning and also permanent disabilities thus caused have not been exceedingly heavy, but were even mild in comparison with the social burdens caused by other weapons and diseases, we must bear in mind that the second World War is a total war in which not only the armies of the belligerents, but the entire population is directly affected. The aim of total war is the annihilation not only of the armed forces, but of the productive and regenerative power of the defeated people. If in such a war gases are used against the civil populations, the social burdens thus caused will be incomparably heavier and probably intolerable for the defeated country. If entire populations like the Poles and Czechs are forced into slavery and migration, it will be difficult to calculate the part which will be played by chemical warfare with regard to the social effects caused by it. The number of civil victims and their fates cannot be estimated in advance. None of these peoples, if they are unable to win final victory in the later course of this war, will be able to compensate by pensions the victims of gas and war. Each individual will bear the burden of the defeat of his people. This thought alone should bring forth the will for a maximum of preparedness for the United States.

Economic Aspects of Chemical Warfare

The economic aspects of chemical warfare are so manifold that one could fill a whole volume with the discussion

of this problem concerning the United States alone or any other single nation. Only a few viewpoints can be mentioned in this chapter. Problems concerned are the source and stock of raw materials available; producing capacity of the mining and manufacturing industries — especially of the chemical industries — storage and transport facilities; training and distribution of the human forces which are available in time of peace and must be differently used in time of war. The planning for peacetime preparedness and for service after mobilization day is mainly an economic problem. There would be no end of discussion, if we do not confine this chapter to a very few concrete instances which may illustrate the kind of work that must be done for preparedness and mobilization.

War Gas Production

We may first quote the figures which are available on the production of war gases during the World War. These figures have frankly been made public by some governments, especially by the United States. French figures, it seems, are also authentic, as quoted in one of the following tables. Germany has not published its figures of production which have been estimated by American and other non-German experts.

A few occasional remarks may be added. André Meyer (l.c.) mentions that at the beginning of the World War, the French chemical industry possessed practically no facilities at all for the production of chlorine. The manufacture of chlorine is one of the backbones of the chemical industry. The construction of factories able to produce 24,000 tons of chlorine until the end of the war in connection with other developments led to the creation of a strong national French chemical industry after the World War.

When the German patents were made available to France through the treaty of Versailles, not much initiative was needed on the part of the French to develop and organize chemical research of their own in order to create an independent national industry. To a certain extent this was done, insofar as private profit and national interest ran parallel. Where profit could more easily be made by international arrangements, this method was preferred. French chemical industries were not nationally centralized, but the German chemical industries were organized in the national concern that is known as I.G. and practically represents a monopoly, at least for the important branches of production.

This strong and powerful industry of the defeated neighbor soon became the helpful friend of private enterprise in France. Certain branches of production which required special experience and trained labor were simply left to the Germans who were free to decide for themselves whether they would produce these products in France or would prefer to import them there from Germany. Their decisions were made rather in the interest of German national defense. Commercial considerations were of secondary importance only.

Thus the French chemical industry between the two World Wars was not developed according to the national interests of France. Even such minor commodities as Jena glass for chemical research was imported from Germany. When this supply was interrupted at times, not one poor test-tube could be had in all Paris.

This instance is symptomatic for the degree to which French industry remained dependent upon the German I.G. Under such conditions it was not difficult for the Germans to observe carefully and even control the French production

of war gases and the development of the chemical production capacity in France between the two World Wars.

The superiority of the German chemical industry over that of the French which existed before the first World War was thus maintained and contributed to France's crushing defeat in 1940. While I consider myself competent only in the limited field of chemical warfare, the conclusion may be drawn from the fact of the French disaster that similar conditions prevailed in other fields. I mentioned elsewhere the cemetery atmosphere in French research laboratories, and in other connections the difficulties with which France was confronted, when the production of mustard gas was to be taken up in 1917. Equipment and trained labor for the production of mustard gas in Germany were amply available. France had to refer to a different method of manufacture for which the facilities were to be newly created. For such reasons it took France one year to create a producing capacity of about 20 tons of mustard gas daily.

France did not take up the production of diphosgene or of diphenylarsinechloride. In the production of irritant gases France and Britain were equally handicapped by the shortage of bromine and acetone and were forced to use a great number of chemical compounds which had very little or no practical effects at all in the battle field. These conditions are mentioned in detail in the chapters dealing with the individual irritant gases.

The production of chemicals for war in France and Germany during the World War is recorded as follows:

Agent	*France* [4] Metric Tons	*Germany* [4] Metric Tons
Chlorine	23,900	
Chlorpicrin	493	7,130
Phosgene	15,800	10,700
Diphosgene		12,000
Mustard gas	1,968 [5]	9,000
Diphenylarsinechloride		4,200 [6]
Vincennite [8]	4,160 [7]	
Bromacetone	481	
Acrolein	183	
Brombenzylcyanide		
Tin tetrachloride	4,116	
Titanium tetrachloride	191	
Arsenic trichloride	2,710	

The following table shows:

American Offense Production at the End of the World War [9]

	Production (tons)	Shipped in bulk (tons)	Total monthly producing capacity (November 1, 1918), (tons)
Chlorine, liquid	2,723	1,488	895
gaseous	1,104	none	1,500
Chloropicrin	2,776	1,903	1,500
Phosgene	1,616	420	1,050
Mustard gas	711	190	900
Brombenzylcyanide	5	none	90
White phosphorus	1,006	171	100
Tintetrachloride	695	106	91
Titanium tetrachloride	181	none	30

[4] André Meyer, Gaz de combat, p. 15. Paris (1938).

[5] From March, 1918, to October, 1918.

[6] Since 1917.

[7] Since 1916.

[8] Vincennite is a mixture of 50% CNH, plus 30% $AsCl_3$, plus 15% $SnCl_4$ plus 5% $CHCl_3$.

[9] Report of the Director of Chemical Warfare Service, pp. 55 and 56. United States Government Printing Office, Washington (1920), Prentiss, l. c., p. 85.

Production Capacity and Bottlenecks

For chemical warfare it is not only necessary to possess sufficient raw material and to plan in advance, how it should be used; it is also necessary to know the productive capacity of the country. The table on American capacities of filling plants at the end of the first World War gives an idea of the magnitude of these figures. They must be incomparably higher at this time, in order to match with the combined productive capacities for ammunition of all Europe and Asia. Errors of judgment in these fields which might be due to widespread self-conceit would by far more contribute to the defeat of a country than anything else. Nothing is easier for the future enemy than to appeal to the national pride and self-confidence of a people, in order to create fundamental errors or delays of planning. No better way to prepare defeat can be thought of. False self-satisfaction of the responsible functionaries of a people in the field of planning of defense industry is the most important step towards defeat. It is more important to control the planning of preparedness in peace time than to directly control the strength of the armed force itself.

Monthly capacities of American filling plants in November, 1918:[10]

75 mm. shell (ultimate capacity)	1,300,000
(demonstrated capacity)	1,100,000
4.7 inch shell	450,000
155 mm. shell	540,000
6 inch shell	180,000
Gas grenades	750,000
Smoke grenades	500,000

[10] Prentiss, l. c., p. 86.

Stokes mortar 4 inch bombs	120,000
Livens drum	40,000
Incendiary drop bombs	25,000

When productive capacities are planned, one should keep in mind that capacities and factual production are not identical. The industry of a country is a living organism. There are a great number of factors involved which cannot easily be calculated on paper. To produce gas shells the production of all the parts from which they are composed must be coordinated. Many bottlenecks may occur where they are least expected.

When Germany, during the first World War, tried to increase the production of gas ammunition to one-half of her total ammunition output, she did not succeed in this purpose because of a complex co-action of various technical, economic, and political factors of which a few may be mentioned here. The production of fuses remained far behind schedule, almost all the time. A great number of manufacturers delivered sometimes not even one-tenth of the number of fuses which they had promised to deliver under existing government contracts.

It was always a depressing time, when these figures were read to the Thursday afternoon meeting of the German War Ministry during those critical years of 1916 and 1917.

Technical factors, such as shortage of certain metals or alloys, like nickel, tungsten, brass, were of fundamental importance. In addition there were not always enough lathes. The army officers, belonging to the German War Ministry, who were in charge of the distribution of contracts, frequently had no technical experience. Sometimes they gave big contracts to a little business man who would only try to equip his factory with the required machinery, after he had received the contract, while a big factory in the neigh-

borhood that possessed all the necessary equipment remained idle. In most cases lack of familiarity with the business was the reason for such mistakes, rather than corruption.

The professional superiority complex prevented these army officers from asking the aid of experts in industry. In the best of faith they contributed not little to the defeat of their country, because they were economically inexperienced.

The Human Factor in Economic Relations

Economic forces are no abstract power. In back of every economic move there stand the human being, individuals, and masses, their will to work for ideals and for profit, their readiness to sacrifice and their ambitions. Economic experts who forget that materials are produced and machines are handled by men are bunglers. Planning materials and production in chemical warfare without considering the human forces must lead to defeat. It did so in Germany.

As was said before, gas shell production in Germany from 1916 to the end of the war remained behind schedule for various reasons. One reason was that German workers threatened to strike. At the end of the year 1916, they wanted higher wages and better food. Money could then be had; if need would be, it could be easily printed. But food was scarce. If the striking workers would get more food, the rest of the people would have less. If this strike could not be prevented, it meant workmen striking against the people; it was already civil war, still invisible to the masses. It meant that every day of strike would reduce the ammunition which was then to be prepared for the great defensive battle of 1917 on the western front by hundreds of thousands of artillery shells and gas shells. I do not

remember the exact figure of gas shells by which the daily production would have been diminished by that strike.

The High Command of the German Army made it clear beyond doubt that this strike was to be avoided in such a way that no loss of production would take place. Everything else did not matter. These directions were given to General Groener who was authorized by the government to settle this labor dispute. This general had to decide, whether to concede higher wages and more food to the workers of the defense industry, or to accept final defeat of the Central Powers in the summer of 1917. He did what every general of every army would have done in such a situation. As a general he decided against defeat in the battlefield; he granted higher wages and more food to the workers, and avoided the strike, before the danger became publicly known. Through this decision he postponed Germany's final World War defeat by one year. The western front in summer 1917 had sufficient mustard gas shells to halt the tremendous onslaught of the Allies and enough diphenylarsine-chloride and other gas shells to make even the necessary counter-attacks. The industrial production of munitions was not interrupted, the profit of the industry was, however, somewhat diminished by the increase of wages, but the battle in the field was not lost in 1917, defeat was postponed until one year later.

The few men in Germany around Fritz Haber who knew about this crisis felt a deep relief. The experimental work on and the preparation of the blue and yellow cross gas ammunition could be continued and completed in time. But the people of Germany read in their newspapers that certain classes of munition workers would receive higher rations of bread and butter and other food; the rest of the people would have to be satisfied with still less than they

already received. Organized labor had won a victory for itself at the cost of national unity.

The blame for this compromise was charged on General Groener, mainly by Dr. Carl Duisberg, the head of the chemical industries. General Groener's decision was backed by the High Command of the Army, General Field Marshal von Hindenburg and the Kaiser. Duisberg was backed by the economic power of the entire German industry, which was then stronger than the Kaiser and the Army in the field. Groener was released from his highly responsible position in the War Ministry. He became a simple commander of an army division at the western front. It was a punitive measure for him to be sent to the front. Since that time it became a more and more general habit in the German Army that men or officers in charge of special functions, who lost the favor of their superiors, were punished by being transferred to the fighting troops.

Groener was defeated in 1916 and the morale of the German Army was badly shaken at the same time; two years later after Germany's final defeat in 1918, when Ludendorff had fled to Scandinavia, Groener was called back by von Hindenburg to take Ludendorff's position as General Quarter Master. He was the right personality then to prevent civil war between the army and the socialist masses, because he, Groener, was considered in public as a socialist. Duisberg had blamed and discredited him as a socialist, Marxist, almost communist after the prevention of the strike in 1916. He had never been anything like that. No German general could ever be a socialist. Groener, like all of them, was only a soldier, who had done his military duty, in 1916 and at all times. Devoted to his military profession, just as Haber and his collaborators were devoted to science, he must have felt contempt for the eco-

nomic powers of both labor and business alike which, at that focal moment, thought only of their own advantages forgetting the common cause of the people.

This episode proves, how closely human relations are connected with psychological, social and economic aspects of chemical warfare. It is not only difficult, it is rather impossible to decide which factors are most important to obtain final victory in total war. No thought, no economic problem, no individual can be considered as an isolated unit. No scientific, no technical problem can be considered for itself. It is always subjected to the influences which emanate from the whole of human society.

CHAPTER IV:

HOW TO DEVELOP A NEW GAS

The Complexity of the Problem

A large organization is needed to develop a new gas. The High Command of the army determines the strategical and technical requirements. The War Ministry provides the material and human forces which are needed. The research institute on chemical warfare is in charge of all the experimental work for scientific, technical and military perfection of a new war gas.

In addition there must be a man endowed with extraordinary qualities who coordinates the work. He may be either the director of the chemical section of the war department or the general director of the research institute; or he may hold both positions at the same time, as Fritz Haber did during the World War, while in France, England and the United States the coordinating work was less strictly centralized than in Germany.

The best way to make the reader understand these complicated conditions is to make him see what happened during the World War and to discuss the principal reasons why the events took the course that they did.

It has been mentioned elsewhere that the idea of chemical warfare flashed through the brains of hundreds of chemists, on both sides of opposing forces in 1914. Scarcely anyone of these men realized at that time the complexity of the problem.

Gas Clouds

The first great gas attack of the World War took place April 22, 1915, at Ypres, where the contents of 5700 cylinders of chlorine were blown off within three minutes along a front of six km. (about 3½ miles). Each cylinder contained 20 kg. of the gas. 5,000 Frenchmen were killed and 15,000 gassed, 6,000 were captured alive by the Germans, 51 artillery guns and 70 machine guns were lost. This attack was perfect in almost every respect. The toxic effect, the military effect, and the technical arrangements were adequate. The economic conditions, however, were not adequate. The chemical industry of the country was not able to supply the army with sufficient quantities of chlorine to repeat these attacks so soon and to such an extent that they would defeat the Allies before they would be able to supply their troops with gas masks.

The most fateful error was due to the lack of foresight of the German High Command, which did not expect such a result and consequently had not prepared for the military exploitation of this gas attack, which remained not only the first but also the most successful one in the military history.

It took about three months to prepare for the gas attack at Ypres. Everything, from the conception of the idea to the completion of the attack, was included in this preparation: laboratory experiments, the manufacture of the 6,000 steel cylinders and other apparatus and of 120 tons of liquid chlorine. Also included were the new formation and training of officers and men of two batallions, the establishment of a meteorological service to determine the time, when wind, weather and atmospheric conditions would be favorable for the attack.

In addition several divisions of troops in and adjoining

the sector of the front, where the attack would take place, had to undergo general training in gas protection and gas discipline. All this was accomplished without arousing the suspicion of the Allies.

Every task was unprecedented; every man was new to the work. It is important to remember that the military command had conceded to the non-commissioned reserve officer, Haber, full authority to accomplish all this. It is equally important to remember that it took the British about five months and the French almost a year merely to copy what this scientist had created in three months—for the first time in military history.

The next German gas attack of this type took place on May 31, 1915, on the Bzura-Ravka River along a front of 12 km. (about 7½ miles) with 12,000 steel cylinders containing 240,000 kg. liquid chlorine. 6,000 Russians were killed, 3,100 poisoned, 15,000 made prisoners.

Fifty more German attacks of this type followed during the remainder of the war.

The first British gas attack using the same method took place at Loos on September 25, 1915. The first French gas attack of this kind took place in February, 1916.

In the course of the war the amounts of gas used in such attacks were doubled from 240 to about 500 metric tons for each attack. The toxicity of the gas was increased by the addition of phosgene or chlorpicrin to the chlorine.

The last gas attack of this type was made by the Germans on January 31, 1917, along a front of 9 km. (about 5½ miles) on the Prosnes River, in the Champagne with 18,000 steel cylinders containing chlorine and chlorpicrin, causing the death of 2,500 Frenchmen. Two factors, the economic inability to produce sufficient chlorine and the effectiveness of the Allied gas masks against such gases,

forced the Germans to change their tactics. (The production of chlorine in Germany reached its maximum with 1,000 tons per month in the Fall of 1918, while at about the same time the United States alone had reached a capacity of production of about 2,500 tons per month in addition to the chlorine output of the French and British industries.)

This difference in production made it possible for the Allies to continue their gas attacks until the end of the World War.

Had the Germans calculated correctly the economic factor, they would perhaps never have introduced this method of gas attack which, in the long run, became more advantageous for the Allies, thanks to their economic superiority. This miscalculation taught the Germans that ample productive planning is indispensable in chemical warfare.

Gas Projectiles

The earliest gas weapon of the French was a 26 mm. rifle grenade shell containing 10 cc. of methyl—and ethyl—bromoacetate. This product is toxic and irritant, but in the small quantity in which it was used in these little shells it was practically without effect in the open field. It can be said, about this weapon, which was the first gas shell on the Allied side (used for the first time at the front in March, 1915) that the pharmacological factor was miscalculated, because it was not sufficiently toxic for use at the front. The technical, economic, and military factors were equally miscalculated in various respects, but especially in this one, namely, that there was not enough bromine in France and Britain for producing the quantities of ammunition needed for a reasonable military effect.

The first German attempt to use a chemical in artillery

shells was made on October 27, 1914, when 3,000 shrapnel shells charged with dianisidine were fired against the French at Neuve Chapelle. Dianisidin irritates the mucous membranes but has no other irritant or toxic effect. The effect of the chemical was nil. This proves that the first approach of the Germans, before Fritz Haber took over the task, was just as incompetent as that of the French.

The military factor, by using 3,000 shells at once, was, however, more correctly evaluated by the Germans. From the physiological viewpoint it was a failure, because the chemists had neglected to consult a pharmacologist.

They did not even consult a pharmacologist later, when they introduced the T-shells on January 7, 1915, at the eastern front, near Lodz and later at Bolimoff and in the Argonnes.

Chance played an important role in the selection of the gases at that time. There were chemists who through their scientific and industrial experience were familiar with compounds that are highly irritant.

Such a chemist was Dr. Tappen, who happened to be the brother of a general of the staff of General Field Marshal von Mackensen. He succeeded early in 1915 in getting attention for his suggestion to put the liquid compound xylylbromide into 15 cm. artillery shells. He became acquainted with this irritant, while he was working on his thesis. These shells were not effective and of little military value.

These shells were marked with a "T" in honor of Dr. Tappen. This mark was generally misunderstood to mean tear gas. Thus this great soldier was soon forgotten.

The first successful shells were developed by the French and used at Verdun, on February 22nd, 1916. They contained phosgene. As this product is a gas at ordinary temperature, only a small quantity of explosive was needed to

burst the shell and to form a cloud of phosgene gas. Thus the entire space taken by the explosive in ordinary shells could be used for the liquified phosgene. These shells were intended to act specifically through the poisonous gas. The effect of the splinters was negligible. This was the first specific and effective gas shell.

With this achievement the French had overcome all the inefficiencies of the two early attempts to use gas in shells, their own and the Germans'. More than a year passed between the first German shooting with the irritant "T" ammunition and the first French shooting of phosgene shells. It took the Germans three more months to improve the French shells by using diphosgene instead of phosgene Diphosgene is a liquid and can be handled readily. The toxic effect is about the same as that of phosgene. The first German attack with these shells took place at Chattancourt on May 19, 1916.

The substitution of phosgene by diphosgene made very easy the mass production of such shells. The Germans shot 100,000 such shells at one time against the French in Fleury near Verdun in the following month. Enormous military advantages were gained by phosgene mines, a modification of the artillery phosgene shell, used for the first time by the British at Arras on April 4, 1917. Several hundreds of these mines were simultaneously fired by electric ignition. It took the Germans six months to copy this method. They applied it for the first time at the Italian front on October 24, 1917.[1]

As presented so far, the developments show that chemi-

[1] **Trench mortar bombs which contained 8.5 liters (about 19 pounds) of phosgene or diphosgene. From July, 1918, similar projectiles (G-Minen) contained 12.5 liters of a mixture of diphosgene and chlorpicrin.**

cal warfare methods could gradually be improved over a long period, by altering technical and military conditions on the one side, while, on the other side the non-toxic irritant gases were replaced by toxic gases, such as chlorine, phosgene and diphosgene. When this progess from irritant to toxic gases was carried through, the importance of the economic conditions was given consideration as is explained elsewhere.

Gases Against Gas Masks

Another most important factor involved was the improvement of the gas masks. When the masks finally provided complete protection against the gases mentioned so far, the British gas mines made this protection almost ineffective, because the gas concentrations thus produced replaced almost completely the respirable air in the trenches, so that death occurred either by choking, from lack of oxygen, or occurred, because the dose of phosgene inhaled during the time needed for putting on the gas mask was sufficient to be fatal or highly injurious.

So far we have mainly discussed the development of the progress in the technical, engineering and artillery fields.

At the same time, efforts were made to find other chemical compounds which would be more toxic than those used in the past. Phosgene and diphosgene are more toxic than chlorine. Chlorpicrin had been introduced, because it was more irritant than phosgene, though somewhat less toxic, but still more toxic than chlorine. The character of all those products used so far was that of lung irritants causing edema of the lungs.

Both the Allies and the Germans had developed highly effective gas masks. The protection of the troops against

gases of this kind was practically complete and perfect, so that it was necessary to look for new gases.

One way to find a new gas was to use mask-penetrating compounds, the main poisons of which were the products of the arsine group diphenylarsinechloride and diphenylarsinecyanide.

The other way was to displace the effectiveness of the gas mask by a poison that would directly attack the human body. This poison was mustard gas. These two new groups of gases were introduced by the Germans respectively on July 10, and July 11, 1917.

Yet there was still another reason that led to the introduction of mustard gas in chemical warfare. This was the length of time mustard gas remains undecomposed in the field. It is this quality which made it fit for defense. The decisive animal experiments on mustard gas were made in September and October, 1916. The valuable military qualities of this gas were already known, when the High Command of the German Army demanded a gas that could be used for the defense of the Western Front in the coming Summer of 1917. This timely coincidence was characteristic of the high degree of cooperation between the military leaders and the scientists. This cooperation was, as a matter of fact, Haber's achievement.

The Russian front was broken down at that time. The Allies felt depressed. The German people were in highest spirits expecting final victory and the end of the war in the very near future, contrary to the information Fritz Haber gathered from a conference with Hindenburg and Ludendorff. The latter had recently taken over the command of the Western Front.

Fritz Haber was informed by the two generals that the German people could not expect an early victory. The

best that could be expected for the coming year of 1917 would be the prevention of a breakdown of the German Western Front. The German High Command demanded that Haber develop a new gas for defense that would make it possible to halt the tremendous influx of the Allied Armies that was expected for the Summer of 1917.

At that time none of the chemical factories of Germany was ready for mass production of mustard gas. The chemical process for the industrial manufacture and handling of this highly toxic compound was still to be invented. There had to be developed, tested and constructed a model equipment to fill this poison into the shells without undue danger to the workmen.

Two prominent chemists, Lommel and Steinkopf, who had originally suggested the use of mustard gas, did not seem to succeed in developing an industrial process of manufacture. Immediately, there were called in some of the most famous chemists of Germany. Within three months the task was completely accomplished.

Among the chemists consulted I remember especially the impressive personality of Paul Friedlaender who was world famous through his historical studies on the chinoline synthesis and the industrial manufacture of artificial indigo.

The mind of this man was so concentrated on his work on aniline dyestuffs that one day, when we went out together for luncheon, he, looking at the trees ablaze in their colorful Autumn dress and realizing the beauty of the colors, exclaimed: "Look at these colorful Manchester-Yellow leaves!" thus expressing himself in the technical name of an aniline dyestuff.

This man was extremely definite in his work, rejecting many suggestions with this phrase: "We have no time for satisfying the curiosity of baby chemists!"

By the use of certain chemical reactions applied in the technical manufacture of synthetic indigo, there was developed within a few weeks a practical method for the industrial manufacture of mustard gas. Then industry began to work.

The reason, why mustard gas did not appear at the front in the Spring of 1917, but three months later, in July, 1917, is explained elsewhere.

Victory Through Mass Production

The foregoing presentation reveals that there is a definite line of thought which was followed by both the Allies and the Germans. One achievement of the Germans called for another achievement on the part of the Allies. When we forget that this was war and consider only the scientific aspects, we realize that our review proves that there was rather a collaboration by competition between the scientists on both sides. Both of them followed the same line of thought. It could be assumed for this reason that no better solution of the gas warfare problems of the time could be found.

It took the Germans from three to six months to create a new weapon in the field of chemical warfare. The Allies needed about twice as much time to copy a new method of gas warfare after it had been used at the front for the first time by the Germans. This is about the lapse of time that is needed for developing a new gas from the original idea to its first practical application.

The developing of new war gases during the World War was subject to the general idea that the Germans must be superior in the quality of their means of chemical warfare to be able to oppose the material and economic superiority

of the Allies: quality against quantity. This was the main result of Haber's first interview with Hindenburg and Ludendorff in 1916. This general direction determined the speed and thoughtfulness of chemical warfare on the German side at that time.

There was an additional factor on the side of the Allies, the possibility of using limitless sources of raw material and production. Except for the invention of the French phosgene "shells No. 5," which represented a very original and independent contribution to the technique of gas shooting, the most effective improvements, mask-penetration and persistent gases came on the Allied side about a year later. The victory of the Allies was mainly due to their ability to produce the same weapons, though later in overwhelming quantity.

One may learn for future wars and for the present war that scientific superiority alone is not enough to secure victory. Scientific superiority must be combined with superiority in the economic field. There was technical ability and mass production on the Allied side which provided the means for final victory. If the Allies would also have had a Haber and have been able to work with the same speed, bringing a new gas weapon to the front in three months instead in six to twelve months, Germany would have been defeated two years earlier.

The Research Institute on Chemical Warfare

Victory and technical progress in this field must be preceded by scientific experiments. For this work there should be a research institute on chemical warfare, in peace time as well as in war. Such institutes exist in most countries. These institutes are usually invisible for the sake of military

secrecy; their work is not subjected to sound competition. Though the work and achievements of these institutes will become generally known after the outbreak of war only, it may be interesting to the reader to know, how such institutes work. The following description of a model research institute is based on experience of the Kaiser Wilhelm Institute that was built up by Fritz Haber in Germany during the World War; and on post war institutes or gas warfare services in Germany and in other countries. In Russia, these institutes belong to the state exclusively, as it was in Germany during the war. A great part of the research is done in industrial laboratories in post war Germany and also in democratic countries. The research work is less centralized under such circumstances; a great number of scientists may be in a position to contribute their ideas, but the cooperation with the General Staff must necessarily be incomplete as the latter can not well afford to reveal its intentions to men employed by private industry.

The following description of a research will, therefore, mainly include all that can be done for the purpose of preparedness under the supervision of the government.

Let us suppose that a certain idea for a new gas has been conceived or that an individual inventor or private industry proposes that a new chemical compound should be used for chemical warfare, the research must follow three lines:

1. The toxicity of the chemical product must be investigated. This is being done in a number of laboratories which are enumerated below. Even if the compound is not to be used as a toxic gas but as a smoke, for example, the research must be done in order to guarantee that the industrial workers and the troops who handle this product in the field will not be endangered.

2. Another line of investigation is concerned with technical and military factors which involve a great number of problems, such as stability to atmospheric and chemical agencies of explosion, stability on storage and absence of attack on metals.

3. The third line of investigation determines the means of protection for the workers in the industry and for the troops, and the special means of protection which may be needed for collective protection for the navy and air force. This research includes also the problem as to what extent the gas protection of the prospective or actual enemy may be effective against the new weapon.

The following laboratories are needed for this purpose. After the enumeration of the laboratories and their principal tasks, we shall discuss, how the work of so many specialists must be coordinated.

1. *The Laboratory of Physiology and Pathology* is in charge of all physiological, toxicological, biochemical, pharmacological and anatomical research on the effects of agents occurring in chemical warfare.

2. *The Zoological-Veterinary Laboratory* takes care of the breeding of experimental animals, especially different animals than those usually used for experiments, of the hygienic control of the experimental animals; the breeding etc., of insects. rodents and the like against which war gases may be used. The staff of these laboratories may be consulted on and may actively take care of the development of gas protection and special masks for horses, cattle, dogs and other animals in agriculture.

3. *The Hospital for War Gas Intoxications* should exist in peace time in close local connection with the pathological

and other laboratories. Patients suffering from accidents or occupational intoxications acquired in the chemical and defense industry, should be directed to this hospital for examination and treatment, — to make possible in this way chemical, pharmacological and therapeutical research in peace time.

4. *The Botanical Laboratories* study the action of the compounds used in chemical warfare on useful and noxious plants and cooperate in research on the contamination and de-contamination of the soil and fields.

5. *The Biological Laboratory for Physical and Colloid Chemistry* is charged with biological and biochemical problems on proteins, enzymes, hormones and other colloid substances in connection with the physiology and pathology of the intoxications.

6. *The Laboratory of Organic Chemistry* is charged with the synthesis of chemical compounds which are needed for research and cannot be obtained on the market; with the synthesis of new compounds; with the improvement of methods used in the manufacture of gases; with organic chemical work in connection with research of the physiological and pathological sections of the institute; with chemical and technological examination of materials used for gas shells; with protective devices and etc., and with analytical research in organic compounds used in the field of chemical warfare.

7. *The Laboratory of Inorganic Chemistry* is charged with analytical, synthetic and technological tasks concerning inorganic compounds for analogous purposes as enumerated for the laboratory of organic chemistry.

8. *The Physio-Chemical Laboratory* specializes in research on problems of absorption, filters, obstruction of filters and mask-penetration, studies on mists, de-contamination, etc.

9. *The Laboratory for Gas Physics* specializes mainly in research on the air currents in gas chambers; the physical changes of the poisonous gases under varying climatic and meteorological conditions; the qualities of mists; especially the relations between colloid dispersions of gases and the permeability of gas filters, the changes which the gases or mists undergo during the explosion of shells, etc.

10. *The Laboratory for Chemical Analysis of Gases* specializes in the analytical methods connected with research on the respiration of experimental animals and human beings; development of simple standard methods for the practical use in hospitals, development of practical sufficiently sensitive methods for the detection and determination of poisonous products in the field and methods of analysis of the air for the protection of the employes in the factories of the chemical defense industry.

11. *The Laboratory for Technical Construction* is charged with the construction of models or apparatus for experimental use or for teaching purposes, for example: stable or transportable standard laboratories or apparatus for detection and determination of gases, stable and transportable equipment for first aid, for the transformation of ordinary hospitals into special gas hospitals; airplanes for first aid in mass accidents caused by gas; models of gas shelters or models of parts of such shelters.

This laboratory should be in charge of every construction job in the course of research of any kind; for example, the construction and improvement of gas chambers, and similar tasks belong to the competence of this laboratory.

12. *The Laboratory for Technical Standards* is charged with the examination and control of all the materials used in chemical warfare and air defense, such as textiles, rubber, metals, paints, insulation, gasproof, waterproof, oil proof, fire proof building and other materials, control of gas masks, respirators, protective clothing in both, experimental research and industrial production. The study of substitute products which may be needed or developed during a long lasting war belongs to the domain of this laboratory, in so far as the limitations are to be established within which the synthetic products may replace the genuine ones.

13. *The Laboratory for Individual and Collective Protection Against War Gases* specializes in the development of new gas masks, filters and other protective devices for collective protection and de-contamination, excluding architectural problems.

14. *The Laboratory for Active Gas Defense* is charged with the examination of procedures or devices for gas attack used by foreign countries. This knowledge is needed for the current adaption of gas protection. This laboratory develops all methods of gas and air defense which exceed the effectiveness of the traditional methods. In order to serve this purpose, this laboratory must be supplied by military attachés of the legations and consulates abroad with such samples and models, as are available in the respective countries.

15. *The Laboratory for the Physiology and Pathology of the Respiration* specializes in research on respiration of experimental animals and men, in good health and under abnormal or pathological conditions; in the establishment of data concerning the effects of rest and work on respiration

and circulation; in the establishment of the physiological requirements for general gas masks and for special masks or respirators which replace the ordinary devices under special conditions, for example, in military or civil use in airplanes, submarines etc., gas masks and respirators for various groups of the population, such as babies, schoolchildren, aged people etc., or for special groups of patients, for example, patients with diseases of the respiratory or circulatory organs, patients with injuries of the head, unconscious patients,—all of those who cannot use the ordinary types of standardized protective devices.

16. *The Laboratory for Architectural Problems* specializes in testing of materials used for construction everywhere concerning resistance against fire, explosions, impermeability and absorption of gases. This laboratory should survey the natural products, available in certain localities which can be used for protective constructions without overcharging the available transportation facilities. This laboratory should also dispose of specially trained and experienced architects who may be sent as consultants or supervisors to places, where new buildings, especially public buildings, such as hospitals and medical institutions, are constructed so that these constructions may be already adapted to the requirements of air defense in peace-time.

17. *The Department for Experiments in the Manoeuvering Field* is in charge of the preparation of experiments for the purpose of testing the effects of experimental shells, bombs and other devices for gas attack or air defense. This department takes care of the technical preparations for tests taking place under field conditions.

18. *The Scientific Archive* comprises a library of all the

domestic and foreign literature on chemical warfare and air defense including catalogues of domestic and foreign industry and other business enterprises which produce or trade in this field. The most important activity of the archive is the registration and classification of the regular periodical and the irregular special reports of the various laboratories and of the entire scientific and official correspondence. The service should provide that important results of the work done in any one of the laboratories are available to the other laboratories at any time. As the greater part of the information is usually kept secret, not only in this country, but in all countries, it is obvious that one of the main tasks of this archive is the presentation of such information. In other fields of scientific research it is usually found in the scientific literature.

19. *The Gas School* trains physicians, nurses, chemists, architects, army officers for various tasks, special technical fields of scientific research it is usually found in the scientific literature.

20. *The Exhibition and Museum* collects the devices and models of domestic and foreign gas protection and air-raid precaution, and takes care of the scientific preparation for the demonstration of the physiological and pathological effects of gases, models demonstrating effects of various means of attack and defense. The exhibit and museum serve for scientific and technical training of specialists as well as for popular education. Transportable exhibits and films for the education of the inhabitants of remote districts are to be prepared, instructors are to be trained by this section.

The Laboratory Chiefs.

As can be seen from the foregoing chapters, the individual laboratories are established according to the methods in which scientists usually specialize. It is obvious that each laboratory may, more or less frequently, be called for cooperation with other groups of laboratories in solving a certain problem. Biochemical problems may require research in the field of organic and inorganic chemistry, or an analytical method may be needed for control of processes in manufacture and also for detection of gases in air defense.

As mentioned above, the three main lines of defense characterize the main activities of the laboratories only. There are in addition a number of laboratories or sections of the institute which are of a more general character, serving educational or similar purposes.

The coordination of the work of such manifold researches and so many scientists is the main task of the general director of the research institute on chemical warfare.

The direction of each laboratory section is entrusted to two specialists equally competent in the entire field of the activity of the section. One of them may be the responsible chief, the other should be able to replace him at any moment. In no case should they divide their field of activity, in order to avoid that each one would, after a certain time, know thoroughly only a part of the total matter for which he should be responsible.

The periodical and special reports in which the laboratories' work is to be recorded, should be signed by both of them, even if one of them may hold the position as a chief and the second as a vice chief or assistant chief. These two men direct the work of the laboratory and are responsible for this work. They should hold their positions for

many years in order to accumulate experience. In the case of urgent necessity only they should be replaced by other men.

In the course of time such men must become highly experienced in methods and problems in their fields. They are the routine conductors of the orchestra of chemists and scientists under their guidance. They guarantee the correct use of each instrument.

The great leading ideas, however, must not necessarily come from their brains. Whenever there is a need for increased progress in any kind of emergency, the best specialists of the nation may be called in, not only as consultants, but for taking over the direction of a laboratory for limited periods of time, let us say, from three months to two years or for the solution of special problems.

It is obvious that the routine chiefs of these laboratories must have the human qualities that enable them to cooperate with the guest-conductors. On the other hand, every scientist (of the nation), whoever he may be, should understand that it is a great honor to be called in for the temporary direction of such a laboratory. During the war such specialists may be drafted.

The routine chiefs of these laboratories should not be subjected to military draft in time of war, so that the continuation of the work in these laboratories is assured on mobilization day.

There is certain risk, however, that the narrowly limited field of activity may at length cause a lack of new ideas and initiative. Just to avoid this risk, the specialists as consultants or temporary directors would prevent bureaucratic ossification.

If these temporary directors behave themselves like primadonnas, as they frequently do, the permanent laboratories'

chief and staff members should be sufficiently tactful to deal with such occasional situations. If the scientists called in for temporary direction are, however, very or even too modest (which may also occur especially with the great scientists), the permanent chiefs and members of the laboratory should all the more willingly and harmoniously cooperate with them. Even the most mechanized scientific or technical work is done by human beings and requires harmonious cooperation between them.

It is understood that, both, the permanent chiefs and the temporary directors of these laboratories, must remember at every moment the fact that they serve their country with their person and with their work. It is a matter of experience that in the course of such work—directed towards a practical aim—many problems of great scientific interest may occur and captivate and distract the interest of the scientist. Such distraction should not lure him into side tracks. As soon as such a case becomes apparent, it is up to the institute director to step in and to take care that everybody adapts his activity to the practical aim. Where scientific curiosity is the only motive for research, which may result sometimes in greatest achievements, such research may be continued elsewhere.

The scientist called in as consultant or temporary director is free to follow the ideas occurring to him in connection with this work, by his return to his regular university or research activities. The permanent chiefs and staff members of the laboratories are usually not free to do so, at least not without the consent of the general director of the institute.

Coordination of Research and Practice

The Director General of the entire Institute, i.e. of the twenty laboratory sections, must be a scientist of great superiority who is able to combine in his mind the scientific, medical and military views which are involved in every problem in this field.

Fritz Haber was such a man. If his equal cannot be found, there may be formed a directing committee or council. Such councils were formed in most countries after the World War, especially in Germany, Great Britain and Soviet Russia. It is also common practice in the United States. It may be remembered that the word "council" is the correct English translation of the Russian word "soviet." Obviously such a council is the way to insure the country against the possible mistakes of an untalented individual director, but it is certainly preferable and should be possible to find the one outstanding man among 130 million Americans, if he has not been found already, who could accomplish for this country what Haber did for Germany during the first World War.

The peace—and war—time activity of the institute in the service of the government takes place under the direction of the directorial council or better of the individual director.

Of course, he receives his general instructions from the General Staff or High Command or from the secretaries of war, navy and air-force. These instructions concern military, strategic and practical requests for the future. According to the needs of the armed forces, the director plans the practical technical work of the institute sections and determines the time limits within which the work must be accomplished.

This planning of scientific research is sometimes a complicated task. For example, let us suppose, the general staff has reason to assume that troops and civilians will be exposed, to a large extent, to enemy gases which penetrate ordinary clothing and injure the skin in a way as mustard gas or Lewisite would do. For the protective clothing would be needed certain very large amount of rubber.

Before the development of such rubber suits is attempted, the director must get information, whether the limited national supply of rubber would allow sufficient production of protective rubber clothing. If this is not possible, the research of the institute must be planned in another direction. No one could understand the actual problems, if he has no information on the national economy of the people under war conditions. If the director of this institute is not allowed to get the necessary information, his activities and those of the entire institute would be frustrated.

When the decision was taken in Germany in 1916 to introduce mustard gas as a defensive weapon, it had to be foreseen what this would mean in the medical field, at first among the workers in the industry, then among the soldiers. There would be a great number of injuries to the eyes and for their treatment unguents made from purest vaseline would be indispensable. At that time the purest white vaseline could not be produced in Germany, it was imported from the U. S., and the importation was interrupted by the British blockade. Immediate investigation revealed that at that time only a few hundred pounds of white American vaseline were available for all Germany and Austria.

This limited supply was, therefore, immediately confiscated for the industry and the troops that would be exposed to mustard gas. Research of medical laboratories had to

be planned for finding other prescriptions which would not require so much white vaseline.

There must be a bureau, or expert, or committee for chemical and industrial planning, not only for providing information but also for assuring cooperation of various government agencies as well as private institutions and business. This bureau was in Germany during the World War the Chemical Section of the War Department under the direction of Professor Fritz Haber, who was—at the same time—the director of the scientific institute in charge of research on chemical warfare.

In Soviet Russia, in 1936, the same result was attempted and accomplished by the establishment of a special Peoples Commissar for Defense Industry who is in charge of all planning and producing activities in this field.

In the U. S., various Defense Councils serve the same purpose.

The individual director or the directorial committee cooperating in close contact with the Defense Council will have to make the final decisions, whether the results of the research activities recommended by the laboratories could or should be introduced into practice. Actual war brings surprises even if the preparedness of a country is perfect. It is, therefore, absolutely necessary that the organization of the Institute for Chemical Warfare should be perfect in order to accomplish every task in minimum time. The request for speedy action is best fulfilled by an outstanding personality in the position of the director general of the institute. The interference of a bureaucracy may mean disaster.

There Will Be New Gases

In order to develop a new gas or, more correctly, a new weapon in the field of chemical warfare, one needs in the first place an idea. Hundreds of chemists had such ideas in the beginning of the World War. The ideas were not good, because most of the essential factors had been overlooked at that time.

Now, after we have discussed the means of developing a new gas, one may understand that it is not sufficient to be merely a chemist or a toxicologist or an officer of the army or navy.

The direction in which the idea may be looked for must be indicated to the general director of the research institute for chemical warfare by the high command and the general staff. He must be in a position to understand the intentions of the general staff and the scientific and technical possibilities, so that he can develop a plan for practical research that assures the solution of the problem in due time. It is up to the general director to work out this plan and to tell about it just as little or as much as is necessary to be known by the chiefs of the special laboratories. If the general director is a man like Haber, his country will be fortunate. If there is no such man, he must be found. Scientists of genius are rare, and still more rare are those able to adapt themselves to the needs of urgent reality. There is no rule for finding such a man; yet, it is safe to say that he can not be found by determining of his intelligence quotient, nor by passing civil service or state board examinations. The greatest obstacle to the admission of the proper man to his proper place is the jealousy of his colleagues and of the bureaucratic officeholders. For this reason the peace-time commanders on both sides had to be frequently

replaced within a very short time after the beginning of the war, partly by men who had been forced out of service, like Hindenburg and de Gaulle.

Again during this second World War, the peace-time commanders were unable to win the war. Only after the Norwegian disaster Britain called in Winston Churchill, who accomplished within a few weeks what his predecessors had missed or intentionally omitted for several years.

Everybody had known all the time that Winston Churchill was the man to save Britain, but the mediocrity of the bureaucrats kept him out of office.

G. M. Young[1] writes about him: "History will read, with a puzzled brow and a wry smile, his forecast and his defense of that ill-starred Norwegian venture which brought him to supreme power."

The defeat of France was so sudden that there was not time even to think of calling a better man to replace Gamelin.

In Nazi Germany also, the peace-time general von Blomberg, who was good enough to advertise the Nazi doctrine to the army but was not sufficient as a war minister, in time was replaced by a shabby pretext by a more able man.

The same thing had happened in the field of chemical warfare. The unsuccessful commanders of the German World War, von Moltke and von Falkenhayn, had too little understanding of gas warfare and of a man like Haber. When Haber returned from his interview with Hindenburg and Ludendorff, in November or December, 1916—after they had taken over the High Command—he told me that he felt a deep relief, because he had finally found the right understanding. Certainly Hindenburg and Ludendorff knew no more about chemistry than their predecessors, yet they

[1] Britain To-day, No. 35, p. 11. (1940).

tried to learn from Haber who was an artist in presenting the complicated and new idea to experts and laymen. In 1916 Ludendorff was entirely free from the superiority complex that obsesses so many generals and professors in all countries and that later took possession of his mind to such a degree that he was considered insane.

In Germany and in the Democracies the gas warfare services went underground after the World War. This means that the offices in the war ministries fell into the hands of routine men. So far as new ideas were concerned, the chemical industry took the initiative.

The President of the Polish State, Moscicki, was a professor of chemistry and highly interested in chemical warfare and new gases. I was so informed by a friend of mine who knew him well. At first-glance this personal union of scientist and state president would seem extraordinary favorable, were it not for the unsound graft, so characteristic of the Polish government, that led to its defeat, as corruption leads to defeat everywhere. Thus we come to the conclusion that it is extremely difficult to have, in peacetime, the outstanding man holding the job that belongs to him. It seems to be a general law derived from recent history that only a national emergency can overcome the obstacles which prevent efficiency in national defense—especially in the field of chemical warfare and air-defense.

Lack of scientific knowledge and creative imagination have led almost all writers and experts in the field of chemical warfare to agree upon and publicly state the opinion that nothing new can be expected in future gas warfare. This opinion is wrong.

Medical science knows more poisons than remedies. There are so many natural and synthetic poisons, with general and specific effects, that even the seemingly fantastic wishes

of a general staff might be satisfied by an efficient chemical warfare service.

The general staff needs only to demand that the enemy be harassed by overwhelming sneezing or tear-shedding by unbearable toothache or violent vomiting. The enemy may be brought to stare into space with wide-open eyes, unable to aim his guns at the approaching aggressor. The gassed troops may be unable to move a limb, although entirely conscious. A poison may insidiously creep into man through mouth, nose or skin, and fell him hours afterwards as though a stroke. Other poisons may cause conditions similar to those of common diseases, such as typhoid with or without fever, acute or chronic bronchitis, or a simple neurasthenic tremor, just enough to make the man unfit for service.

Some of the poisons cannot even be detected in the air or in the organism of the victims. They would be ideal weapons for individual murder. Fortunately, such poisons are not known or not accessible to the general public. Most physicians know little about them. It would not be ethical for a physician to describe poisonous weapons of this kind in a book written for the general public. Of course, in every case there must be solved the problem of adapting the poison to the requirements of modern armament and the battlefield. Problems of this kind are being studied in some countries. The silent men in these laboratories are protected by a profound military secrecy which hides a deadly, horrible weapon in one country from the ignorance of pretentious office holders in another country.

CHAPTER V:

THE EVALUATION OF NEW GASES

Objectives Achieved by War Gases

The military evaluation of gases depends mainly upon military and medical considerations and upon the time at which the evaluation takes place.

In the beginning of 1915 chlorine and phosgene were considered extremely valuable gas weapons. Only a few months later they were degraded to weapons of minor effectiveness through the improvement of the gas mask, which had taken place meanwhile. For the evaluation of a gas one must further consider the military purpose which is to be achieved. For example, to make uninhabitable a Finnish or Russian village, where all the houses are built of wood, incendiary bombs would be more effective than mustard gas. If a place is built mainly with iron and concrete or even underground, it will be easier to make such a place untenable through mustard gas than through explosive or incendiary bombs.

It may be understood that incendiary and explosive projectiles largely aim at material destruction, while gases have no such effects but act directly on the living being.

The objectives which can be achieved by gases are the following:

1. Casualties caused by the gas itself.
2. Casualties caused by the contamination of land and settlements.

3. To reduce or arrest industrial and commercial activities.
4. To render food unfit for consumption.
5. To cause widespread discomfort, anxiety and moral disablement.

The ideal universal gas should, therefore, be highly irritant to cause immediate fighting inefficiency. It should also be highly toxic to cause death or at least long-lasting disability. It should, at the same time, be persistent and penetrate gas filters and protective clothing.

There is no gas which combines all of these qualities, but the total effect has been accomplished through tactical methods of attack by which several different gases are simultaneously released against the enemy. Through such tactics it is possible to cause casualties directly or by contamination of the localities to a limited extent in so far as modern gas filters cannot be penetrated by the gases which are known. At least, it can be said, that it will be possible to make protective filters against every possible gas, mist or smoke.

If a new gas would excel only one of the limitations of the older gases, it would be highly valuable. However, much can be accomplished by the combination of gases if at the same time the standard of protection available to the enemy is duly considered.

For example, the use of heavy bombs containing mustard gas against troops and civil population would still be highly effective, because neither the troops nor the population are equipped with protective clothing. In addition, the protective clothing that is known gives only a limited protection. Therefore, mustard gas is still a highly valuable war gas and will certainly be used in the field as soon as the military circumstances are considered favorable.

The evaluation of the individual gases will be given in the special chapters. Here we deal rather with the general aspects of this problem.

Classification of War Gases

About 50 different gases were practically applied during the World War. They are discussed in later chapters. A far greater number of poisons were subjected to experimental research in this field. This work was continued after the war by the war department of all countries. The results, of course, are carefully guarded. But the toxicological lines which lead these researches can be outlined in order to show what has been achieved and what may still be achieved in a future war. The understanding of these principles will enable the physician to fulfill the tasks which may be expected of him in a future war, not only in the field, but also in the producing and manufacturing industries.

The problems concern diagnosis of intoxications, treatment and prevention. For such purposes, war gases may be grouped according to physical, chemical, toxicological and military viewpoints. Only a few words can be said about each one of these subjects.

Physical Viewpoints

War gases are not at all gases in the physical sense of the word. They are also liquids and solid substances. These products are applied in shells, mines, or bombs, which, after explosion, form not only gases, but also vapors and smokes which represent very manifold degrees of dispersion.

It is important to know that only gases and vapors, the degree of dispersion of which is similar to that of true

gases, are absorbed by the active carbon filters of the gas masks. To retain smokes and fogs, special cellulose or cotton filters are used, but there exists no colloid filter that is able to retain equally all particles of different diameters present in a certain fog.

A fog, formed by a shell, containing diphenylarsine-chloride, contains particles of the following diameters, and a special filter would only retain the following percentages of these particles:

Diameter of particle in μμ	*Percentage of particles penetrating the filter*
< 50	52.4
50-100	87.6
100-200	93.9
200-400	30.4
400-800	4.2
> 800	0.0

The particles of smoke or fog have an average diameter of $10/^{5}$. The extremes are $10/^{4}$ to $10/^{7}$. Such particles, in a quiescent atmosphere, move with a speed of $3 \times 10/^{3}$ cm/sec. The particle of true gas may have a diameter of $10/^{8}$ and a speed of 0.01 cm/sec. These particles are retained by the charcoal gas filter of the mask. The modern development of gas warfare aims, therefore, at producing a fog which would either penetrate or obtrude the filter of the enemy. As the physical limits between which this can be done are known, every army is able to construct protective filters against every special kind of fog, but there is no universal filter for fogs. As the qualities of the fogs, produced by the future enemy, are kept secret, the competition between the different war departments lies especially

with the mutual intelligence services. One country can only develop an effective filter, if the intelligence service succeeds in finding out what kinds of gases and fogs will be used by the future enemy.

This is one of the principal problems of the gas warfare services of the different countries. It is a purely technical problem, but it may also include toxicological problems of the future war.

The physician should, therefore, at least understand this principle. The toxicological action of a poison may, to a certain extent, be modified by the degree of dispersion. Should it be proved that colloid filters cannot be supplied for the varying kinds of fogs, it would be necessary to equip every one with a self-contained oxygen breathing apparatus.

Chemical Viewpoints

The grouping of war gases according to their chemical composition is not especially informative, neither as to the toxicological, nor military qualities. A detailed discussion is, therefore, not useful.

We know too little about the connections between chemical composition and toxic effects. None of the attempts that have been made to classify war gases with regard to these connections is satisfactory. Nevertheless, it may be interesting, especially for chemists, to remember that Paul Ehrlich suggested to consider certain chemical atoms or radicals within a molecule as toxophoric groups which are responsible for the toxic effects of a compound.

In the second line other radicals also present in the same molecule may increase the toxic effect and are therefore called auxotoxic groups. Based on these principles, Yankowski classified the war gases as follows:

Class	*Toxophoric group*	*Auxophoric group*	*Includes*:
I.	Halogens Cl, Br. I, etc.	Phenyl, benzyl, xylyl, xylylene, etc.	Benzyl chloride, Benzyl bromide, Benzyl iodide, Xylyl bromide, Phenylcarbylarsinechloride
II.	The unsaturated oxides:	CO, SO_4	Nitrous oxides
III.	CO	Halogens or double bonds	Phosgene, Acrolein, Chloroacetone, Ethylchloroacetate
IV.	S S = O O = S = O	Halogens, Methyl, etc.	Mustard gas, Thiophosgene, Dimethylsulfate
V.	— C = N — N = C — NO_2	Halogens,Benzyl, etc.	Hydrogen cyanide, Cyanogen chloride, Cyanogen bromide, Chlorpicrin, Tetrachlorodinitromethane
VI.	As	Methyl, Ethyl, Vinyl, Phenyl	Methyldichloroarsine, Ethyldichloroarsine, Lewisites Diphenylcyanoarsine

Another classification proposed by Engels forms 8 groups, hydrocarbons, alcohols, ethers, aldehydes and ketones, acids, esters, amines, arsines. Within each of these groups, 4 sub-classifications are made. The sub-groups include the methyl, ethyl, phenyl and other derivatives or substitution products.

It is apparent that these classifications are not of great practical help. The chemist may be tempted to use such tables as result from these classifications in his search for more effective products. However, physiological effects of a chemical compound do not only depend upon its chemical composition but also upon its physical properties. A chemist who would follow such principles of paper chemistry would easily be sidetracked and waste his time.

Toxicological Viewpoints

Such groups have been formed by French and American authors.

The French grouping is as follows:

1: Les grands toxiques (the great poisons)
In this group, only hydrocyanic acid is listed.

2. Les suffocants (suffocating poisons)
The French list in this group: chlorine, phosgene, chloropicrin, phenycarbylaminchloride, palite, and surpalite.

3. Les lacrymogènes (tear gases)
In this group are listed: chloroacetone, methyl-and ethyl-bromo-and iodo-acetates.

4: Les vésicants or les caustiques (vesicants or caustics)
In this group are listed poisons of the mustard gas

type as, dimethylsulfate, ethylarsinedichloride and others.

5: Les sternutatoires (sternutatives)
In this group are listed aromatic arsines of the phenylarsinedichloride type.

6: Les labyrinthiques, which act on the ear.
To this group belongs dichloromethylacetate.

7: Les fumigènes (smoke forming gases)

8: L'oxyde de carbon (carbon monoxide).

The Americans formed six similar groups:

1: Lung irritants
Chlorine, phosgene, palite, surpalite, and chloropicrin.

2: Sternutatives
Diphenylarsinechloride

3: Lachrymators
Benzylbromide, bromoacetone

4: Vesicants
Mustard gas, Lewisite

5: Direct poisons of the nervous system
cyan group

6: Gases interfering with the respiratory properties of the blood
Carbon monoxide.

Later, the American classification was somewhat simplified to include the following four groups:

I. Toxic suffocants (lung irritants): chlorine, phosgene, etc.

II. Vesicants: mustard gas, Lewisite.

III. The irritants: benzylbromide, bromoacetone and others.

IV. The toxic gases: carbon monoxide, hydrogen cyanide.

Military Viewpoints

The British formed four principal groups:

1. Non-persistent, toxic war gases, without after-effect, only for offensive use—chlorine, phosgene, diphosgene.
2. Persistent, toxic gases, with after-effect:
   a. Tear gases: ethyliodoacetate (KSK, Bromobenzylcyanide (BBC.)
   b. Blister gases: mustard gas, Lewisite.
3. Non-fatal gases (tear gases): chloroacetone.
4. Fatal gases (poisons) (compare below).

Later they accepted the aforementioned American way of grouping. Instead, one may also find in more recent government regulations that only three groups are mentioned:

1. Non-persistent gases.
2. Persistent gases.
3. Semi-persistent gases, mainly including arsine compounds.

Contamination may be brought about by:

a. Fine spray
b. Gross spray from low-flying aircraft
c. Heavy local contamination from gas bombs.

The Germans applied, for their grouping of war gases, a combination of military and toxicological viewpoints.

1: The first group comprises the offensive gases. The ammunition containing these gases was designated by a "green cross." The whole group of war gases got its name from this symbol. "Green cross ammunition" was the main group in the beginning of chemical gas warfare to be developed and to be effective against unprotected enemies.

The aim of attack was to cause fighting inefficiency of the enemy, either immediately, or within a short time. For this reason, this group comprises:

a: Tear gases, as "T-stuff" (xylylbromide), chloropicrin, bromoacetone, brombenzylcyanide, and others.

b: Irritant gases as chlorine, phosgene, diphosgene, chloropicrin, cyanogen compounds, and others.

2: The gases of the first group do not penetrate ordinary gas masks with charcoal filters. When this protection was generally available, the need arose for certain gases which could penetrate ordinary charcoal filters, and thus force the enemy, by their irritative effects, to remove their masks and inhale the gases of the first group which were shot simultaneously with the gases of the second group. This second group was designated by a "blue cross" and the poisons with such effects were called "blue cross gases."

The prototype of these gases is diphenylarsinechloride. Protection against them, in the form of colloid filters, made from filter paper or cotton, was almost immediately developed and made available to the soldiers.

3: The third group comprises defensive gases ("yellow cross ammunition"). The defensive purpose is attained by the fact that these gases by their persistency exercise a protracted after-effect in the field. They are not readily decomposed and may, therefore, contaminate the area to which

they are applied for a protracted period, thus making it uninhabitable.

The prototype of this group is mustard gas. Mustard gas does not penetrate the gas masks, but it affects the skin directly. Similar effects are exercised by the Lewisites. Certain poisons of the second group, especially the arsines, also characterized by a long lasting after-effect and may, therefore, be used for the same purpose as mustard gas, but the effect on the skin is less violent and the irritative effect would be of greater importance in this respect in so far as the enemy would be compelled to wear gas masks for very long periods in the area thus contaminated.

Medical Classification

A medical classification which is, for example, used in British government regulations distinguishes the following groups:

I. Gases which may produce disablement or death.
   a. Vesicants: mustard gas and Lewisite.
   b. Asphyxiants or lung irritant gases: chlorine, phosgene, diphosgene, chloropicrin.
   c. Paralyzants: hydrogen cyanide and hydrogen sulfide.

II. Gases used primarily as harassing agents:
   a. Lachrymators or tear gases: chloroacetophenone, (CAP).
   b. Nasal irritants or nose irritant gases: organic arsenical compounds, diphenylchloroarsine (DA), diphenylchloroarsine (DM), diphenylcyanoarsine (DC).

III. Gases liable to be encountered under war conditions:

a. Carbon monoxide

b. Nitrous fumes

c. Screening smokes; phosphorus, chlorosulfonic acid, titanium tetrachloride, chlorinated hydrocarbons.

d. Fumes which may be encountered in fire fighting.

If we consider the medical aspects of war gases with regard to their evaluation as military weapons, we must discuss separately the irritant and toxic effects.

IRRITANT EFFECTS AND "SUBJECTIVE EXPERIMENTS":

The irritant effects of poisons cannot be studied and compared by experimenting on animals. The sensitivity to poisons among animals is not uniform and it differs from that of man. In addition, animals are not able to tell about the peculiarities of special irritations. The sensitivity of monkeys to irritant poisons is different from that of man; yet their capability of expression makes them extremely valuable for a special purpose, namely, to test whether higher concentrations, toxic and fatal ones, have an irritant effect proportionate to the concentration, or whether higher concentrations exercise less or no irritation at all because of their paralyzing effects. These questions have been solved by experimenting with monkeys in a very satisfactory way. Their vivid expressiveness makes such experiments extremely illuminating and unforgettable.

In order to get exact results about the comparative efficaciousness of different irritant gases, no other way was suitable than to make experiments on man. At the start

of gas warfare preparation in Germany no medical experts participated. The chemists active in this field organized "subjective experiments" of their own. Only later (1916) when a pharmacological section was organized, Flury and Wachtel took care of these experiments, which even at that time of war were looked at with suspicion. Indeed, at the first, these experiments were still primitive.

Almost every chemist in the field was willing to serve his fatherland by voluntary participation in these experiments. Thus the first comparative experiments with German and French irritant gases were carried out.

As soon as the pharmacological service mentioned above was established, these experiments were organized along indisputable hygienic and medical lines. Every man whose lungs and respiratory and circulatory systems were not functioning properly, or who was not well and healthy, was excluded from these experiments. Then the experiments were arranged in analogy with the well-known homeopathic methods of research. In these ways reliable results were obtained. The participants, being normal and healthy individuals, both mentally and physically, had to acquire a certain technique of cautious, but regular and equal breathing so that the results were influenced, as little as possible, by uncontrolled subjective factors. The time of exposure of these individuals to the dangerous atmosphere was reasonably limited.

The participants were further trained to note their sensations according to a fixed schedule by means of a stopwatch and to write them down immediately after leaving the cloud, each independent from the other participants.

Regular monthly physical examinations and medical supervision of the participants in the individual or mass ex-

periments successfully prevented injuries to the participating chemists.

Facts and figures were thus obtained making it possible to compare different irritants exactly. A certain amount of error was inevitable, since the results were determined by subjective statements.

Some products irritate one organ before the others, for example, the eyes are irritated at far lower concentrations than the respiratory organs by the following substances (the figures indicate the concentrations (mg per m^3) just sufficient to cause tears):

Bromobenzylcyanide	0.3
Ethyliodoacetate	1.4
Bromacetone	1.5
Xylylbromide	1.8
Benzylbromide	4.0
Brommethylethylketone	11.0
Chloracetone	18.0
Chlorpicrin	19.0

These figures are all below the toxic and fatal doses.

Animal Experiments

The technical details on animal experiments are discussed in the following chapter. Here it may therefore suffice to mention a few viewpoints which distinguish animal experiments made for the purpose of evaluation of war gases from the usual animal experiments that are made for purely medical purposes. The latter serve the purpose to improve our understanding of physiological processes with a view on the medical treatment of human beings.

In so far as the medical treatment of gas poisoning is concerned, animal experiments in the field of chemical war-

fare are not different from those used in other fields of medical research.

Yet, before a new gas is used at the front, it must be ascertained, beyond doubt, that the gas attack will be effective. While for the irritant effects of gases experiments can be made on men directly, we must use animals for the evaluation of the toxic effects of a new gas. In these experiments we are interested in interpreting the symptoms which the animal shows, assuming that the latter substitutes for a soldier at the front.

Instead of more theoretical explanations, it may be rather informative to describe an experiment. For this purpose I select from my notes the record of the first monkey in history that was exposed to a low concentration of mustard gas, such as would occur in a field or room contaminated by that gas in a regular gas attack.

The monkey had a weight of 4482 grams, that is, almost 10 pounds. He was exposed to a concentration of 1 $mm/^3$ per m^3 during 150 minutes on October 9, 1916, from 4:35 P. M. to 7:05 P. M. His reactions were observed by the author of this book and another scientist who was a prominent expert on animal psychology. The observation went on all night. At the end of the exposure, the monkey was still apparently quite well. After 15 minutes he became sensitive to light. This would mean that a soldier at this time would already be somewhat disabled for fighting. At 3 o'clock A. M., that is, about eight hours after the exposure, the monkey kept his eyes closed most of the time, rubbing them with his hands. For a soldier in the field, supposing he is not more sensitive than the monkey, this would mean complete fighting inefficiency. After four more hours, following the exposure, at 7 o'clock in the morning, the patient showed slight attacks of trembling or shivering which

ran throughout his body, his organism now was generally affected and hospital treatment would have been indicated. There was no irritation of the nose, no affection of the respiratory organs. But his sight was seriously impaired. He recognized food only from a very near distance. The cornea of both eyes was injured through the vesicant action of the gas.

The soldier in the field could have avoided this effect by the use of his gas mask, but in fact, he would have done so only if he had been warned by a highly efficient service of gas detection. Such service did not exist in July, 1917, when mustard gas was first used. The experiment, therefore, made it highly probable that this gas would cause the following military results:

1. The soldiers, not warned and not aware of the exposure to the low concentration of this persistent gas which is not perceivable through its smell, taste or irritative effect, would not make use of their gas masks in time. Unwarned, they would remain exposed to the gas for many hours.

2. After a latency period of about 8 hours, all the men thus exposed would be unable to continue their work or their functions. Shortly thereafter they would have to be transferred to hospitals and would be disabled for service, for many weeks or even months, some perhaps permanently. There would, however, be no, or very few, fatalities.

In addition, the observation of the monkey which was continued for many weeks showed that after a few days of not too heavy suffering, he recovered and after several weeks, his eyesight was almost completely restored.

Militarily speaking, it could be expected that mustard gas, through its persistence, would incapacitate for service a great number of men without causing many permanent disabilities. This experiment does not refer to the effects of high

concentrations and to injuries caused through direct exposure to sprays.

Naturally, more than one such experiment was made: a great number of cats, rabbits, dogs and monkeys were exposed to varying concentrations and for various lengths of time to mustard gas. Not only to the chemically pure product but also to samples of the technical products that would result from mass production in industry. In order to study the effects of this gas on the skin, the tender skin of sucking pigs was exposed to the action of the gaseous and liquid product and a number of involuntary experiments directly on men came about through accidents occurring to chemists and research workers who handled this product with insufficient caution.

In such a way laboratory research gives quite a satisfactory basis for the evaluation of a gas. I may, however, mention that the final decision in this case was to be taken in an atmosphere loaded with excitement. There was the fact that the chemists did not yet know how the product could be manufactured in industry. They were inclined to oppose its introduction by all kinds of arguments. The most temperamental objections came from the men who were in charge of the gas defense and foresaw difficulties for themselves, when skin injuries would occur with the workers and soldiers handling this weapon. There were times, when these objectors were so strong that it seemed that mustard gas would never see the front.

To take a firm stand against these influences, I had to be pretty sure of my physiological experiments on animals. In order to definitely convince the objectors of the effectiveness of the new gas, a large-scale field experiment was made. About 1,000 animals were exposed on a manoeuvering field

(Warthe-Lager in Posen) to the effect of 500 mustard gas shells, fired from a 7.5 cm field battery.

The animals were placed in the field in little cages made of wire. The dogs were tied to pegs. Not one of the animals was injured by a splinter but all showed the toxic effects of the poisonous gas. Some to the direct effects of sprays and gas waves, others were only exposed after the shooting was over to the after-effect of the persistent gas in the field.

This experiment was decisive and shortly afterwards confirmed at the Ypres front, on July 11, 1917.

Final Evaluation

The final evaluation of a new gas was made in the war ministry. Every Thursday afternoon, under the direction of Fritz Haber, a meeting took place to which not more than about ten persons, the responsible directors of the various laboratories, including economic experts, were admitted. At these meetings scientific, political, military and economic problems were discussed and decisions made.

The reports of the persons attending these meetings had to be and were extremely brief and exact. There was no small talk, no vanity talk of boasting professors. Nowhere else later, either in Germany or in other countries, either in government or in industrial circles, did I ever meet with a similar atmosphere of scientific and practical efficiency.

With regard to the introduction of mustard gas at one of these meetings, dimethylsulfate was discussed. The medical expert gave the toxicity figures which were satisfactory. The chemist would say that there was no difficulty for industrial manufacture of this product. But the economic expert would object.

There are two methyl groups in this compound. To produce quantities sufficient for war needs so many tons of methyl alcohol would be needed but would not be available. Even if a new factory could be built in time, the amount of methyl alcohol thus produced would not be sufficient Therefore, another compound, one that would contain only one, or better still, no methyl group, would be preferable.

Thus the attention of the meeting returned to mustard gas which contained ethyl groups and two chlorine atoms in its molecule. Ethyl alcohol was abundantly available, but chlorine was rather scarce.

The economic expert immediately suggested a decree prohibiting the bleaching of paper all through Germany for the duration of the World War. In this way a certain number of tons of chlorine would be made available for the manufacture of sufficient quantities of mustard gas.

There was another expert present who had a very satisfactory knowledge of the capacity of the Allied chemical industries, and who foretold that the Allies would need at least one year to produce sufficient quantities of dimethylsulfate or mustard gas for possible counter-attacks with the same gas.

The course of the World War proved that the estimate of this expert was correct. In fact, the problems were much more complex than can be described here. The stability of a gas while in contact with the steel, brass and copper parts of the shell, or with the cement and other parts of the ignition system, the reactions which take place between the explosive and the gas during the explosion or the decomposing influence of the high temperature at which the explosion takes place, changes of chemical or physical character during the storage of the war gas or of the completed shell, ballistic problems of purely military importance, strategic,

tactical and transport problems were involved in every such case.

The complex and manifold interrelations involved in the evaluation of a new gas may be schematically tabulated as follows:

A new gas is evaluated for:

Tactical properties to be used in:	Technical properties to be used in:	Toxic properties, to act on men as:	Effect on the gas defense of the enemy which may render:
Millitary attack military defense; attacks on civil population	Gas clouds; gas shells; gas bombs;	Irritant; poison;	No protection; partial protection; full protection.

This table naturally contains only a few of the main factors which are important for the evaluation of a gas under certain well-defined circumstances. The possible combinations and permutations between these 12 factors are further increased if the economic factors and especially the time factor is considered. It is obviously of greatest importance, how much time will be needed to prepare a new gas weapon against a gap in the gas defense, of the enemy, that has just been discovered: The best gas weapon developed by most excellent research scientists must be evaluated as practically useless, if the state of preparedness that exists would make its introduction into the field impossible or would imply undue delay. We must, therefore, conclude this chapter on the evaluation of a gas by a few words on preparedness in the field of chemical warfare.

Preparedness

Reviewing the various factors which decide the selection of special weapons or methods in the field of chemical war-

fare we understand that the possible combinations cannot be counted. The possibilities become more complicated, if the special plans of a general staff, strategical requirements, political factors are also considered. According to the geographical, political and economic circumstances, the military preparedness in the field of chemical warfare is a major problem for modern armies, navies and air forces; with a view on chemical warfare, plans for preparedness must include a great number of measures of which the most important may be enumerated as follows:

1. The civil profession of the draftees should be considered in such a way that a sufficient number of chemists, pharmacists, physicians and laboratory technicians be selected for special training in chemical warfare.

2. A certain percentage of soldiers, non-commissioned officers and officers is to be trained for special gas service. This training transcends the average training in gas warfare and gas protection which every member of the armed forces receives and is not confined to special gas regiments.

3. Officers who serve in the higher staffs and high commands must acquire a thorough understanding of the strategical and tactical possibilities of chemical warfare. This means specifically that commanders, or prospective commanders, who have studied strategy, must be thoroughly trained in and be absolutely familiar with the cooperation of all kinds of troops and weapons of which chemical warfare is one of the most important ones, especially for the maintenance of the mobility of preparedness.

4. Preparedness for chemical warfare requires peacetime planning of raw materials and productive capacity of the chemical industry. The planning should include provisions that a sufficient number of specialists, chemists,

pharmacists, technicians and foremen are exempt from being drafted for the armed forces.

5. Raw material needed for the production in the field of chemical warfare must be provided in time and stored in safe places. Sufficient quantities of such by-products or ready prepared war gases, which do not alter their composition by storage must be kept ready in sufficient quantity for mobilization day. Stocks should be sufficient to last for at least 2 years.

6. Most important is the ability of the entire organization of chemical warfare to adapt itself to new tasks which may result from changed political and military situations. For this purpose, it is necessary that the personal forces of chemical warfare possess a very high standard of training and scientific and military understanding. Materially it is necessary that the production capacities of the industry are listed in advance as to the quality and quantity of the products which they can produce with their actual equipment and also which they could produce after certain changes of equipment will have taken place. For such planning the cooperation between the industries concerned and government experts, such as may serve with the defense councils is indispensable. The mobility of preparedness in chemical warfare is more important than the preparedness itself.

CHAPTER VI:

TOXICITY FIGURES AND STANDARDS

Toxicity Figures For Men and Animals

Toxic concentrations for men cannot be determined experimentally with the same exactitude, as is possible in animal experiments; yet, the figures for men are the only ones which are of interest for both chemical warfare and in occupational diseases. For that reason, we have to discuss in general the practical value of such figures as are available on the basis of our actual knowledge and experience.

In some cases, it is possible to estimate the toxic and fatal concentrations for men directly from conditions found in accidents and occupational exposures in industry. For most of the poisons the toxic and fatal concentrations as derived from direct observations in industry are rather unsatisfactory. Therefore, there is no other way than that to refer to the figures obtained from animal experiments. Such figures are known for many more substances, but by far, not for all poisons. In addition, even these figures are not as exact as physical and chemical data.

Sources of Error Due to Technical Laboratory Equipment

Not only biological factors, but also, purely physical and physico-chemical conditions occurring in the experimental determination of toxic concentrations include many sources of error which are connected with the different laboratory methods. Almost every laboratory possesses different ap-

paratus and uses different methods, so that only a relatively small number of toxicity figures quoted throughout the scientific literature may be compared with each other. There is not, as yet, any standard method generally accepted for the establishment of toxicity figures.

Most of the older determinations were made with inadequate apparatus, such as glass bells of far too small dimensions. Under such conditions, the absorption of the gas mixture on the walls of the bell and on the fur of the animal is so important that the figures obtained are not only 10-, but even 100- and 1,000-fold wrong. What is even worse, is the fact that only recently did research workers themselves realize the enormous extent of this source of error.

The conditions concerned were largely studied for the first time during the World War. It is characteristic that in our age of admirable developments of physical research and knowledge, and the spreading of that knowledge through medical science, no medical research worker made a sufficient study of this question. The accidental coincidence that a large amount of toxicological research work in the field of gas warfare was carried out under the direction of a physico-chemist, Fritz Haber, brought valuable progress to toxicological science. The results of this work are not yet sufficiently evaluated throughout the world because the German publications on the subject are very brief.

These experiments led to the following conclusions:

1: Experiments in glass bells produce no valuable results at all for the reasons already described.

2: The gas chambers used should be of sufficiently large dimensions in proportion to the size of the animals used. For smaller animals, like several mice, rats, or guinea pigs,

the gas chamber should not be smaller than one cubic meter.

3: For experiments on single cats, or equally small dogs, gas chambers of one cubic meter content may be used, but only for provisional experiments.

4: For the establishment of exact figures, which can only be obtained by the simultaneous intoxication of a greater number of such animals, a gas chamber should have a content of from 10 to 40 cubic meters. In chambers of this size the animals have the opportunity to move freely within the chamber during the process of the experiment.

5: These large gas chambers create new sources of error for various reasons. It is difficult, for instance, to obtain an equal mixture of the gas with the air throughout the chamber. If the mixture is made by means of fans only, the resulting mixture is not at all equal. Such a fan, if installed symmetrically to the form of the chamber, causes a constant movement of the air in one direction only. There may result different vertical or horizontal layers of air, each with different concentrations of the gas. Another inequality of the distribution of the gas and the air is caused by the density of the vapors. Under certain conditions, the lower layers, where the animals move, contain higher concentrations than the upper layers. If there are different animals in the gas chamber at the same time, for instance, cats and monkeys, and the monkeys take their place on a higher level, the results would not be comparable.

6: For such reasons, the experiments in these gas chambers are to be controlled by numerous chemical analyses of the air. The samples of air to be analyzed should be taken from different spots within the chamber. Such analyses, made in large number for the gas chambers used in Berlin during the World War, have proved that the concentration of the gas, introduced into the gas chambers of 10—40 m^3

content, decreases as much as 50% within a few minutes after the spraying of the poison. During the initial period, the loss is caused by the absorption of the gas on the walls of the chamber. After this period, there follows a slower decline of the concentration so that it has been found useful to introduce the animals into the gas chamber not less than 5 minutes after the spraying of the poison. A gradual, but essentially slower decline of the concentration takes place during the following period, making it possible to get fairly reliable figures for an exposure from 10 to 30 minutes. For exposures longer than 30 minutes, the decline of the concentration would be too great without renewed spraying of the poison. These conditions must be studied by numerous analyses for every individual chamber and poison. It would, therefore, be useless to show here a special curve obtained from the analysis of an individual gas chamber for a special poison. Where such complete and reliable curves are not established, the toxicity figures obtained will not be beyond doubt.

7: In gas chambers equipped with an apparatus providing current of a gas-air mixture, the physico-chemical conditions are also very complicated. Such an apparatus should provide a continuous current of air containing a constant content of poison. This is, however, extremely difficult to accomplish. It is, furthermore, difficult to provide an equal distribution of the gas-air mixture throughout the entire space.

For exposures of long duration, satisfactory results are obtained in smaller chambers; yet, for short exposures, it depends on many details, whether a smaller gas chamber with a streaming apparatus is more exact than a larger gas chamber with a stable atmosphere. Only such experiments in which all the physical and physico-chemical conditions are

carefully controlled by numerous chemical analyses can be used for reliable results. These requirements, unfortunately, are only fulfilled in a very small number of experiments recorded in the scientific literature.

For these reasons, it often requires very careful consideration to choose the figures for the toxic and fatal concentrations. Furthermore, it is not informative to quote all the figures published by different authors. On the other hand, figures are necessary and cannot be dispensed with. The physician needs information on the quantitative toxicity of different poisons.

To give a trivial example, it should be mentioned that for chloroform vapors, two equally famous and reliable authors give the following figures for the fatal dose:

Lehman—Hess:[1] 200,000 mg per m^3 within 30 - 60 minutes: ct=6,000,000 to 12,000,000.

Flury:[2] 120,000 mg per m^3 within 5 minutes: ct=600,000.

If figures are so divergent for such a well-known substance as chloroform, how unreliable must be the figures for other substances, where only a few cases of intoxication are known?

Both of the foregoing figures are quoted throughout toxicological hand- and text-books, not only in America, but all over the world. This proves that, for some reason, the authors of these books did not decide which figures were more reliable. If an author does not make the decision, how can a student possibly do so?

In the example mentioned above, I know that Flury's experiments were made with more modern apparatus than those of Lehman. It is, therefore, understandable that Flury's

[1] Flury-Zernik, Schaedliche Gase, p. 315 (1931).

[2] Flury, Arch. F. Exp. Path. u. Pharmar., vol. 98, p. 65 (1928). ct = c (concentration mg per m^3) t (time in minutes).

figures are lower than those obtained by Lehman in smaller gas chambers.

If we have to deal not only with gases and vapors, but also with fogs and dusts, the conditions become still more complex. Fogs and dusts are of very different composition. The toxicological effects largely depend upon the degree of dispersion and upon the diameter of the individual particles. Large particles of lead or very big drops of chromic acid solution in the neighborhood of a galvanic bath will be kept back effectively in the very entrance of the nose. Very small dust particles or drops will enter the finest branches of the bronchioli. The big particles and droplets can be removed by mechanical cleansing. Only the finest particles of the lead dust will be absorbed through the lungs into the blood, and the finest particles of the chromic acid solution will cause bronchitis. Under such conditions, it is obvious that the simple chemical analysis of the content of the lead or chromium in the air would not give sufficiently exactly, the hazard incidental to the working conditions. It is clear that the great variety of possible conditions makes it difficult to find toxicity figures which are generally valid and which could be transferred from the experiment to working conditions, or from one animal to another, or even to men. Toxicity figures, therefore, can, under no circumstances, be considered as generally valid figures as is the boiling point, or the flash point of a certain substance.

If toxicity figures are so uncertain, one might be tempted to ask, if it is worth while at all to quote them. Surely, it is. Not only do these figures allow a reasonable comparison of the relative toxicity of different poisons, but if the possible sources of error are reasonably considered, they also permit the establishment of toxicity standards below which work is

practicable for average healthy adults, and above which work might be dangerous or fatal.

Sources of Error Due to The Animals Used In Laboratory Experiments.

As we are not able to make toxicological experiments on men, we will always be compelled to refer to the results of animal experiments.

Laboratory experiments on cold-blooded animals,such as, frogs, fish, amphibians, may be useful in the study of special problems, as, the action of a poison on a certain function, or on certain organs; but it is not at all possible to transfer toxicity figures from such experiments to men, because these animals absorb toxic gases and vapors through the whole surface of their bodies. In other words, their susceptibility to poisons is too different from that of men.

Among the warm-blooded animals, little birds, like canaries, are very sensitive to narcotic gases and blood poisons, such as, carbon monoxide—much more so than men. Concentrations fatal to them are hardly toxic to men. For that reason, miners sometimes take such birds with them into the pits as indicators for dangerous concentrations of mine gases.

On the other hand, doves are much less sensitive to irritant gases like phosgene so that carrier pigeons have been very useful under certain conditions in gas attacks. However, pigeons are as sensitive as cats to narcotic gases and blood poisons.

The protective respiratory reflexes of rodents have already been mentioned, as a reason for the unreliability of gas experiments made on them. Furthermore, rodents are vegetarians. Their susceptibility to poisons is, therefore, different according to the food they get. Dry food contains

much more calcium than green food. The content of calcium, minerals, and vitamins in the food is of great influence on the resistance to poisons of the individual animal. Therefore, toxicity figures obtained for mice, rats, rabbits, guinea pigs, etc., do not provide reliable clues for the estimation of the corresponding toxicity figures valid for men.

Yet figures obtained from experiments on cats, dogs, and monkeys are very well informative. One should know that cats are more sensitive to poisons than men. It may be a very rough approximation to assume that the toxicity figures for cats are half that for men.

The sensitivity of cats also largely depends upon the race, age, food, and living conditions. Cats, that have lived a half-wild life in the country, are different from those that have lived in rooms together with men. Cats are largely affected by psychic influences. A cat, according to his natural and racial origin, is a beast of prey. Cats used to catch their prey by night, but domesticated cats are compelled to adapt their habits to those of men and take their food by day instead of by night, and to sleep by night. These are unnatural conditions for cats. Cats, coming into the laboratory from a life-long stay within an urban tenement house, show reactions quite different from those of cats accustomed to living in the open country. The latter will suffer much more, when confined to the laboratory cage. Lack of motion, change of food, psychic depression are injurious. Systematic observations proved that such cats, even if their food is as adequate as possible, frequently die within about a month, if no experiments are performed on them, as a result of psychic depression and the unnatural conditions of such captivity.

One can also observe that the food of such cats is eaten

by night, even if offered during the day, and that the main quantity of urine and excrement is eliminated during the night. These observations are in agreement with the fact that the cats have been domesticated and have been living together with men only for the last few thousand years. This is a far shorter period than is assumed for dogs which have been living together with men for the last 20,000 years or so.

Therefore, dogs are much more adapted to live in company with men. Again, there are wide differences caused by race; small dogs react in a different way from large ones. Young dogs are less sensitive to asphyxiants than older animals. The sensitiveness of dogs can also be altered by different kinds of food. Addition of milk and calcium to the food may augment their resistance to the different gases. Toxicity figures found by experiments on dogs are higher than those for men. In some cases, they may be about equal. It is not possible to establish rules for these relationships, but a personal experience can be acquired by toxicological research workers in the course of time and on the basis of numerous single experiments.

Monkeys are still wild animals, not at all domesticated. They are vegetarians and accustomed to eating only the best fruits in freedom. The toxicity figures found for monkeys are about the same as those found for dogs. For that reason, as far as naked figures are concerned, the choice of monkeys as experimental animals offers no advantage, but monkeys are able to express symptoms far more vividly than any other animal. As soon as their belly or head begins to ache, they will react by pressing their hand against the aching part of the body. Vomiting is much more human-like on the part of monkeys than on dogs or cats. The conditions under which this symptom appears in mon-

keys correspond more closely to those under which it would appear in men. Symptoms of bronchitis, of conjunctivitis and injuries to the cornea of monkeys are very similar to the like symptoms of men.

The monkeys, which are used generally for these toxicological experiments, are macacus and rhesus. Their capability to express symptoms is largely sufficient for all observations needed in this field. It is not necessary to take more anthropomorphous apes that are too expensive and rather too sensitive to all kinds of influences, particularly, confinement and general treatment. The psychic qualities of macacus and rhesus are sufficiently complex, and by this complexity, superior to all other kinds of laboratory animals. It is merely necessary to take the psychic qualities of these highly developed animals into account.

For such reasons, when we undertook gas warfare experiments on monkeys, Flury and I brought in for consultation an expert on animal psychology, an outstanding specialist in this field, Emil Pfungst, who examined the monkeys, before any experiment began. He used to qualify the monkey by comparing him with a human being. He finally concluded that a monkey corresponded for instance, to a man of 16 or 20 years of age. It was learned from such examinations that most of the macaci and rhesi available corresponded to men from 12 to 20 years of age. Older animals were scarce. Even if they were available, they generally were less useful for experimentatal research. The probability was that they had acquired some disease during their longer period of captivity. This discussion again proves that the establishment of toxicity figures is not only a physico-mathematical problem but also includes biological considerations of a complicated nature. For such reasons, experimental researches on monkeys, if reasonably executed, may

produce results which cannot be obtained by experiments on any other laboratory animals.

Finally, it may still be mentioned that experiments on toxic concentrations valid for the effect of poisons on the skin, can be made on suckling pigs. The skin of these animals is more similar to that of man because of the tenderness and lack of hair. It will not always be possible to find men who are willing to offer their skin for experiments of irritative effects, and it is impossible to make such experiments on men, if the irritant is supposed to be toxic by absorption. Experiments of this kind on suckling pigs may, therefore, enable the toxicologist to find toxicity figures not otherwise obtainable.

Conditions In Industry

Sources of error are still greater if toxicity figures are derived from our direct experiences and observations of industrial conditions.

Physical and chemical factors incidental and accidental, of drafts of air or ventilation conditions and effects, climatic changes may contribute to create a great variety of conditions in industrial practice which can hardly and fully be considered in the establishment of toxicity figures or standards in industrial practice. In industrial exposures, poisons may be inhaled, swallowed as dusts or absorbed through the skin. In each case, the amount of a poison ingested is far less accurately determinable than it is if the poison is introduced by sub-cutaneous or intravenous injection.

The conditions under which inhalation takes place are even in experiments, not sufficiently determinable. The absolute doses inhaled can be exactly determined only if an air stream with a content of poison, determined by numerous analyses, is introduced directly into the trachea of an animal, and if

at the same time, the respiratory volume of the animal is also determined. The absolute quantity of the poison ingested can then be calculated. Frequency and volume of the respiration depend upon many influences and conditions which are uncontrollable, as different states of excitement, motility, strain, functioning of the reflexes, which largely diminish or augment the quantity of the poison ingested.

Increased strain of a worker leads to increased formation of carbon dioxide in the blood and consequently to an increased stimulation of the respiratory center and an increase in the rate of respiration. Therefore, in industrial plants, the worker will inhale greater amounts of a poison, if the speed of work is increased, since the respiratory rate will increase in proportion to the increased strain. The figures of allowed concentrations should, therefore, be lowered as soon as new methods of work are introduced, that is, increased speed of work, or otherwise abnormal working conditions.

This again proves that disease may occur, when the concentration of a gas, vapor, or dust is below the limit that is generally estimated as non-injurious. In every single case, the physician, when giving his expert opinion, should apply physiological considerations reasonably and logically, before he takes refuge in the comfortable application of fixed standards, or in the thoughtless excuses of "idiosyncrasy," "individual hypersensitivity," "allergy," and the like.

The toxic doses of the same poison are different in many cases, depending upon whether the poison is swallowed, inhaled, or absorbed by the skin. Sub-cutaneous and intravenous ingestion of poisons are of no importance in industrial intoxications and war gas intoxications. If poisons are swallowed or inhaled, they are first subjected to the protective action of the mucous membranes of the respiratory

and alimentary tract. Here they may be altered into less effective combinations, or they may exert local effects which prevent further absorption. Only those poisons which are not altered by the mucous membranes and secretions present in the respiratory passages show the same toxicity figures, whether inhaled or introduced by intravenous injection.

To prove this effect, a series of experiments was executed with strychnine hydrochloride during the World War in Berlin. It proved that the nervous effects of this poison, which is not altered on its way through the respiratory passages before absorption by the blood, are caused by the same doses, whether inhaled or injected into the veins. These experiments are important insofar as they prove that, in principle, inhalation by the lungs is only a different form of direct introduction of a poison into the blood. Inhalation may even be more effective, insofar as a poison makes contact with the blood, if entering by the lungs, on an extremely enlarged surface. The surface of the parenchym of the lungs of an adult is about 80 - 90 square meters. If the same quantity of a poison is injected into the veins, the contact takes place on a relatively small surface, and at the same time, the poison acts in a far more concentrated solution. This consideration explains that, under certain circumstances, inhalation of a poison may be far more effective than any other kind of ingestion, and may result in far lower toxicity figures. Such conditions must be considered, when toxicity standards are established.

It is impossible to consider all the possible conditions in detail that may influence the establishment of standards from direct experience in industry, but one conclusion that can be drawn from this discussion is that it is extremely difficult to ascertain in industry, whether conditions in a certain factory comply with a given allowable concentration standard. A

very great number of analyses of the air at various points in the plant and at different times during the working day, during the various phases of production would be required to establish the fact that at no time was the allowable concentration standard exceeded. Whatever may be the situation, the establishment of such standards should not keep the expert from using his own judgment.

STANDARDS.

If such are the difficulties in arriving at reliable toxicity figures, it is still more difficult to establish toxicity standards, which could be safely applied by those who are not fully acquainted with the conditions of toxicological research. Especially in industrial medicine, it would be extremely desirable to have standards of allowable concentration for poisons used in industry. Attempts to establish such toxicological standards have been made for decades. But, as everybody knows, practical results are still unsatisfactory. This cannot be otherwise as long as it is not fully understood that toxicity figures can never be of general validity, such as molecular weight, boiling and melting points and the like. Even these figures are not the same under all conditions and circumstances. They are given for a certain air pressure or are limited by other conditions. Toxicity figures, too, must be limited by certain conditions. If reasonable limitations are established in the basic definitions of certain figures which may serve as standards, satisfactory practical results can be expected.

In spite of the fact that such suggestions originated with Fritz Haber's invasion into the field of toxicological research during the World War, only a part of his suggestions has been accepted by a very small number of toxicologists or pharmacologists. Attempts to establish allowable concentra-

tion standards of a more general validity have not yet disappeared. It is, therefore, necessary to discuss this problem rather fully. I shall follow the ideas established by Fritz Haber 25 years ago, the ideas that have been applied in the German research work on noxious gases. Instead of establishing general figures on allowable concentrations, Fritz Haber, together with Flury and Wachtel established various more specially defined terms concerning effects of poisons:

A: *Irritation*: Irritation as caused by a poison under industrial or field conditions can be defined by specific figures. Under certain conditions, this can be done by direct experience on men. Irritation may cause:

1: Sudden immediate death by reflex reaction. This figure can only be derived from direct observations of accidents. It is, therefore, hardly ever recorded.

2: Incapacity to work or to continue work in industry. If a gas is a war gas, the same figure would mean fighting inefficiency. Such figures are established for a number of irritant poisons, for example, phosgene. 40 mg per m^3=10 parts per million cause fighting inefficiency within a few seconds (Vedder); 20 mg per m^3=5 parts per million within one minute represents the intolerability limit.

3: There are no effects, if the concentration is below a certain limit. There are, for instance, no irritative effects of hydrogen sulfide below a concentration of 16 parts per million. These toxicity figures can and should be determined for every industrial poison. Our knowledge today extends over only a very limited number of poisons. In fact, so limited is our knowledge that it is impossible to give even one poison as an example for which all three figures are known. Wherever such figures are known, they may be found in the special paragraphs on toxic concentrations in the special chapters.

In many cases, irritative effects are caused by concentrations which are too small to be directly toxic. Nevertheless, under industrial conditions, chronic or repeated irritation of mucous membranes may cause pathological effects which are to be compensated as occupational diseases, even if these effects are not the specific effects of a poison.

In compensation practice, the problem occurs very frequently, as to whether a broncho-pneumonia or a bronchitis was caused by the irritative effects of vapors or acids which were far below the toxic concentrations. In connection with our knowledge of the facts that irritant gases may indirectly contribute to infections of the respiratory passages it would be of greatest importance to know for each poison the exact concentrations that cause certain irritative effects, such as tearing, reddening of the eyes, conjunctivitis, pain of the eye, sneezing, running nose, coughing, dsypnœa and other effects that are characteristic of certain groups of poisons.

B: *Toxic Dose*: The toxic dose is the minimum concentration that causes disability or disease. In this connection, it must be remembered that acute exposure may cause acute, sub-acute or chronic disease, and accordingly, temporary or permanent partial or total disability. On the other hand, chronic exposure may also cause acute, sub-acute or chronic disease. Certain exposures may specifically cause only one form of disease or may cause an outbreak of symptoms only after a certain time has elapsed.

For the determination of the effectiveness of war gases, it is extremely important to know whether a certain concentration would cause immediate outbreak of symptoms, fighting inefficiency, or disease of long or short duration, and so on.

It is necessary to know whether a certain concentration will cause disease and the outbreak of symptoms during the exposure, in the course of the working day, or whether sym-

ptoms could be expected to appear only some time soon after or whether they would be delayed for a more prolonged period. In other words, toxicity figures must contain the *time* factor; otherwise, they are without meaning.

1: A certain toxic dose may cause immediate disability, incapacity to work or fight. Such would be the case if the exposure is to carbon monoxide: a concentration of 1,100 mg per m^3=1,000 parts per 1,000,000 within one hour would cause acute immediate disability.

2: A certain toxic dose may cause pathological processes within the organism which cause subjective symptoms of disease and disability only after a period of latency which may last for hours or even days. The typical example is phosgene as the prototype of all irritant gases. The period of latency, in these cases, even if it does not cause subjective or objective symptoms, is already a dangerous effect incidental to the poisoning effect of such a toxic dose.

3: A certain toxic dose may cause symptoms of disease and inability to work or fight, only after a period of latency has passed, which is not dangerous in itself. Such is the case, for example, in acute intoxication by benzol chloroform, carbon tetrachloride and other narcotic poisons, 10,000 mg per m^3 of benzol=3,000 parts per 1,000,000 may cause narcotic effects on men after more than one hour of exposure only.

4: A certain toxic dose may cause disease after protracted chronic exposure only. The resulting disease in most cases will be a chronic one, for instance, inhalation of 1 mg lead daily for several months may cause the outbreak of chronic lead intoxication. Exposure to silica dust of a certain concentration and size of particles would cause silicosis only after very long lasting exposure. Such figures, in most cases, cannot be determined by laboratory experiments, but

must be derived from direct experiences and observations in the industrial field. It is, therefore, most difficult to establish these figures as standards that can be more or less generally accepted,

C: *Fatal dose*: To the general practitioner, fatal doses are most familiar in the way in which they are used in pharmacology and especially in immunology. There, the fatal dose of a toxin means the dose of toxin that causes the death of an animal of a certain weight within four days after ingestion. In industrial toxicology the fatal dose cannot be defined so simply. For practical convenience, it would be desirable to distinguish between fatal doses which cause:

1: Immediate Death: Hydrocyanic acid, 300 mg per m^3 =270 parts per 1,000,000 will cause immediate death, or hydrogen sulfide, 1,400 mg per m^3=1,000 parts per 1,000,000 will also cause immediate death.

2: Delayed Death: Such may be the case with poisons that cause a period of latency or a slow development of irreversible pathological processes; for example, the fatal dose c x t=3,000 may mean an exposure to a concentration of 50 mg phosgene per m^3 for one hour and cause death after three days of disease; the same exposure to mustard gas may cause death after a disease of three to four weeks. In these examples, death is caused by the direct toxic effect of the poison and by the pathological processes which are caused by the poison. They do not mean the effects of secondary infection which may cause late death after intoxication, but which are not direct effects of the exposure and must, therefore, not be included in such standards as they are more or less accidental effects.

D: *Allowable concentration standards*: In addition to these toxicity figures, it is desirable for practical convenience

to establish allowable concentration standards for industry. If such standards would not contain the time factor, they would be unfair to the employer. If the concentration is somewhat higher than the standard (that does not take the time factor into consideration) the employer would be required to take all kinds of safety precautions, even though the exposure is transitory and of short duration. In every case, the allowable concentration standard must include the time factor. For example, hydrogen sulfide, 28 mg per m^3=20 parts per million may be considered as allowable concentration for an exposure not exceeding 8 hours per day. However, such exposure may cause irritation of the eyes, as has been recorded in literature, to persons who are not accustomed to it. Exposure to 280 mg per m^3=200 parts per 1,000,000 for not longer than one hour has also been reported as a tolerable dose. If only the former figure is established as the official concentration standard, an employer who exposes his employes to a concentration ten times higher for only a few minutes might be considered guilty of negligence, because engineers, referees, judges, and even physicians who are not very familiar with the special toxicological experiences might be led to errors. For such reasons, it is so much more difficult to establish toxicological and biological standards in general than it is to standardize technical devices and appliances which we can arbitrarily determine, for example, the size of pipes, taps, water hydrants, etc.

Toxicological standards, too narrowly limited, may paralyze the freedom of thinking on the part of all persons concerned, instead of leading them to use their own judgment on the basis of our scientific knowledge. Perhaps, it would be more helpful, if standard committees, instead of establishing one figure only, would establish tables for certain poisons. These tables would be made up of those figures selected from

the literature that are considered to be the most reliable ones by a committee of technical and medical experts. Such tables may serve as a guide to all experts who are called in to give their opinions in special cases. The tables, however, should and must not prevent these experts from using their own judgment or from giving their final opinions.

The following table may serve as an example. It shows that the time factor is very important and that Haber's formula, applied to industrial conditions, is as informative as it is for war gases:

	C (concentration)		T (time of exposure)
	mg/m³	parts per million	
CARBON MONOXIDE:			
A. Irritation	—	—	—
B. Toxicity			
Minimum toxic dose	750	650	1 hour
Acute immediate disability	1,100	1,000	1 hour
C. Fatal dose	4,600	4,000	1 hour
D. Allowable concentrations	460	400	1 hour daily
	110	100	8 hours daily
HYDROGEN SULPHIDE:			
A. Irritation			
Conjunctivitis	14-20	10	6 hours
Intolerability limit	280	200	5-8 minutes
Working incapacity	280	200	30 minutes
B. Toxicity			
Minimum toxic dose	140-210	100-150	8 hours
Acute immediate disability	700-1,000	500--700	1 hour
C. Fatal dose	1,400	1,000	immediately
D. Allowable concentrations	28	20	8 hours daily
Maximum tolerable dose	280	200	1 hour

The figures given in these two tables are recorded in the literature. Their inclusion in these tables does not mean that just these figures are recommended standards, but such tables that contain more or less the available information on special poisons would give a better lead to all experts than would figures on allowable standards. It would be the task of a standards committee to select the most reliable figures from the literature and to compile them in such tables. Insofar as satisfactory figures are not known, the standards committee should encourage special research work just for the purpose of establishing such figures.

The Time Factor and Haber's Formula.

Keeping this in mind, it should be understood that for practical purposes, it is sufficient to establish toxicity figures which satisfy the purely practical needs and permit, at the same time, a comparison of the toxicity of different poisons. This aim is attained in the best way for practical use by the application of the *formula of Fritz Haber.* This formula represents an important progress in comparison with other expressions, used for the determination of toxicity figures, by the fact that it represents the time factor which is not contained in absolute toxicity figures, but which is of extreme importance for industrial exposures. The formula is:

$$c \times t = ct$$

c = the concentration expressed in mg per m^3 or mm^3 per m^3.

t = the time of exposure expressed in minutes.

Both factors can easily be determined.

ct, the resulting product, expresses the toxic or lethal dose in one figure.

If such figures, as determined for different poisons, are to be compared with one another, it is obvious that the

sources of error contained in these figures are relatively equal and, therefore, of no importance for the result.

It may further be emphasized that this formula illustrates another important fact. For many poisons, for instance, phosgene, the product, ct, is constant. This means that the poison is equally fatal or toxic, whether a high concentration is inhaled for a short time, or a very low concentration is inhaled for a correspondingly long time.

There are other poisons, like hydrocyanic acid, for which the product, ct, is not constant. The fatal product, ct, in this case, is only valid for a certain limited concentration. If the concentration is lowered below this limit and the time prolonged, the product, ct, is no longer fatal. Such a statement is of great practical importance, for instance, for the judgment about the danger of work executed in a certain atmosphere which is below the dangerous concentration. In such cases, it is merely necessary to determine the concentration of the poison in the air. The duration of the exposure is of no, or, minor, importance.

Haber's Formula Made History

Haber's formula enabled German gas warfare to decide upon the introduction of mustard gas into practice long before the Allied Armies thought of using gas for defensive purposes. Haber's formula made it clear that even the lowest concentration of mustard gas is effective, as its ct product is constant. It also made it clear that hydrocyanic acid, believed to be the most effective "traditional" poison, was not effective as a war gas. The Germans used cyan compounds as a means of dilution only, on account of an insufficient supply of other, more effective gases. The application of Haber's formula proved that hydrocyanic acid, at a certain high concentration, is immediately fatal, yet below

this limit, even by protracted exposure, causes slight disturbances of short duration, or even, none at all. As the immediate fatal effect, under field conditions, is difficult to attain, this gas is unsuitable for purposes of gas warfare.

The Allied Armies, not in possession of Haber's formula, and encouraged by the German use of similar compounds, ignorant of the fact, however, that they only served as a means of dilution for economic reasons, wasted enormous quantities of relatively inefficient ammunition. This could easily have been replaced by more efficacious shells, as the Allied powers suffered no lack of either production or raw materials.

Even after the World War, the result of Haber's formula was not generally understood. The war industries of some countries may still be producing these relatively ineffective cyanogen shells. It may require a new world war to convince the experts of certain countries of the facts. One great power outside Germany has learned this lesson very recently.

The historical importance is amazingly far-reaching for such a simple scientific fact as is Haber's formula, $c \times t = ct$.

Conversion Table for Gases

In the special chapters which follow, the toxicity figures are given in mg per m^3 if not mentioned otherwise.

Inasmuch as figures indicate "parts per million," they relate to a temperature of 25°C and an air pressure of 760 mm, if not mentioned otherwise.

The figures of liter weigh (vapor weight) are calculated for a temperature of 20°C and an air pressure of 760 mm Hg.

The following table, taken from U. S. Bureau of Mines, Technical paper, p. 248, 1921, easily permits the finding of

the corresponding figures in "parts per million," if needed.

It would be still more correct and satisfactory to measure the concentration in equimolecular quantities. For many practical purposes, however, this would be too complicated to be used generally. If it could be done for scientific research only, concentration figures would be much more informative. Particularly, the comparison of the toxicity figures of different poisons would be more instructive and accurate.

CONVERSION TABLE FOR GASES: PARTS PER MILLION VERSUS MILLIGRAMS PER LITER.[1]

[25° C. and 760 mm. mercury, barometric pressure.]

Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.	Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.
1.....	24,450	0.0000409	19.....	1,287	0.000777
2.....	12,230	.0000818	20.....	1,223	.000818
3.....	8,150	.0001227	21.....	1,164	.000859
4.....	6,113	.0001636	22.....	1,111	.000900
5.....	4,890	.0002045	23.....	1,063	.000941
6.....	4,075	.0002454	24.....	1,019	.000982
7.....	3,493	.0002863	25....,	978	.001022
8.....	3.056	.000327	26.....	940	.001063
9.....	2,717	.000368	27.....	906	.001104
10.....	2,445	.000409	28.....	873	.001145
11.....	2,223	.000450	29.....	843	.001186
12.....	2.038	.000491	30.....	815	.001227
13.....	1,881	.000532	31.....	789	.001268
14.....	1,746	.000573	32.....	764	.001309
15.....	1,630	.000614	33.....	741	.001350
16.....	1,528	.000654	34.....	719	.001391
17.....	1,438	.000695	35.....	699	.001432
18.....	1,358	.000736	36.....	679	.001472

Factors for conversion of some units.

1. Mg. per L X 28.32=Mg. per cu. ft.
2. Mg. per L X 1.000=Mg. per cu. m.
3. Mg. per cu. ft. X 35,314=Mg. per cu. m.
4. Mg. per cu. meter X 0.02831=Mg. per cu. ft.

[1] U. S. Bureau of Mines, Technical Paper 248 (1921).

Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.	Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.
37.....	661	0.001513	79.....	309	0.00323
38.....	643	.001554	80.....	306	.00327
39.....	627	.001595	81.....	302	.00331
40.....	611	.001636	82.....	298	.00335
41.....	596	.001677	83.....	295	.00339
42.....	582	.001718	84.....	291	.00344
43.....	569	.001759	85.....	288	.00348
44.....	556	.001800	86.....	284	.00352
45.....	543	.001840	87.....	281	.00356
46.....	532	.001881	88.....	278	.00360
47.....	520	.001922	89.....	275	.00364
48.....	509	.001963	90	272	.00368
49.....	499	.002004	91.....	269	.00372
50.....	489	.002045	92.....	266	.00376
51.....	479	.002086	93.....	263	.00380
52.....	470	.002127	94.....	260	.00384
53.....	461	.002168	95.....	257	.00389
54.....	453	.002209	96	255	.00393
55.....	445	.002250	97.....	252	.00397
56.....	437	.002290	98.....	249.5	.00401
57.....	429	.002331	99.....	247.0	.00405
58.....	422	.002372	100	244.5	.00409
59.....	414	.002413	101.....	242.1	.00413
60.....	408	.002554	102.....	239.7	.00417
61.....	401	.002495	103	237.4	.00421
62.....	394	.00254	104.....	235.1	.00425
63.....	388	.00258	105	232.9	.00429
64.....	382	.00262	106.....	230.7	.00434
65.....	376	.00266	107.....	228.5	.00438
66.....	370	.00270	108.....	226.4	.00442
67.....	365	.00274	109.....	224.3	.00446
68.....	360	.00278	110.....	222.3	.00450
69.....	354	.00282	111.....	220.3	.00454
70.....	349	.00286	112.....	218.3	.00458
71.....	344	.00290	113.....	216.4	.00462
72.....	340	.00294	114.....	214.5	.00466
73.....	335	.00299	115.....	212.6	.00470
74.....	330	.00303	116.....	210.8	.00474
75.....	326	.00307	117.....	209.0	.00479
76.....	322	.00311	118.....	207.2	.00483
77.....	318	.00315	119.....	205.5	.00487
78.....	313	.00319	120.....	203.8	.00491

Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.	Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.
121.....	202.1	0.00495	163.....	150.0	0.00667
122.....	200.4	.00499	164.....	149.1	.00671
123.....	198.8	.00503	165.....	148.2	.00675
124.....	197.2	.00507	166.....	147.3	.00679
125.....	195.6	.00511	167.....	146.4	.00683
126.....	194.0	.00515	168.....	145.5	.00687
127.....	192.5	.00519	169.....	144.7	.00691
128.....	191.0	.00524	170.....	143.8	.00695
129.....	189.5	.00528	171.....	143.0	.00699
130.....	188.1	.00532	172.....	142.2	.00703
131.....	186.6	.00536	173.....	141.3	.00708
132.....	185.2	.00540	174.....	140.5	.00712
133.....	183.8	.00544	175.....	139.7	.00716
134.....	182.5	.00548	176.....	138.9	.00720
135.....	181.1	.00552	177.....	138.1	.00724
136.....	179.8	.00556	178.....	137.4	.00728
137.....	178.5	.00560	179.....	136.6	.00732
138.....	177.2	.00564	180.....	135.8	.00736
139.....	175.9	.00569	181.....	135.1	.00740
140.....	174.6	.00573	182.....	134.3	.00744
141.....	173.4	.00577	183.....	133.6	.00748
142.....	172.2	.00581	184.....	132.9	.00753
143.....	171.0	.00585	185.....	132.2	.00757
144.....	169.8	.00589	186.....	131.5	.00761
145.....	168.6	.00593	187.....	130.7	.00765
146.....	167.5	.00597	188.....	130.1	.00769
147.....	166.3	.00601	189.....	129.4	.00773
148.....	165.2	.00605	190.....	128.7	.00777
149.....	164.1	.00609	191.....	128.0	.00781
150.....	163.0	.00613	192.....	127.3	.00785
151.....	161.9	.00618	193.....	126.7	.00789
152.....	160.9	.00622	194.....	126.0	.00793
153.....	159.8	.00626	195.....	125.4	.00798
154.....	158.8	.00630	196.....	124.7	.00802
155.....	157.7	.00634	197.....	124.1	.00806
156.....	156.7	.00638	198.....	123.5	.00810
157.....	155.7	.00642	199.....	122.9	.00814
158.....	154.7	.00646	200.....	122.3	.00818
159.....	153.7	.00650	201.....	121.6	.00822
160.....	152.8	.00654	202.....	121.0	.00826
161.....	151.9	.00658	203.....	120.4	.00830
162.....	150.9	.00663	204.....	119.9	.00834

Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.	Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.
205.....	119.3	0.00838	247.....	99.0	0.01010
206.....	118.7	.00843	248.....	98.6	.01014
207.....	118.1	.00847	249.....	98.2	.01018
208.....	117.5	.00851	250.....	97.8	.01022
209.....	117.0	.00855	251.....	97.4	.01027
210.....	116.4	.00859	252.....	97.0	.01031
211.....	115.9	.00863	253.....	96.6	.01035
212.....	115.3	.00867	254.....	96.3	.01039
213.....	114.8	.00871	255.....	95.9	.01043
214.....	114.3	.00875	256.....	95.5	.01047
215.....	113.7	.00879	257.....	95.1	.01051
216.....	113.2	.00883	258.....	94.8	.01055
217.....	112.7	.00888	259.....	94.4	.01059
218.....	112.2	.00892	260.....	94.0	.01063
219.....	111.6	.00896	261.....	93.7	.01067
220.....	111.1	.00900	262.....	93.3	.01072
221.....	110.6	.00904	263.....	93.0	.01076
222.....	110.1	.00908	264.....	92.6	.01080
223.....	109.6	.00912	265.....	92.3	.01084
224.....	109.2	.00916	266.....	91.9	.01088
225.....	108.7	.00920	267.....	91.6	.01092
226.....	108.2	.00924	268.....	91.2	.01096
227.....	107.7	.00928	269.....	90.9	.01100
228.....	107.2	.00933	270.....	90.6	.01104
229.....	106.8	.00937	271.....	90.2	.01108
230.....	106.3	.00941	272.....	89.9	.01112
231.....	105.8	.00945	273.....	89.6	.01117
232.....	105.4	.00949	274.....	89.2	.01121
233.....	104.9	.00953	275.....	88.9	.01125
234.....	104.5	.00957	276.....	88.6	.01129
235.....	104.0	.00961	277.....	88.3	.01133
236.....	103.6	.00965	278.....	87.9	.01137
237.....	103.2	.00969	279.....	87.6	.01141
238.....	102.7	.00973	280.....	87.3	.01145
239.....	102.3	.00978	281.....	87.0	.01149
240.....	101.9	.00982	282.....	86.7	.01153
241.....	101.5	.00986	283.....	86.4	.01157
242.....	101.0	.00990	284.....	86.1	.01162
243.....	100.6	.00994	285.....	85.8	.01166
244.....	100.2	.00998	286.....	85.5	.01170
245.....	99.8	.01002	287.....	85.2	.01174
246.....	99.4	.01006	288.....	84.9	.01178

Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.	Molecular Weight	1 Mg./L.-p.p.m.	1 p.p.m. Mg./L.
289.....	84.6	0.01182	295.....	82.9	0.01207
290.....	84.3	.01186	296.....	82.6	.01211
291.....	84.0	.01190	297.....	82.3	.01215
292.....	83.7	.01194	298.....	82.0	.01219
293.....	83.4	.01198	299.....	81.8	.01223
294.....	83.2	.01202	300.....	81.5	.01227

In practice the need may occur to convert toxicity figures as met with in scientific literature, or as given in this book, into such forms as may be necessary to make them comparable. Chemists and engineers will have no difficulty in making the necessary calculations themselves. Physicians who are less familiar with this practice, may find the formulas handy for such purposes, conveniently listed in Vedder, Medical Aspects of Chemical Warfare, Baltimore, 1925.

A convenient list of figures concerning the physiology of the respiration may be found in the following: Bethe, Handbuch der Normalen und Pathologischen Physiologie, Vol. II, Berlin, Germany (1925,)
Junk, Tabulae Biologicae, Berlin, Germany (1926,)
Flury-Zernik Schädliche Gase, p. 63-68, Berlin, Germany, (1931).

CHAPTER VII:

IRRITANT POISONS

The principal war gases which were used during the first World War number between thirty and fifty. They are listed in the following table in the chronological order of their introduction:

The gases were selected from many hundred chemical compounds. This research has largely contributed to the knowledge of the poisonous action and the physiological effects of many chemicals which are useful in peace-time needs and occur in industry as by-products or are important intermediate products in the manufacture of many chemical commodities.

In so far as the enumeration of such compounds and their effects serves to illustrate certain facts or problems, a number of chemicals not hitherto used shall be mentioned in the following discussion. The list of more than sixty arsenic compounds—from which only four had been selected for practical gas warfare—will illustrate certain connections between chemical constitution and physiological effects. Such knowledge may contribute to scientific efforts aiming not only at the discovery of new war gases, but rather at the advance in pharmacology and therapy.

CHRONOLOGICAL LIST OF WAR GASES 1914-1918[1]

Date of first use	Name	Chemical Warfare Service symbols in France	Germany	U. S. A.
	Dianisidine			
1914	Ethylbromoacetate			
1915 January	Xylylbromide		T	
March	Chloracetone	Tonite	A	
	Benzylbromide	Cyclite		
	Benzyliodide	Fraissite		
April	Chlorine	Bertholite	Chlor	
	Bromine	Sulvanite	Brom	
	Ethylchlorosulfonate	Villantite	C	
	Methylchlorosulfonate		K	
	Monochloromethylchloroformate		C	
July	Bromoacetone	Martonite	B	BA
	Bromomethylethylacetone	Homomartonite	Bn	
September	Perchloromethylmercaptan	Clairsite		
December	Phosgene	Collongite		CG
	Ethyliodoacetate			SK

[1] Sartori, The War Gases. New York (1939). Some errors of Sartori are corrected in this table.

Date of first use	Name	Chemical Warfare Service symbols in France	Germany	U. S. A.
1916 January	Acrolein	Papite		
May	Trichloromethylchloroformate	Surpalite	Per	
July	Hydrocyanic acid	Forestite		
	Chlorpicrin	Aquinite	**Klop**	**PS**
1917	Cyanogen chloride	Mauguinite		
	Cyanogen bromide		E	
May	Phenylcarbylaminochloride		K II	
July	Dichloroethylsulfide	Yperite	Lost	HS
	Diphenylchloroarsine		Clark I	DA
September	Phenyldichloroarsine			
1918	Dichloromethylether	Cici		
	Dibromomethylether	Bibi		
March	Ethyldichloroarsine		Dick	ED
	Thiophosgene	Lacrimite		
May	Diphenylcyanoarsine		Clark II	CDA
May	Methyldichloroarsine		Methyl dick	MD
September	Dimethylsulfate	Rationite	D	

The beginning of modern chemical warfare is usually considered to be the day of the first cloud-gas attack at Langemarck, on April 22, 1915. The gas then used was chlorine, in later gas attacks mixtures of equal parts chlorine and phosgene, or chlorine and chlorpicrin were used throughout the first World War until armistice.

These three war gases which were used in cloud-gas attacks will be discussed first. A list, by far not complete, of these attacks will precede the discussion of the single gases, to give an idea of the effects thus accomplished. Phosgene was also used in trench mortar bombs and artillery shells; mixtures of phosgene and chlorpicrin were used, as well, on many occasions. In spite of the completion and perfection of protective measures these gas attacks remained effective throughout the war.

This list of the first cloud-gas attacks shows that the losses caused by gas clouds were high as long as no gas masks were available.

April 22, 1915 at Ypres	
total number of gas poisonings	15,000
number of dead	5,000
May 2, 1915 Bzura-Rawka	
total number of gas poisonings	9,000
number of dead (German estimate)	4,000-6,000
" " " (Russian record)	1,500

With the progress in gas protection the number of casualties decreased.

The German attack at Fort Pompelle, east of Reims, Champagne, against the French front on October 19, and 20, 1915, caused the following results:

Gas cloud, over a front of 17 km (about 10 miles):
500 tons of a mixture of chlorine and phosgene

Total number of gas poisonings	5,096
Including number of dead	815
also including number of those killed in action, on the spot	183

The German attack at Fougues-Court, north of the Somme River against the French front on February 21, 1916, caused the following casualties through a gas-cloud over a front of six km (about 4 miles):

Total number of gas poisonings	1,289
Including number of dead	283
also including number of those killed in action, on the spot	155

A number of German gas clouds, formed from chlorine and phosgene, attacking the British front caused the following casualties:

December 12, 1915 at Wieltje, Width of the front: 4,400 yards

total number of gas poisonings	1,069
number of dead	120
proportion of dead to total losses:	11.2%

April 27, 29, 1916 at Hulluch, Width of the front: 3,500 yards

total number of gas poisonings	1,260
number of dead	338
proportion of dead to total losses:	26.8%

April 30, 1916 at Wulverghem, Width of the front: 3,500 yards

total number of gas poisonings	512

number of dead	89
proportion of dead to total losses:	17.4%

June 17, 1916 at Wulverghem, Width of the front: 3,100 yards

total number of gas poisonings	562
number of dead	95
proportion of dead to total losses:	17%

August 8, 1916 at Wieltje, Width of the front: 1,000 yards

total number of gas poisonings	804
number of dead	371
proportion of dead to total losses:	46.2%

These attacks were directed against the British troops who possessed perfect gas masks. All attacks were carried out at night or at dawn, the results were obtained by surprise. The action was so quick that the men were gassed, before they were able to put on their gas masks. This explains the relative high percentage of fatalities which could be lowered by increased gas discipline.

The total figures resulting from these five attacks are:

total number of gas poisonings	4,207
number of dead	1,013
proportion of dead to total losses:	24%

German attacks with phosgene mines against the British front carried out until May, 1918, caused the casualties recorded in the following table:

Date	*Front*	*Total Gas Poisonings*	*Dead*
1917 Dec. 11	Cambrai	78	21
Dec. 31	Givenchy	34	2
1918 Jan. 26	Lens	2	—
Jan. 31	Lens	19	3
Feb. 14	Bullecourt	66	4
Feb. 16	Lens	10	—
Feb. 19	Lens	9	—
Mar. 6	Avion	70	13
Mar. 7	Gonnelieu	40	6
Mar. 7	Gonnelieu	17	7
Mar. 21	Monchy	—	—
Apr. 14	Lens	—	—
Apr. 22	Lens	—	—
May 1	Hill 70	7	—
May 19	St. Elie	75	20
May 31	Hill 70	17	5
Total		444	81= 18.2%

Further improvement of the gas masks and gas protection service at the front led to further decrease of casualties. This is illustrated by the following table which records the British casualties caused by German gas attacks with green cross ammunition. It includes the attacks between July 14, 1916 and July 13, 1917. This is the period preceding the introduction of blue cross and yellow cross ammunition on the German side.

Date 1916	Number of Gas Casualties	Killed	% Killed
July 21 to August 12.....	1,465	104	7.1
August 19 to September 9....	1,049	35	3.3
September 16 to October 7 ...	345	25	7.3
October 14 to November 4....	225	33	14.7
November 11 to December 2..	343	26	7.6
December 9th to 31st.....	133	7	5.3
1917			
January 7th to 28th.....	159	14	8.8
February 3rd to 24th.....	351	36	10.3
March 3rd to 24th.....	407	25	6.1
March 31 to April 21.....	348	34	9.8
April 28 to May 19.....	1,169	43	3.7
May 26 to June 16.....	1,616	57	3.5
June 23 to July 13.....	1,196	93	7.8
Total	8,806	532	6.

After the gradual decrease of the effects of gas attacks due to the improved gas defense, the introduction of new weapons became indispensible. The new weapons were the arsenic compounds and mustard gas. Their introduction resulted in a new increase of gas casualties. The following table includes the German gas attacks against the British which were executed from July 12, 1917 (the date of the first attack with mustard gas) up to Armistice Day. Various kinds of gas shells, green, yellow and blue cross were simultaneously used in these gas attacks. Yet, it has been stated that the majority of the gas poisonings were due to the effects of yellow cross ammunition (mustard gas).

It is, therefore, interesting to compare these figures with those recorded in the table concerning gas poisonings through mustard gas only (see chapter on mustard gas!)

British gas poisonings caused by shells including mustard gas.

Week end		*Total casualties*	*Killed**
1917			
July	21.....	2,934	101
"	28.....	6,476	146
August	4[2].....	4,866	35
"	11.....	1,583	27
"	18.....	1,890	36
"	25.....	1,263	22
September	1.....	431	2
"	8.....	1,614	17
"	15.....	2,037	62
"	22.....	894	24
"	29.....	1,612	31
October	6.....	1,756	54
"	13.....	512	12
"	20.....	3,249	54
"	29.....	1,933	26
November	3.....	3,845	45
"	10.....	2,675	49
"	17.....	1,653	31
"	24[3].....	1,106	26
December	1[4].....	1,763	14
"	8.....	1,479	30
"	15.....	768	9
"	22.....	288	4
"	29.....	579	9
1918			
January	5.....	653	9
"	12.....	189	1
"	19.....	198	5
"	26.....	356	2
February	2.....	903	7
"	9.....	411	6
"	16.....	408	3
"	23.....	660	16
March	2.....	428	3
"	9.....	904	28

Week end	*Total Casualties*	*Killed*
" 16.....	6,195	39
" 23[5].....	6,874+	36
" 30[6].....	2,686+	30
April 6.....	1,302	10
" 13[7].....	6,940	20
" 20[8].....	3,926	13
" 27[9].....	4,544	30
May 4.....	2,461	31
" 11.....	1,721	14
" 18[10].....	4,421	40
" 25[11].....	3,918	32
June 1.....	3,495	48
" 8.....	1,485	23
" 15.....	1,135	24
" 22.....	525	22
" 29.....	707	44
July 6.....	781	11
" 13[12].....	478	9
" 20.....	605	5
" 27[13].....	1,968	19
August 3.....	2,268	23
" 10[14].....	1,762	20
" 17.....	3,720	23
" 24[16].....	5,367	25
" 31.....	6,265	54
September 7[16].....	6,134	36
" 14.....	2,590	36
" 21.....	4,172	32
" 28[17].....	2,578	12
October 5.....	4,315	24
" 12[18].....	2,206	25
" 19.....	4,407	31
" 26[19].....	2,568	27
November 2[20].....	2,162	23
" 9.....	1,561	12
" 16.....	367	9
" 23.....	27	1
Total	160,952	1,859

+ Incomplete.

CHLORINE. French: "Bertholite."

Physical and Chemical Properties: Chlorine is a gas, slightly yellow green colored and with a biting smell, readily soluble in water and organic solvents. As a liquid it is dark green yellow. Chlorine readily reacts with many inorganic and organic products.

Formula	Cl_2
Molecular weight	70.91
Vapor weight	2.95
Boiling point	—33.6
Specific gravity	2.47 (air 1)

1 liter liquid chlorine=1.47kg=463 liters gaseous chlorine at O°C

1 kg liquid chlorine= 300 liters chlorine at O°C

Tactical properties: As a gas at ordinary temperature, chlo-

Annotations to Table Pages 149—150

[8] Rudolf Hanslian, l. c., pp. 122, 123, 124.
[9] British attack at Ypres on July 31, 1917.
[9] Attack at Cambrai on November 20, 1917.
[4] Attack at Bourlon Forest on November 30, 1917.
[5] Gas shooting on Cambrai on March 11 to 14, 1918.
[6] German offensive on March 21, 1918.
[7] German attack on the Lys river on April 9, 1918.
[6] Gas shooting on Villers-Bretonneux on April 17, 1918.
[9] Kemmel Hill conquered by the Germans on April 25, 1918.
[10] Gas shooting on Fogue Villers on May 11 to 12, 1918.
[11] German offensive at the Ainse river on May 27, 1918.
[12] French attack at Ainse-Chateau-Thiery on July 22, 1918.
[13] Gas shooting on Villers-Brenonneux on July 22, 1918.
[14] British attack on the Somme river on August 8, 1918.
[15] British attack on the Somme river on August 21, 1918.
[16] Advance through Lens on September 3 to 4, 1918.
[17] Cambrai offensive on September 27, 1918.
[18] Advance at Ypres on September 28, 1918.
[19] Attack at Cambrai-St. Quentin on October 8, 1918.
[20] Attack at Valenciennes on November 1, 1918.

rine can be used for cloud-gas attacks. It was highly effective in the field only as long as no adequate gas masks were available. After that time it was still useful in mixtures with more toxic gases, such as phosgene and chlorpicrin.

Technical properties: Chlorine may be used as a gas under pressure or as liquid in steel cylinders. At the temperature of 25°C, 1 liter of liquid chlorine forms 434 liters of gaseous chlorine. In contact with water, moisture, metals and organic substances, such as plants, it reacts rapidly and is immediately neutralized. As chlorine may be advantageously used in the chemical manufacture of war gases of much greater effectiveness than itself, chlorine will probably not be used much in the future.

Toxic properties: Chlorine is an irritant and is also toxic to the respiratory organs.

Toxic concentrations: for men

mg per m³	time of exposure in minutes	product cxt	effect
3	immediately	—	smell is perceivable
40	—	—	irritation of throat[a]
80	—	—	cough[a]
10	30	300	severe irritation, no disease
50	30	1,500	toxic[a]
100	30	3,000	fatal[a]
150	1	150	fighting in efficiency[b]

The American mortality product is 56,000; about the reasons for such discrepancies compare Chapter VI.

Tolerance to chlorine may be acquired by animals through repeated exposure. Men having recovered from a chlorine intoxication are frequently unable to perceive its smell; they

[a] U. S. Dept. of the Interior, Bureau of Mines, Technical Paper 248 (1921).

[b] Lehman-Hess, as quoted by Flury-Zernik, Schaedliche Gase, pp. 119, 120 (1931).

[c] Vedder, Medical Aspects of Chemical Warfare, p. 70 (1925).

are not warned by cough and irritation of the throat, but only by an acid taste and tear-shedding. There is no tolerance for the toxic effect of the gas. The resulting disease in repeated intoxications may be even heavier than usual.

Effect on men: Irritation of eyes, nose and throat, cough and vomiting are caused as initial symptoms, at lower and medium concentrations. Higher concentrations may cause dyspnœa and sudden respiratory failure. The initial symptoms may calm down after a few minutes, to be followed by a period of several hours, period of latency, during which little or no complaints are felt. Then, from two to eight hours after exposure to the gas, edema of the lungs, haemorrhagic pneumonia or bronchopneumonia may become apparent, or violent bronchitis may develop with or without formation of pseudomembranes in larynx, trachea and bronchi. The resulting disease is very similar to that caused by phosgene.

Affections of the respiratory organs may cause protracted disability.

Late sequelae causing disability have been recorded in some statistics. The results vary greatly.

Meakins and Priestly[24] reported that of about 700 Canadians who were poisoned by chlorine at Ypres, 61.4% were disabled and sent back to Canada, while only 38.6% returned to their regiments to continue in service. After four years, the medical examinations showed the following results:

Permanently disabled	17.4%
Including cases of cardiac disturbances	11%
Asthma and bronchitis	3-4%

It seems that these cases suffered heavily because the gas protection was not satisfactory during the first attacks in

[24] Vedder. Medical Aspects of Chemical Warfare, p. 250 (1925).

1915 and only became more perfect later. These statistics are of importance in the problem of permanent disabilities caused through gas poisoning.

Treatment is the same as in other irritant gases.

Protection is provided by gas masks.

Detection is easy by the smell, 3 mg per m^3 are perceivable; this concentration is decidedly below irritant or toxic concentrations. Potassium iodide paper may be used to detect chlorine, but it is not much more sensitive than the human nose.

BROMINE French: "Sulvanite"

was used during the first World War to very limited extents, partly in special bombs, partly in admixture with chlorine with the purpose of increasing the persistency of the latter.

It can hardly be assumed that bromine will play an important role in future gas warfare. In combinations, however, it increases the toxicity of many organic compounds. As Britain is short of bromine, economic conditions require careful advance planning for preparedness on the part of the Democracies. Otherwise bromine compounds would not be available in sufficient quantities for future gas warfare.

PHOSGENE (and Diphosgene) French: "Collongite"
German: "D-Stoff"
British-American: "CG"

Physical and Chemical Properties:

Phosgene is a gas at ordinary temperature, heavier than air, and has a pungent suffocating smell. In contact with water, both phosgene and diphosgene are decomposed into hydrochloric acid and carbon dioxide.

Diphosgene is a colorless liquid, like water, at ordinary temperature. Phosgene may be considered as the chloride of carbonic acid, diphosgene as the perchlorated methylester of carbonic or formic acid (perchloromethylcarbonate, perchlo-

romethylformate or trichloromethylmonochlorocarbonate).

	Phosgene	Diphosgene
Formula	$COCl_2$	Cl—CO—Cl
Molecular weight	98.92	197.84
Vapor weight	4.11	8.23
Boiling point	8.2°C	127°C
Melting point	—126°C	—
Specific gravity	1.432	1.65

Tactical properties: Phosgene is slightly irritant; after a few respirations the irritation is less felt. It is impossible to estimate the concentration of phosgene in air by the intensity of its smell or irritant effect. It is, therefore, rather insiduous. It is also far more toxic than chlorine and the "traditional" poisons, as hydrocyanic acid. It was first used in cloud-gas attacks in admixture with chlorine (German attack on the British at Wieltje, on December 19, 1915: 4,000 cylinders containing 88 tons of the gas mixture caused 1,069 casualties including 120 dead.

On February 21, 1916 the French used phosgene for the first time in shells. It remained the main gas for offensive on the Allied side during the first World War, and was used in shells, trench mortar bombs and projector drums.

Technical properties: Phosgene is stable to explosion and storage, and also to iron and steel, if completely dry. Its evaporation is slow; for this reason it must be mixed with equal parts of chlorine for cloud gas attacks. This is due to its low boiling point which also makes the filling a more complicated technical operation.

It was, therefore, a technical improvement of great significance when Germany began to use diphosgene in shells, for the first time at Verdun in May 1916, instead of "K-stoff" (monochloromethylchloroformate).

Toxic properties: Phosgene and diphosgene rapidly react with the moist surfaces of the mucous membranes and destroy the function and structure of the cells, causing immediate irritation. Then follows the development of edema of the lungs which is formed in the course of several hours during which the plasma of the blood permeates through the destroyed walls of the bronchioli. This phase corresponds to the clinical period of latency, which is more or less free from subjective complaints. When the edema has reached a certain degree, it becomes suddenly clinically apparent through impairment of the respiration. The breathing surface of the lungs is reduced through the liquid in the bronchioli, lack of oxygen, suffocation occurs. The victim is drowned from within and may now succumb. This process develops within 24 hours, sometimes slower.

Toxic concentrations of both phosgene and diphosgene are of the same magnitude. The susceptibility of man is also of the same magnitude as that of the commonly used laboratory animals.[25] My own experience confirms this statement of Laqueur and Magnus. It is, therefore, not easy to understand, why so widely different toxicity figures for both products are quoted throughout the literature. The mortality product c x t for both products is constant at 1,000.

40 mg per m^3 in a few seconds cause fighting inefficiency [26]

160 mg per m^3 in 1 minute is highly toxic [26]

40 mg per m^3 in 25 minutes may be fatal

20 mg per m^3 in 50 minutes may be fatal

Smallest concentrations affect the sensations of smell and taste. Tobacco smoking after such exposure is felt as disagreeable.

[25] Laqueur and Magnus, Zeitschr. f. exp. Med., vol. 13, p. 35 (1921).

[26] Vedder, Medical Aspects of Chemical Warfare (1925).

Effect on men: The initial period of irritation to the eyes and throat is followed by a period of latency lasting from 2 to 8 hours, in some cases for three days, during which no or almost no complaints are felt. Then, the color of the face becomes ash grey; while there may still be not more than a slight feeling of discomfort, the slightest effort of the patient, an attempt to change his position in bed, may produce sudden collapse or death. This state is called the "grey stage asphyxia." The tissues of the body are at a minimum of oxygen supply, at the same time no accumulation of carbon dioxide takes place, as in the case of ordinary asphyxia. First aid men and doctors must know this condition. When such patients were loaded into ambulances, they arrived dead at the hospital.

In the further development of the disease, carbon dioxide is accumulated in the organs and especially in the blood and produces the familiar picture of cyanosis and dyspnœa which is now called "blue stage asphyxia." At this time the edema of the lungs is at its summit. The patient breathes rapidly and spasmodically, the chest is tight and constricted, severe pains in the chest, highest degree of asphyxia, blue red cyanosis, desperate restlessness, delirium, expectoration of yellow-reddish liquid from the lungs, vomiting and desperate anxiety produce a most impressive clinical picture. It is hardly bearable even for the most cool-heartened physician to pass through a hospital room, where many such patients lie and suffer. At such moments it is good to remember that the mortality rate of these war victims is only about one-tenth of those injured by explosive weapons.

The fate of the patient depends upon the resistance which his circulatory system opposes to the tremendous strain of internal asphyxia. Those who survive the first three days may be considered saved.

Complications, especially secondary infection, pneumonia at a late stage of the disease may still develop. Chronic bronchitis, bronchiectasis, emphysema, "alvéolite végétante" were observed in animal experiments [27] and later in human cases.

Late sequelae may be classified as being of the bronchitic, asthmatic, circulatory, cachectic or nervous type.

Treatment is symptomatical, removal of the patient from further exposure to gas, elimination of even the slightest strain, application of warmth and fresh clean but not cool air, inhalation of oxygen from the first, beginning until the blue stage asphyxia is overcome, can all be given by the first aid personal or layman, before medical aid is available. Other measures are reserved to the physician: phlebotomy, intravenous infusions of salt or glucose solutions, calcium preparations, digitalis, strophanthus, caffein, scilla maritima, ephetonin, quinine. The physician knows that in phosgene poisoning no use of morphine, lobeline and other remedies should be made which affect the respiratory center.

Protection through gas masks and respirators is satisfactory.

Detection in air is made by the smell and irritative action of phosgene.

CHLORPICRIN

British: "Vomiting gas" American: "P S"
French: "Aquinite" German: "Klop"

Physical and chemical properties: The pure product is a colorless liquid with a penetrating odor. It is little soluble in water, easily soluble in organic solvents. With acids, it is easily decomposed. Its volatility at 20.5° is about 290,000 milligrams per cubic meter. It is produced by mixing

bleaching powder, water, and picric acid, or by the action of nitric acid on chloral. Chlorpicrin explodes when heated, or by ignition with mercury fulminate.

Formula	CCl_3NO_2
Molecular weight	164.38
Liter weight	6.84
Boiling point	113°
Melting point	—69.2°
Specific gravity	1.66

Tactical properties: Chlorpicrin is less toxic than phosgene, it is also highly irritant.* It penetrated ordinary gas masks of 1914—1918 to a certain degree, because it does not react with the anti-acid chemicals in the canisters. It is absorbed only by the charcoal in these gas masks. For these reasons it compelled the troops to remove their masks and to expose themselves further to chlorpicrin and other gases that were shot simultaneously. Chlorpicrin is also persistent to a certain extent, approximately 3 hours in open grounds. This fact and the fact that modern canisters provide full protection against chlorpicrin make its future use for offensive purposes rather improbable.

Technical properties;

Chlorpicrin is widely used for the extermination of rodents in the fight against bubonic plague, which may be carried by certain kinds of rats, and the fleas which transfer this disease from the rodents to men. When the rodents are killed, the fleas die and the endemic plague is stopped.

As these rodents migrate, it is necessary to organize their extermination over large areas. The Russian Government has done so in wide districts of Central Asia, and the Caucasus. The population is organized under the guidance of zoologists and toxicologists to exterminate the rodents

* Causing irritation of the eye, coughing, nausea and vomiting.

(suslikoff) in these districts. These troops are equipped with tools fit to introduce a certain amount of chlorpicrin into the holes which these animals build. This has to be done at certain periods of the year and at certain hours of the day when these animals are in their holes. To find this out, a careful study of the biology and habits of the suslikoff had to be made in advance.

This method of extermination, if applied with sufficient care and discipline, has been proved to be very efficient. It is perhaps the most impressive work that has been done on an immense scale for the extermination of epidemic and endemic diseases by means of toxic gases.

Toxic effects: Chlorpicrin is inhaled. It acts as an irritant similar to phosgene. At the same time, absorptive effects may occur with slight narcotic symptoms. Irritation of the kidneys and excretion of albumin in the urine may also result from inhalation of chlorpicrin.

Toxic concentrations:

mg per m^3	time of exposure	effect
2	within 3 seconds	irritation of the eyes [30]
26	" 1 minute	fighting inefficiency [28]
100	" a few sec.	fighting inefficiency [29]
300	" 20 minutes	fatal for cats

Effect on men: The clinical picture resembles, to a certain extent, that caused by phosgene and other irritant gases. Acute intoxications may develop with initial symptoms of irritation, a following period of latency, after which edema of the lungs or toxic pneumonia may become apparent. In many cases, the edema of the lungs is developed to a lesser

[28] Vedder, Medical Aspects of Chemical Warfare, p. 70 (1925).
[29] Gildemeister & Heubner, Zeitshr exp. Med., vol. 13, p. 291 (1921).
[30] Fries & West, Chemical Warfare, p. 143 (19—).

degree than after phosgene.

There may be fatal cases in which grave hyperemia of the lungs is the only finding at autopsy, when death occurred within several days after the exposure. At the same time, absorptive symptoms may develop; excretion of albumin in the urine has been observed; in other cases, affections of the circulatory system may prevail after medium or heavier exposures.

Treatment is the same as in phosgene poisoning.

Protection is provided by military gas masks.

Decontamination: The atmosphere may be freed from chlorpicrin by the spraying of a solution of 240 grams potassium sulfide in 10 liters of water.

Halogenated Esters

The chlorinated esters of carbon dioxide or formic acid are violent irritants and lung poisons. In proportion to the number of chlorine atoms entering the molecules of the esters, the irritant effects of the resulting compounds decrease and the toxic effects increase at the same time. According to French research Cl - CO.O.CH.Cl is more toxic than H.CO.O.CH Cl_2.[31]

Tactical properties: The products of this group are irritants and toxics and were used in various combinations during the first World War.

"K-stoff" was used by the German Army during the World War. It contained the following components:

monochloromethylcarbonate	91.4%
dichloromethylcarbonate	8.8%

and caused violent irritation. 50 mg per m^3 within 1 minute, marks the intolerability limit.

[31] André Meyer and Plantefol, C. R. d. l. Acad. des Sciences, vol. 172, p. 136 (1921).

Compounds of this group were components of the German "K-stoff" and "C-stoff", of the French "Palite" and "Surpalite" and of the British "SK" and of the American "Superpalite." Diphosgene is the most toxic product of this group, equal to and replacing phosgene and, therefore, discussed in connection with phosgene. Other compounds were used at times as irritant gases only.

MONOCHLOROMETHYL CARBONATE

Physical and Chemical Properties: A colorless liquid with a suffocating odor. It is formed by chlorination of methylformate or chloromethylformate.

Formula	Cl—CH_2—OOC—Cl
Molecular weight	128.93
Vapor weight	5.36
Boiling point	106-107°
Specific gravity	1.46

Tactical properties: Monochloromethylcarbonate was used as a war gas in shells during the World War by the German Army as a component of "K-stoff"; in mines as a component of "C-stoff"; and by the French Army, under the name of "palite".

Toxic properties: Monochloromethylcarbonate is inhaled, and acts as a violent irritant in contact with the mucous membranes, and after absorption.

Toxic concentrations for men:

mg per m^3	time of exposure	effect
50	few seconds	fighting inefficiency [32]
500	1 minute	toxic [32]

Effect on men: The clinical picture is about the same as that caused by phosgene and other irritant war gases.

DICHLOROMETHYLMONOCHLOROCARBONATE:

[32] Vedder, Medical Aspects of Chemical Warfare (1925).

Physical and Chemical Properties: It is a colorless liquid with a suffocating odor. It is formed by chlorination of methyl chloroformate and chloromethylformate. With water it is easily decomposed forming carbon dioxide, carbon monoxide and hydrogen chloride.

Formula	$Cl_2CH—OOC—Cl$
Molecluar weight	163.39
Vapor weight	6.79
Boiling point	110-111°
Specific gravity	1.560

Tactical properties: It is a component of the German World War gases, "K"- and "C-stoffs".

Effects: Violent irritation and edema of the lungs.

METHYLMONOBROMOACETATE and ETHYLMONOBROMOACETATE:

Physical and chemical properties:

Methylmonobromoacetate:

Formula	$CH_3—OOC—CH_2Br$
Molecular weight	152.96
Vapor weight	6.36
Boiling point	144°

Ethylmonobromoacetate:

Formula	$C_2H_5—OOC—CH_2Br$
Molecular weight	196.98
Vapor weight	6.94
Boiling point	168°
Volatility at 20°C.	21 mg per lit.

Tactical properties: The French admit that 30,000 26 mm rifle gas grenades filled with this product had been prepared "for police" use before the World War. Haber conceived that this was in fact the first gas weapon of the first World War, prepared in peacetime.

It is an irritant, tactically, but is also toxic. The

amounts used in rifle grenades were too small to cause poisoning in the field, in spite of the fact that the volatility of the compound makes it possible to produce field concentrations of nearly ten times the lethal doses. The practical effect in battle was unimportant.

Technical properties: The scarcity of bromine in France made it impossible to use this product in shells or otherwise.

Toxic properties: Violent irritation is caused by the smallest concentrations. Higher doses cause edema of the lungs, similar to phosgene, nervous paralysis and ataxia.[33]

Toxic concentrations:

27 mg per m^3 (methylester)

55 mg per m^3 (ethylester) mark within one minute the limits of intolerability for men. For cats, a concentration of 330 mg per m^3 inhaled during 10 minutes were fatal, the mortality product C X T = 3,300.[34]

American figures for the technical product may be quoted as follows:

0.3 mg per m^3	minimum lachrymatory concentration
40.0 mg per m^3	limit of intolerability
2300.0 mg per m^3 x 10 minutes	— lethal product

ETHYLIODOACETATE British: "SK"

Physical and chemical properties: It is a liquid.

Formula	$C_2H_5—OOC—CH_2I$
Molecular weight	213.98
Vapor weight	8.9
Boiling point	178-180°

Tactical properties: Introduced for the economic reason of shortage of bromine by the British and first used in battle at Loos on September 24, 1915, it remained the main

[33] Wachtel, Z. S. f. Exp. Path. & Ther., vol. 21, p. 1 (1920).

[34] Wachtel, unpublished notes (November, 1916).

lachrymator for the British until the end of the first World War.

As its volatility is low, lethal concentrations in the field cannot easily be obtained.

It was used in British 4.2 inch howitzer shells, in 4 inch Stokes mortar bombs and in gas grenades.

Technical properties: It is easily decomposed on storage, but does not attack iron and steel. It can, therefore, be directly filled into ordinary shells. Its volatility is increased, if it is diluted with alcohol. Iodine is scarce and expensive. Therefore this product will hardly reappear in future battlefields.

Toxic properties: Violent irritation on inhalation and after higher concentrations edema of the lungs, pneumonia, nervous paralysis and ataxia.[35]

mg per m^3	time of exposure	effect
1.4		limit of perception [37]
33	1 minute	intolerability limit [38]
300	10 minutes (according to German research)	fatal for cats, mortality product 3000 [35]

American sources quote the following figures: [36]

3.5	a few seconds	fighting inefficiency
170	1 minute	highly toxic

Halogenated Ethers

In halogenated ethers, the halogen substitutes hydrogen atoms which are directly bound with carbon atoms of one or

[35] Wachtel, unpublished notes (November, 1916).
[36] Vedder, Medical Aspects of Chemical Warfare, p. 70 (1925).
[37] Fries & West, Chemical Warfare, New York and London (1921).
[38] Flury, Z. S. Exp. Med., vol. 13, p. 567 (1921).

several alkyl groups. Such a substitution increases the irritant effect of the ether to such an extent that the narcotic and other effects, which are the specific effects of the not-halogenated compounds, become almost negligible.

The two compounds which are discussed in this chapter served as war gases during the World War.

Dichlorodiethylether, however, is also used in industry.

Tactical properties: The compounds of this group are more irritant than and equally toxic as phosgene. They were used as admixtures to other gases especially ethyldichloroarsine.

Technical properties: The halogenated ethers are manufactured by the action of hydrogen chloride and hydrogen bromide respectively on formic aldehyde. They are stable in mixtures with mustard gas, cyclone, arsines and other war gases.

Toxic properties: Toxic properties of the individual compounds are discussed below. In mixture with other gases, as mentioned before, no increase of toxicity of such mixtures over the toxicity of the individual components could be proved in experiments [39] preceding their introduction in actual warfare.

DICHLORODIMETHYLETHER

Physical and Chemical Properties: A colorless liquid, readily decomposed by water.

Formula	$Cl—CH_2—O—CH_2Cl$
Molecular weight	114.95
Liter weight	4.78
Boiling point	105° C
Specific gravity	1.37

[39] Unpublished notes of the author (March and April, 1917).

Toxic effects: Dichlorodimethylether is inhaled and absorbed by the lungs. It acts like phosgene. To explain the chemical mechanism of the toxic effect one has assumed that, after absorption, hydrochloric acid and formaldehyde are formed within the cells, according to the following formula:

$$Cl\,CH_2— O — CH_2Cl + H_2O = 2CH_2O + 2HCl$$

Toxic concentrations for men:

mg per m^3	time of exposure	effect
14		Irritation of eyes, nose and throat
470	Few seconds	Fighting inefficiency [40]
470	1 minute	Fatal lung edema [40]

Effects on men: Initial symptoms of violent irritation are followed by a period of latency during which edema of the lungs develops. The clinical picture is like that caused by phosgene.

It is believed to specifically affect the labyrinth (hearing and equibalance). French text-books of chemical warfare, therefore, classify this poison in the group of "poisons labyrinthiques."

Dibromodimethylether

Physical and chemical properties: A colorless liquid that is easily decomposed by water.

Formula	$BrCH_2—O—CH_2Br$
Molecular weight	203.87
Liter weight	8.48
Boiling point	154-155°C
Specific gravity	2.18

Toxic properties: It acts on the organism like dichlorodimethylether and like phosgene. Like all bromine substi-

[40] Vedder, The Medical Aspects of Chemical Warfare, p. 70 (1925).

tutes, it is less irritant but more toxic than the analogous chloro-ether.

Toxic concentrations:[41]

Concentration mm per m³	*Time of exposure minutes*	*Mortality Product*	*Effect on cats*
5	100	500	fatal after 7 days
15	40	600	fatal after 2 days
25	20	500	fatal after 5 days
			Effect on dogs
50	20	1,000	fatal after 6 days
			Effect on monkey
50	20	1,000	fatal after 2 days

The toxicity of this substance equals that of phosgene.

Aldehydes

Formaldehyde, acetaldehyde, allyl aldehyde, crotonic aldehyde, furfural and others are known to be irritants and nervous poisons. They are not sufficiently effective for the requirements of gas warfare.

The irritant and toxic effects of aldehydes are increased by halogenation.

Monochloroacrolein and monochlorocrotonaldehyde are not sufficiently irritant or toxic to be used in gas warfare.

Acrolein. French: "Papite"

Physical and Chemical Properties: Acrolein is the only aldehyde which was used on the battlefields of the first World War. It is a colorless liquid with a pungent odor. It is largely used in peacetime industry.

[41] Unpublished notes of the author (January and February, 1917).

Formula	$CH_2 = CH - CHO$
Molecular weight	56.03
Vapor weight	2.3
Boiling point	52.4
Specific gravity	0.8410

Tactical properties: Acrolein is a slightly toxic lachrymator. It was used in artillery shells and gas grenades by the French about January, 1916. It was without practical effect on the battlefield, for reasons explained below.

Technical properties: Acrolein is not stable, it polymerizes readily into disacryl. This decomposition during storage was prevented by addition of 5% amyl nitrate. However, in the presence of this stabilizer the decomposition took another course toward the formation of ineffective acrolein resin.

It had been intended to serve as a powerful lachrymator which contained neither bromine nor acetone both of which France then lacked.

Toxic properties: Acrolein is a violent irritant if inhaled. The liquid substance, pure or in watery solution, directly attacks the skin. After absorption it acts as a narcotic, part of it is eliminated as undecomposed acrolein in the exhaled air.[42]

Toxic concentrations:

mg per m^3	time of exposure	for men [43]
7	—	minimum lacrimatory concentration
50	1 minute	limit of intolerability

[42] Lewin, Arch. f. exp. Pathol. u. Pharmakol., vol. 43, p. 351 (1900).

[43] American Warfare Service, XV, Washington (1918).

350	10 minutes	lethal concentration for cats [44]
200	2½ hours	heavy irritation of the lungs
1500	2¼ hours	fatal after 18 hours
2000	2½ hours	fatal during exposure

According to American opinion (1918)[45] acrolein equals phosgene as a poison, according to German experiments which were not published so far, acrolein is less toxic than phosgene.

Effects on men: Smallest concentrations violently irritate the eyes and mucous membranes of the mouth and nose, causing cough, bronchitis, pneumonia, if the exposure is protracted. Among the initial symptoms congestion in the head, strained exhalation and dizziness are reported.[46] Intestinal disturbances may last for weeks after exposure to higher doses.

Usually, the violent irritation prevents the victims from inhaling fatal doses which cause pneumonia. For the same reason, the warning effect of the irritation prevents the occurrence of narcotic effects which can be observed in animal experiments.

Treatment: Is the same as for other irritant gases.

Protection: The American GMA canister, approved by the U. S. Bureau of Mines, provides protection.

Detection on the battlefield is easily made by the odor and irritant effect of smallest concentrations.

Determination is made by absorption of the gas in sodium bisulfite solution and iodometric titration.[47]

[44] Flury-Zernik, Schaedliche Gase, p. 391 (1931).
[45] American Warfare Service, XV, Washington (1918).
[46] Lewin. Arch. f. exp. Patholu. Pharmakol., vol. 43, p. 351 (1900).
[47] Ivanoff, Arch. Hygiene, vol. 73 (1911).

CHLORACETONE. French: "Tonite"

Physical and chemical properties: The pure product is a colorless liquid, which is little soluble in water and organic solvents.

Formula	$Cl—CH_2—CO—CH_3$
Molecular weight	92.50
Vapor weight	3.85
Boiling point	119° C
Specific gravity	1.16

Tactical properties: Chloracetone is an irritant or "tear" gas, not toxic under field conditions. Its volatility permits the production of higher field concentrations than are ordinarily obtained with ethylbromacetate. Through such higher concentrations it made good for its milder irritant effects. It was introduced into battle by the French, to replace ethylbromacetate, in rifle and hand grenades.

The early gas masks gave, however, full protection against chloracetone. It was therefore discarded the following year, 1915.

Its effects in battle were unimportant with regard to both qualitative and quantitative results.

Technical properties: It polymerizes on storage and is transformed into less irritant forms.

Toxic properties: It is an irritant, mainly for the eyes. Its toxic effects are not realized on the battlefields.

Toxic concentrations:

		for men
18 mg per m^3	immediately	cause tearing [48]
110 mg per m^3	in 1 minute	limit of intolerability [48]

[48] **Flury, Zeitschrift fur experimentelle Medicin, vol. 13. p. 567 (1921).**

2300 mg per m^3 in 10 minutes lethal concentration [49]
Cats exposed to chloracetone survived mortality products of 9,000 (200 mm^3 per m^3 x 45 minutes) and even subcutaneous injection of 1.0 ccm of the substance.[50]

Effect on men: Tearing, conjunctivitis; keratitis and opaqueness of the cornea may occur after heavy and long lasting exposure.

BROMACETONE. German: "B-stoff"
French: "Martonite" [51]

Physical and chemical properties: It is a colorless liquid, little soluble in water, readily soluble in ethyl alcohol and acetone.

Formula	$Br—CH_2—CO—CH_3$
Molecular weight	136.96
Vapor weight	5.69
Boiling point	136.5°C
Specific gravity	1.6

Tactical properties: Bromacetone is a powerful lachrymator. Through its high volatility toxic field concentrations can be obtained in battle. In sprays, the liquid causes, in contact with the skin, painful blisters, which heal within a short time without sequelae. Its effects after battle are practically those of violent lachrymation. It was first used by the Germans in "Green T" shells and trench mortar bombs ("B-Minen"), for a short period in 1915 only, and by the British also for short periods. The French and Americans made larger use of this product until toward the end of the World War. A total of more than

[49] This American figure proves that chloractone is too little toxic for war use. The figure corresponds to a mortality product, c x t =23,000 compared with phsgene c x t=450.
[50] Unpublished notes of the author (January 2nd and 12th, 1917).
[51] Contains 80% bromoacetone, plus 20% chloracetone.

1,000 tons of this substance was used in artillery shells, not including hand and rifle grenades and other weapons throughout the World War.

From the summer of 1918, the French began to replace bromacetone through the more effective brombenzylcyanide. It is now used for the testing of gas masks in gas chambers.

Technical properties: Bromacetone turns brown and decomposes on storage forming hydrobromic acid and resinous products.

Toxic properties: It is a violent irritant, mainly for the eyes.

Toxic concentrations:

	time of exposure	effect on men
1.5 mg per m^3	immediately	tearing [52]
2.8	a few seconds	fighting inefficiency [53]
48	1 minute	intolerability limit [54]
560	1-2 minutes	toxic for men [55]
3200	10 minutes	lethal concentration

For cats, the mortality product was found to be far below the American figure of 32,000 for the lethal concentration quoted above. Cats exposed to a concentration of 200 mm^3 per m^3 for 20 and 40 minutes, corresponding to mortality products of 4,000 respectively 8,000 died after 4 days, showing at autopsy edema of the lungs.[56]

Effects on men: Effects on men in the field are those of violent irritation only. Fatal edema of the lungs hardly occurred. The repeated exposure to the gas makes men

[52] Fries and West, Chemical Warfare, p. 143 (1921).
[53] Vedder, Medical Aspects of Chemical Warfare, p. 143 (1925).
[54] Flury, Zeitschrift fuer exper. Med., vol. 13, p. 567 (1921).
[55] Vedder, op. cit., p. 143.
[56] Unpublished notes of the author (July 3, 1917).

more sensitive. The gas may enter the middle ear through the Eustachian tubes or through a perforated tympanic membrane causing violent pain and inflammation.

Treatment is the same as for other irritant gases.

Protection against the lachrymatory effect is possible by well fitted goggles. Ordinary gas masks provide full protection.

Detection in the field is easily made by the odor and irritation.

IODOACETONE French: "Bretonite"

Physical and chemical properties:

Formula	$CH_3—CO—CH_2I$
Molecular weight	183.95
Liter weight	7.65
Boiling point	52° in a vacuum of 9 mm. Hg.
Specific gravity	2.17

Tactical properties: It was used in artillery shells by the French for the first time in August, 1915. It is somewhat more toxic than the other halogenated ketones. It was introduced for economic reasons, shortage of bromine in France, and definitely abandoned, mainly for technical reasons, towards the end of 1915, to be replaced by benzyl iodide.

Technical properties: The product is easily decomposed on storage and through heat or contact with air.

Toxic properties and concentrations equal about those of brommethylethylketone and chloracetone, insofar as irritant effects are concerned. In experiments on cats the toxicity was found to be far greater than that of the other products mentioned. All cats, three exposed to concentrations of 15 mm^3 and three exposed to concentrations of 25 mm^3 per m^3 died within 3 to 5 days from edema of the lungs at mortality products from 500 to 1,500. The toxicity equals

that of phosgene.[57]

Effect on men: The irritative effect is about the same as that of chloracetone. The toxic effect is greater.

BROMMETHYLETHYLKETONE German: "Bn stoff"
French: "Homomartonite"

Physical and Chemical properties: Brommethylethylketones are obtained by the bromination of acetone oils which contain large amounts of methylethylketone. The product is a slightly yellow liquid, not soluble in water. Exposed to sunlight it is rapidly decomposed. The product used in gas warfare is a mixture of the following compounds.

Bromomethylethylketone, formula $Br.CH_2—CO—CH_2.CH_3$

α-Bromoethylmethylketone, formula

$CH_3—CO—CHBr—CH_3$

Molecular weight	150.98
Vapor weight	6.28
Boiling point	133°C
respectively	145-146°C

Dibromoethylmethylketone, formula $CH_3.CO—CHBr—CH_2Br$

Molecular weight	229.89
Vapor weight	9.56

At boiling it is decomposed above 53°C

Tactical properties: Through its high volatility toxic concentrations may be obtained on the battlefield. The product is, therefore, a toxic lachrymator. Its effects in battle were not too satisfactory. It was introduced first by the Germans, in July, 1915, mainly for economic reasons.

Technical properties: As acetone was urgently needed as a solvent for explosives and lacquers, bromacetone and chloracetone were to be replaced by brommethylethylketone. The latter is corrosive to steel and iron; shells must be lined with lead or enamel.

[57] Unpublished notes of the author (May 18, 25, 1917).

The French" Homomartonite" contains brommethylethylketone and chlormethylethylketone. This mixture is very similar to Martonite (80% bromacetone and 20% chloracetone).

Toxic properties: It causes violent irritation of the mucous membranes of eyes, ears and respiratory passages. Higher exposures cause edema of the lungs like phosgene.

Toxic concentrations:

Bromomethylethylketone		for men
11 mg per m^3	immediately	tearing [58]
12.6	—	fighting inefficiency [59]
1260	1 minute	toxic [59]
Dibromomethylethylketone		
18.8 mg per m^3	immediately	fighting inefficiency [59]
1880	1 minute	toxic [59]

Effects on men are like those of bromacetone, yet somewhat less lasting.

Treatment and protection the same as for bromacetone.

Decontamination is made by a soapy solution of "liver of sulfur."

CHLORACETOPHENONE Am: CN

Physical and chemical properties: Chloracetophenone is a colorless, crystalline mass.

Formula	$C_6H_5—CO—CH_2Cl$
Molecular weight	154.52
Liter weight	6.43
Boiling point	245°
Melting point	58-59°
Specific gravity	1.324

It is little soluble in water, more readily soluble in alcohol.

[58] Fries and West, Chemical Warfare, p. 143 (1921).
[59] Vedder, Medical Aspects of Chemical Warfare, p. 143 (1925).

Chloracetophenone is formed by chlorination of acetic acid, the resulting chloracetic acid reacts with chlorine and sulfur monochloride in the presence of zinc chloride as catalysts. The chloracetylchloride, thus formed, combines with benzol to chloracetophenone, anhydrous aluminum chloride serves as catalyst.

Tactical properties: Chloracetophenone was not used during the first World War. From preliminary studies in the United States, late in 1918, experts drew the belief that this compound would be a very satisfactory lachrymator. Its irritant effect equals that of brombenzylcyanide. It can be used in explosive shells or in burning compositions which distill the irritant gas into the air without explosion.

Technical properties: It is a solid substance stable to heat, water, boiling, explosion and storage. In shells it can be filled either as solid pure substance, or mixed with explosives. It may also be dissolved in organic solvents. Such solutions which can be filled into shells are:

(1) Chloracetophenone plus benzol plus carbon tetrachloride: CNB
(2) Chloracetophenone plus ethylene dichloride: CND
(3) Chloracetophenone plus chloroform plus chlorpicrin: CNS.

Burning composition, containing chloracetophenone plus smokeless powder can be used in hand or rifle grenades, trench mortar bombs, artillery shells or other special devices. These mixtures are as stable as the pure chloracetophenone. On ignition it burns without explosion and forms gas clouds at ordinary temperatures against which ordinary charcoal canisters provide protection. At lower temperatures it may also form smokes (mists) composed of finely dispersed solid particles which penetrate charcoal filters but not special smoke filters or military or civil gas masks.

Toxic properties: ω-chloracetophenone acts on the skin and especially on the eyes. It is a violent irritant.

Toxic concentrations:

0.3 mg per m^3 cause tearing immediately.

4.5 per m^3 limit of intolerability.[60]

850 mg per m^3 10 minutes: lethal concentration.

Effect on men: Small concentrations cause tearing and loss of sight immediately. The sight is soon restored, sometimes only after 24 hours. Conjunctivitis may in some cases last for some time. It irritates the skin, causing a burning sensation, redness, and a dark brown coloring. The effect on the skin usually lasts for not longer than 24 hours.

BENZYLBROMIDE German: "T-stoff"
French: "Cyclite"

Physical and chemical properties: It is a colorless or yellowish to brown colored liquid. It is slowly decomposed by water.

Formula	$C_6H_5—CH_2—Br$
Molecular weight	170.97
Vapor weight	7.11
Boiling point	201°
Melting point	—3.9°
Specific gravity	1.44
Volatility at 20°C	3400 mg per m^3
	=2400 mm^3 per m^3

Tactical properties: Benzylbromide is more volatile but less irritant than xylylbromide. It was introduced into battle at Verdun in March, 1915. It is somewhat persistent. It is readily absorbed by charcoal, so that early gas masks provided full protection.

It was introduced in practice without timely advance con-

[60] Vedder, Medical Aspects of Chemical Warfare, p. 170 (1925).

sultation of the physiologists. The engineers had first to learn from a series of failures on the battlefield—one more of these failures was the introduction of benzylbromide—that they are not competent to decide problems of irritation and toxicity.

Here the superiority complex of chemists over medical experts proved just as disastrous as did—everywhere, in all armies—the superiority complex of the professional army officer over every kind of scientist. This lack of mutual understanding between various professions has caused failures and defeats in the past and will do so still more in the future. In back of it, there is an educational problem of most vital importance.

Technical properties: It is corrosive to steel and iron; shells, therefore, must be lined with lead or enamel. Toluol was mainly needed for the explosive industry. Therefore, only small amounts of benzylbromide were produced during the World War, until its tactical and technical inefficiency was definitely recognized.

Toxic properties: It is inhaled, or may act directly on the skin. It acts as an irritant.

Toxic concentrations:

mg per m^3	time of exposure	effect
3.5	immediately	fighting and working inefficiency (according to American records) [61]
50	1 minute	intolerability limit (according to German researches) [62]

Effect on men: It is an irritant gas with the same effects

[61] Vedder, The Medical Aspects of Chemical Warfare, p. 70 (1925).
[62] Flury, Z. S. exp. Med., vol. 13, p. 567 (1921).

as other irritant gases. It may have a paralyzing effect on the nervous centers, if inhaled in higher doses.

BENZYLIODIDE French: "Fraissite"

Physical and chemical properties: It is a liquid.

Formula	$C_6H_5—CH_2—I$
Molecular weight	217.97
Vapor weight	9.07
Boiling point	226°
Specific gravity	1.77
Volatility at 20°C	1200 mg per m^3
	= 663 mm^3 per m^3

Tactical properties: Its lachrymatory power is about the double, its volatility—about half that of benzylbromide. To accomplish about the same effect as is reached by benzylbromide or iodoacetone "Fraissite" was composed of equal parts of benzyliodide and benzylchloride. It was used by the French from November, 1915 until spring, 1916, in small quantity only.

Technical properties: It is decomposed during storage. The main reason for its introduction was shortage of bromine and acetone in France. It replaced benzylbromide and especially iodoacetone.

Toxic properties: Benzyliodide is inhaled and acts in the same way as benzylbromide. It is more toxic, however.

Toxic concentrations: 27 mg per m^3 represent the intolerability limit within 1 minute.[63] 2mg per m^3 are the minimum irritant concentration. The lethal concentration is 3.00 mg per liter at an exposure of 10 minutes, the mortality product accordingly would be 30,000.

Effects on men: The same as described for benzylbromide.

[63] Flury, Z. S. exp. Med., vol. 13, p. 567 (1921).

α-BROMOBENZYLCYANIDE French: "Camite"
American: "CA"

Physical and chemical properties: It is an oily liquid.

Formula	$C_6H_5—CH—Br—CN$
Molecular weight	195.98
Liter weight	8.15
Boiling point	232°
Melting point	29°
Specific gravity	1.539

It is decomposed during distillation.

Tactical properties: Brombenzylcyanide surpasses all the other lachrymators, its lachrymatory power being seven times that of bromacetone. It was introduced by the French in July, 1918 and also manufactured in the United States after the fall of 1918, where it was considered as a standard lachrymator. Its tactical possibilities are very limited on account of its technical properties and because of its persistency it is not desirable for attacks. Due to its low volatility, toxic concentrations cannot be produced on the battlefield.

Technical properties: It is decomposed on storage, is corrosive to iron and steel and must therefore be filled into specially lined shells. It is also decomposed by heat and made ineffective by the explosion, if the explosive charge of the shell exceeds certain very narrow limits.

Toxic properties: It is a violent irritant especially to the eyes.

Toxic concentrations: 0.3 mg per m^3 immediately cause tearing,[64] and is also considered as the limit of intolerability. The lethal concentration is believed to be 900 mg per m^3 at an exposure of 30 minutes.

[64] Vedder, Medical Aspects of Chemical Warfare, p. 169 (1925).

Effects on men are the same as those of other irritant gases.
Detection: It is perceivable through its smell at a concentration of 1 part in 100,000,000 parts of air.
Decontamination with 20% solution of sodium hydroxide may be necessary, as brombenzylcyanide may persist for as long as 30 days in soil, on plants, clothing or other objects.

BROMINATED XYLOLS German: "T-stoff"

Physical and chemical properties: The technical product is a liquid and contains various brominated xylols. The constants of the technical mixture are:

Boiling range	216-220°
Specific gravity	1.40
Volatility at 20°C	663 mg per m^3
	= 900 mm^3 per m^3

It is slowly decomposed by water. Its chief components are:

bromoxylol $C_6H_4 \begin{cases} CH_3 \\ CH_2Br \end{cases}$

m- and p-bromoxylol $C_6H_4 \begin{cases} CH_2Br \\ CH_2Br \end{cases}$

Pure xylolbromide has the following properties:

Molecular weight	184.99 for the monobromoxylol
	263.90 for the dibromoxylol
Boiling point	135-140°

Tactical properties: Xylyl bromide is a powerful lachrymator but not very toxic. Due to its low volatility in cold weather, it was practically ineffective at the Russian front, where it was first used in battle at Bolimow on January 31, 1915. The next attack with T-stoff was directed against the British at Nieuport on March, 1915. Only 500 tons of the product were used, before it was definitely abandoned in 1917. No serious effects were ever accomplished. Charcoal in canisters provides full protection.

Technical properties: It is a violent corrosive for iron and steel. Originally it was filled in lead containers which were placed into shells. Later the walls of the shells were lined with lead or enamel to eliminate corrosion. The corrosive property in combination with the tactical inefficiency of the product were some of the first technical problems which were to overcome in the further evolution of gas shells. The experiments made with T-stoff were highly informative and contributed to the improvements that took place in the future development of gas shells.

Toxic properties: Brominated xylols are inhaled, and act as irritants.

Toxic concentrations:

mg per m^3	time of exposure	effect
3.8	immediately,	fighting inefficiency (according to American reports) [65]
56	within 1 minute	tolerability limit (according to German reports) [66]

Effect on men: Irritation of the eyes and mucous membranes characterize the clinical picture. Heavy exposure may cause edema of the lungs, but this hardly occurs on the battlefield.

[65] Vedder, Medical Aspects of Chemical Warfare, p. 70 (1925)
[66] Flury & Zernik, Schädliche Gase, p. 341 (1931).

CHAPTER VIII:
ARSENIC COMPOUNDS

The pharmacology and toxicology of arsenic compounds have been well known for a long time. Arsenic trichloride was especially used by the French as admixture to various gases, phosgene, hydrocyanic acid, ethyliodoacetate and also as a smoke producing agent. It is not sufficiently toxic to be used in gas warfare.

Only three arsenic compounds were used during the first World War on the battlefields:

1917, July: Diphenylchlorarsine
1918, March: Ethyldichlorarsine
1918, May: Diphenylcyanoarsine.

All of these were introduced by the Germans. They were selected from a very great number of similar compounds. More than 60 of these compounds are listed below. The list also contains compounds which have been studied in the United States and elsewhere.

The compounds of this group are liquids with high boiling points or solids at ordinary temperature, they are very slightly volatile and stable to heating and explosion. To obtain effective dispersion in the clouds, formed by the bursting shells, it is necessary to fill the products into special containers; in German blue cross shells, glass bottles were used for this purpose.

Such aerosols can also be formed by special generators in which the arsenic compound is mixed with burning ma-

terials that produce adequate temperatures and heat of combustion.

The injuries caused through the irritant organic arsines are rather benign in general. The violent irritation produces defensive reflexes which prevent the person from the inhalation of higher doses. In most cases full recovery takes place within short time, late sequelae are rare. The sudden violent irritation, however, may cause a nervous shock or neurotic reactions in persons thus predisposed. These psychogenic effects are sometimes erroneously diagnosed as toxic effects on the central nervous system.

Protection against the gases and vapors of organic arsines is accomplished by oxygen respirators or gas masks with specially marked filters or military gas masks.

The organic arsine compounds will possibly belong among the most efficient war gases in future wars. For this reason they are studied largely in research laboratories of all countries.

Intoxications may occur in laboratories, in industrial plants, at least in experimental plants during peace time; the industrial importance of these combinations may suddenly increase in the course of the second World War.

For example, phenylarsinedichloride is used as a wood preservative. For this purpose it may be mixed with petroleum distillates or other products, and intoxications and skin diseases may occur in peace time during the manufacture of the products or by the use of freshly impregnated woods.

While the German national economy suffered a shortage of many toxic products such as methyl alcohol and even chlorine, there was an abundance of arsenic in the country. This was one of the reasons for which the study of arsenic compounds was undertaken at that time. As early as October and November, 1916, most of these arsine compounds were being studied in the Kaiser-Wilhelm Insti-

tute in Berlin-Dahlem. The capability of these substances to form colloid vapors and to pass through charcoal canisters of the kind that were used at that time, had been discovered. It was believed that these products would pass through the filters used by the Allied Armies and compel the soldiers to take off their gas masks due to the resulting violent irritation and thus breathe in the mixture of phosgene, mustard gas, and the like.

This plan, however, could not be carried out with full success because the British Intelligence Service had succeeded in learning about it in time. When the blue-cross shells were still undergoing experimental research in the laboratory, the English boxrespirator had already been supplemented with an additional paper filter which was effective in preventing the passage of the German Blue-Cross. Nevertheless, the instant and toxic effects of these substances were so promising that studies were continued until the end of the war and are still being conducted throughout the world, wherever a chemical warfare service is studying the possibilities of future gas warfare.

The problem today is of a physical rather than a chemical character. It is the aim of every war department in Europe to find a compound whose vapors are able to break through the gas filters of the enemy instantaneously. If such a gas is found, the gas filter-masks used at present will be useless. Only the heavy oxygen breathing apparatus would be helpful in counteracting such a gas, but the heavy apparatus necessary would seriously hamper the military activity of the soldier.

For such reasons many more compounds of this group than were known during the World War may be prepared today and may appear on new battlefields.

It is necessary, therefore, to discuss this group as a whole,

The irritant effects of arsine compounds begin only after a period of latency, lasting from 20 seconds to one minute, or even longer.

Then follows the "after-effect,"—this is a period of increasing irritation which appears, even if the inhalation of the poison is interrupted. The "after-effect" may increase equally and steadily, and after a maximum of irritation, disappear in the course of a certain time (from a few minutes to several hours, and even days, according to the degree of the exposure). After certain products it may occur that this process of increasing and diminishing irritation repeats itself several times. Thus, the after effect may form several wave-like attacks.

The arsenic compounds in the table given later are grouped in a certain way which—at first glance—may appear somewhat formalistic. However, certain relations between chemical constitution and physiological effect may be better understood.

It appears that the compounds of the first group (Alkyl-As-H_2) beginning with methylarsine have as little irritative effects as AsH_3 itself from which they are directly derived. Yet, they are highly toxic products.

The products of the second group beginning with CH_3-As=0, are almost throughout the most irritant compounds, with extremely violent effects and long-lasting after-effects. If absorbed, they are extremely toxic, causing disease of the respiratory organs and absorptive intoxications of a general character.

The substitution of sulfur in the place of oxygen deprives the organic arsine compounds almost entirely of their irritative effect and increases at the same time, their toxic effect. As these compounds have no acid character, they produce symptoms of a rather general character, affect-

ing the parenchymatous organs, capillary vessels, metabolism, and frequently cause death by toxic cachexia.

If the place of oxygen is taken by the halogens, chlorine, bromine, and iodine, cyanic and rhodanic radicals, the resulting compounds are extremely violent irritants and may, at the same time be highly toxic.

The irritant effect is more violent, if the halogen is substituted for oxygen and directly bound with the arsenic atom. Less irritant poisons result if the halogen enters the organic radical and is directly bound with a carbon atom.

In Lewisite the irritative and toxic effect is due to the presence of an unsaturated organic radical, the vinyl group ($CH_2=CH$). Chlorine atoms directly bound with the arsenic atom increase the irritative and toxic effects far more effectively than chlorine atoms which enter into the vinyl group. The last number of this series, the trichlortrivinylarsine ($CH\ Cl=CH)_3=As$ is relatively little toxic compared to the triphenylarsine and to the other compounds enumerated in the first group.

The next group includes esters of arsenious acid. The irritative effects of these products are more moderate, sometimes even mild. Some of these products are highly toxic.

The last group including two thio-esters, again proves that sulfur directly bound to the arsenic atom increases the toxicity of the resulting compound far more than the sulfur atoms which are directly bound with a carbon atom.

It can be mentioned that the entrance of aromatic radicals may decrease the toxicity of the resulting compound in comparison with the analogous aliphatic compounds.

One should also remember the general rule that the compounds which contain pentavalent arsenic are less toxic than those with tri-valent arsenic.

ORGANIC ARSINE COMPOUNDS

Name	*Formula*	*Irritation*	*After-Effect*	*Intolerability Limit mg per cbm*	*Toxic*	*Fatal*
Methylarsine	$CH_3-As=H_2$	none	....	....		
Phenylarsine	$C_6H_5-As=H_2$	none	....	....		
Diethylarsine	$(C_6H_5)_2=As-H$	none	....	....		
Triphenylarsine	$(C_6H_5)_3\equiv As$				3000	>3000
Methylarsineoxide	$CH_3-As=O$	violent	severe	>5	1000	2000
Dimethylarsineoxide	$\begin{matrix}(CH_3)_2=As\\(CH_3)_2=As\end{matrix}>O$	severe	severe	45		
Ethylarsineoxide	$C_2H_5-As=O$	extreme	violent and long lasting	6		<1000
Phenylarsineoxide	$C_6H_5-As=O$	extreme	severe	10		300
Diphenylarsineoxide	$\begin{matrix}(C_6H_5)_2=As\\(C_6H_5)_2=As\end{matrix}>O$	medium	moderate		3000	
Methylarsinesulfide	$CH_3-As=S$	mild	mild			
Methylarsinedisulfide	$CH_3-As<\begin{matrix}S\\S\end{matrix}$	mild	mild			250
Dimethylethylarsinesulfide	$\begin{matrix}(CH_3)_2\\C_2H_5\end{matrix}\!\!>\!\!A=S$	mild	mild			3000
Trimethylmercaptoarsine	$(CH_3S)_3\equiv As$	....	....		3000	
Phenylarsineimide	$C_6H_5-As=NH$	none	....			

Name	*Formula*	*Irritation*	*After-Effect*	*Intolerability Limit mg per cbm*	*Toxic*	*Fatal*
Dimethylarsinechloride	$(CH_3)_2=As-Cl$	violent	medium	30	1500	2500
Diethylarsinechloride	$(C_2H_5)_2=As-Cl$	violent	medium			
Diphenylarsinechloride	$(C_6H_5)_2=As-Cl$	extreme	violent and long lasting	1–2	300	600 cats 4000 dogs >5000 monkeys
Diphenylaminarsinechloride	$NH<\begin{matrix}C_6H_4\\C_6H_4\end{matrix}>As-Cl$	extreme	violent			>4000 dogs
Phenyl-o-chlorphenylarsinechloride	$o\text{-}Cl\diagdown\begin{matrix}C_6H_5\\C_6H_4\end{matrix}>As-Cl$	violent	severe			<2000
Phenyl-p-chlorphenylarsinechloride	$p\text{-}Cl\diagdown\begin{matrix}C_6H_5\\C_6H_4\end{matrix}>As-Cl$	violent	violent			<2000
Methyl-p-nitrophenylarsinechloride	$p\text{-}NO_2\diagdown\begin{matrix}CH_3\\C_6H_4\end{matrix}>As-Cl$	violent	violent			<1000
p-Nitrophenyl-phenylarsine chloride	$p\ NO_2\diagdown\begin{matrix}C_6H_5\\C_6H_4\end{matrix}>As-Cl$	violent	severe			<3000
Methylarsinedichloride	$CH_3-As=Cl_2$	violent	severe	25	1000	1500
Ethylarsinedichloride	$C_2H_5-As=Cl_2$	violent	violent and long lasting	3	350	1000
Amylarsinedichloride	$C_5H_{11}-As=Cl_2$	moderate	mild			
Phenylarsinedichloride	$C_6H_5-As=Cl_2$	violent	violent and long lasting	16	500	1000
Dimethylphenylarsine dichloride	$\begin{matrix}(CH_3)_2\\C_6H_5\end{matrix}\diagdown\!\!\diagup As=Cl_2$				3000	

Name	*Formula*	*Irritation*	*After-Effect*	*Intolerability Limit mg per cbm*	*Toxic*	*Fatal*
2.5-Dichlorphenylarsinedichloride	$Cl_2=C_6H_3-As=Cl_2$	severe				< 3000
Phenylarsinedichloride	$OH-C_6H_4-As=Cl_2$				3000	
α-Naphthylarsinedichloride	$\alpha C_{10}H_9-As=Cl_2$				3000	
p-Nitrophenylarsinedichloride	$pNO_2-C_6H_4-As=Cl_2$	extreme	violent		250	500
o-Nitrophenylarsinedichloride	$oNO_2-C_6H_4-As=Cl_2$	violent	severe		500	1000
Dimethylarsinetrichloride	$(CH_3)_2=As\equiv Cl_3$	mild				
Diphenylarsinetrichloride	$(C_6H_5)_2=As\equiv Cl_3$					3000
Dimethylarsinebromide	$(CH_3)_2=As-Br$	medium	moderate			
Diphenylarsinebromide	$(C_6H_5)_2=As-Br$	medium	moderate			< 3000
o-Chlorphenylphenylarsinebromide	$oCl<\begin{matrix}C_6H_5\\C_6H_4\end{matrix}>As-Br$				> 3000	
Methylarsinedibromide	$CH_3-As=Br_2$	medium	moderate	35		
Ethylarsinedibromide	$C_2H_5-As=Br_2$	medium	moderate			< 3000
Phenylarsinedibromide	$C_6H_5-As=Br_2$	medium	moderate			
Arsenic tribromide	$As\equiv Br_3$					< 3000
Diphenylarsineiodide	$(C_6H_5)_2=As-I$					< 3000

Name	*Formula*	*Irritation*	*After-Effect*	*Intolerability Limit mg per cbm*	*Toxic*	*Fatal*
Dimethylarsinecyanide	$(CH_3)_2=As-CN$	violent	severe	15		750
Diphenylarsinecyanide	$(C_6H_5)_2=As-CN$	extreme	extreme	0.25	300	500
Methylphenylarsinecyanide	$\begin{matrix} CH_3 \\ C_6H_5 \end{matrix}\!\!>As-CN$	violent	severe			<3000
Dimethylarsinerhodanide ...	$(CH_3)_2=As-SCN$	extreme	moderate	20	250	500
Diphenylarsinerhodanide ...	$(C_6H_5)_2=As-SCN$	violent	severe			500
LEWISITES:						
b-Chlorvinylarsinedichloride	$CH\ Cl=CH-As=Cl_2$	extreme	extreme			ca 150
bb-Chlordivinylarsine-chloride.....	$(CHCl=CH)_2=As-Cl$	extreme	extreme			<3000
Trichlortrivinylarsine.....	$(CHCl=CH)_3\equiv As$	moderate	moderate		3000	>3000
Cacodylacetylene	$(CH_3)_2{=}{=}As-C \equiv C-As{=}{=}(CH_3)_2$	violent	severe	6	>2000	

Name	*Formula*	*Irritation*	*After-Effect*	*Intolerability Limit mg per cbm*	*Toxic*	*Fatal*
Triphenylarsine	$(C_6H_5)_3 \equiv As$				3000	>3000
Diphenylarsine methyl ester	$(C_6H_5)_2-As-OCH_3$				>3000	
Phenylarsine dimethyl ester	$C_6H_5-As=(OCH_3)_2$	severe	moderate			1000
Diphenylarsine ethyl ester	$(C_6H_5)_2=As-OC_2H_5$				2000	>3000
Phenylarsine diethyl ester	$C_6H_5-As=(OC_2H_5)_2$	severe	moderate		300	500
p-Nitrophenylarsine diethyl ester	$p=NO_2C_6H_4-As=(OC_2H_5)_2$				3000	
Naphthyl-arsinediethylester	$C_{10}H_9-As=(OC_2H_5)_2$				3000	
p-Nitrophenyl-arsinediamyl-ester	$p=NO_2-C_6H_4-As=(O\,C_5H_{11})_2$	severe	moderate			500
Diphenylarsine-phenylester	$(C_6H_5)_2-As-OC_6H_5$					3000
Trichloro-methylarsenite	$As \equiv (OCH_2Cl)_3$				1000	3000
Phenylarsine-diphenylester	$C_6H_5-As=(OC_6H_5)_2$				3000	
Trimethyl-thioarsine	$As \equiv (SCH_3)_3$				3000	
Ethylarsine-diethylthioester	$C_2H_5-As=(SC_2H_5)_2$				very	<3000
Phenylarsine-diethylthioester	$C_6H_5-As=(SC_2H_5)_2$				very	<3000

ETHYLARSINEDICHLORIDE German: "Dick"
American: "ED"

Physical and chemical properties: A colorless liquid of fruity odor..

Formula:	$C_2H_5—As=Cl_2$
Molecular weight	174.92
Liter weight	7.278
Boiling point	156° C.
Specific gravity	1.68
Volatility at 21.5° C	22mg per liter, or 22 g per m^3

With water it is decomposed by hydrolyse, forming ethyl-arsine-oxide and hydrochloric acid.

Tactical properties: It is mainly a lung irritant, causing casualties through edema of the lungs.

At the same time it is also a vesicant poison, quick acting and non-persistent. These latter properties were at times overrated by the military and technical experts. Against the advice of the medical experts, the military engineers and chemists who have to make the final decisions in gas warfare, classified "Dick" as an offensive vesicant to be used for attack and called "Yellow Cross." This was soon found to be an error, when it failed to produce success in the battle of spring, 1918. It was later classified with the gases of the phosgene type and called "Green Cross 3."

Long before these events became known to the Allies, "Dick" was taken into consideration as a gas that would penetrate the early types of French, Italian and even British gas masks. Indeed, some of the early models did not give full protection against Dick. At that time, October, 1916, Dick appeared to some of the military experts in Germany as a kind of universal gas weapon, lung irritant, quick acting

vesicant, thus avoiding the protective defense, and also mask penetrating.. Haber was reluctant toward "Dick" for a very long time. I had no confidence in the effectiveness of this gas. Flury was undecided at all times. Toward the end of 1917 the bureaucratic tendencies in the German Research Institute on Chemical Warfare became more powerful and made it possible for a war gas like "Dick" to be admitted for use in battle. From then on, the efficiency of the German Chemical Warfare Service began its decline. Bureaucracy and mediocre scientists of the type of selfish careerists succeeded — even in this field of warfare — to lead Germany towards defeat.

Ethyldichlorarsine and ethyldibromarsine were combined in shells with dichlormethylether. The irritation of the nose, throat and chest appears after a short period of latency, during which enough of the gas is inhaled to make it impossible to keep on the gas mask. The irritation causes fighting inefficiency within a few minutes. The persistency of these mixtures is so low, that one hour in summer and two hours in winter, after the disappearance of the gas clouds, infantry could attack and invade the gassed area.

Technical properties are very similar to those of other arsines.

Toxic properties: It is a violent irritant and a little powerful vesicant. Conditions for absorption and elimination are the same as described for arsines and arsenic compounds elsewhere.

Toxic concentrations:

mm^3 per m^3	mg per m^3	time of exposure	effect
0.1	0.17	5 minutes	no smell, no irritation [1]
0.5	0.85	5 "	slight irritation of nose [1]
1.0	1.7	5 "	heavy irritation of nose and pharynx

3.0	5.0	1 minute	*limit of intolerability* [1]
5.0	8.5	5 "	heavy irritation "after-effect" last 2-4 hours [1]
8.0	14	1-2 "	fighting inefficiency [2]
20.0	35	1-2 "	intolerable irritation, long-lasting "after-effect" with dyspnoea [2] and tightness of chest, disease of respiratory organs.

Effect on men: Due to its acid character ethyl-arsinedichloride is a violent irritant. The skin is directly affected by its vapor. The liquid substance causes redness, tumors, and pustules within a few minutes to 24 hours, according to the concentration. After absorption it acts like the other irritant arsines.

Treatment, prognosis and prevention: Are the same as for other arsenic war gases.

DIPHENYLARSINECHLORIDE — American: "DA"
German "Clark I"
"Blue Cross"

Physical and chemical properties: A colorless, crystalline substance. If heated, or by explosion, it forms vapors or fogs, the diameter of the particles thus formed being between 10^{-4} and 10^{-5} cm.

Formula	$(C_6H_5)_2$ As—Cl
Molecular weight	264.50
Melting point	38°C
Boiling point	333°C

[1] **Flury, Zeitschr exp. Med., vol. 13, p. 541 (1921).**
[2] **Vedder, The Medical Aspects of Chemical Warfare, p. 71 (1925).**

The technical product is a thick, semi-solid mass. It is not decomposed by detonation. It is a little soluble in water, readily in organic solvents, such as, carbon tetrachloride and phosgene. With chlorine, it forms a non-toxic compound.

Tactical properties: It was developed and introduced simultaneously with mustard gas. It forms aerosols which penetrate ordinary charcoal canisters. The tremendous irritant effect of the gas was intended to force the attacked troops to take off their gas masks and to inhale greater amounts of the gas that is also toxic or other toxic gases shot at the same time.

The shells filled with this gas were marked as "blue cross" ammunition which also contained, somewhat later, diphenylcyanarsine. About 14,000,000 artillery shells were used with these products. The result did not correspond with the expectation.

The explosion disperses the product to particles which have a diameter of 10^{-4} to 10^{-5} cm. In toxic smoke generators or candles these substances can be more finely dispersed. Such generators were prepared by the Germans in 1917 and later by the Allies but for various reasons none of them reached the field before the armistice.

Technical properties: As a solid substance it can be handled easily. The main technical difficulty was to construct a shell which disperses the product. This problem was not solved to satisfaction. The smoke candles which are more satisfactory in this respect have other tactical disadvantages as dependency upon wind and other weather conditions.

Toxic properties: The vapors or smokes of the substance may act on the skin and mucous membranes by direct contact. Higher concentrations cause irritation of the respiratory or-

gans, edema of the lungs and bronchopneumonia. Disturbances of the central nervous organs may occur.

Toxic Concentrations: For men:

mg per m^3	time, in minutes	effect
1	a few seconds	fighting inefficiency
1-2	1 minute	intolerability limit
10	2 minutes	vomiting
2160	1-2 minutes	disease of respiratory organs[3]

It has been reported that under industrial conditions a certain tolerance may be acquired; some workers are able to work for months without complaints in an atmosphere that is intolerable for most other persons.

Effect on men: The *instant effect* is most violent on man; 1—2 mg per m^3 cannot be borne for more than one minute. The irritation first affects the nose, then the pharynx, respiratory passages and eyes. These effects increase even after leaving the gassed atmosphere. This *after-effect* appears in a few minutes, sometimes only after twenty minutes, the complaints becoming more and more violent, increased excretion from the mucous respiratory membranes, coughing, vomiting, nausea, pains in the accessory sinuses of the nose and forehead, painful headache, toothache, pains in the ears and jaws and chest, followed by dyspnoea and oppression. The maximum of the irritative effects appears within 6 to 12 minutes; they decrease within two hours to two days.

Higher concentrations cause violent pains radiating into the arms and the back. Toxic concentrations may produce symptoms similar to those described for phosgene. Disturbances of the gastro-intestinal tractus and the parenchymatous

[3] Vedder, The Medical Aspects of Chemical Warfare (1925).

organs may also occur. Dizziness, coma, lethargic conditions lasting for 12 to 24 hours occurred.

Psychic depression may lead to temporary loss of control. Men sometimes behave like mad because of pain and misery. Alterations in motor power and changes in the mental conditions are reported by Vedder as being not infrequent. He also reports about laboratory workers complaining of formication in the finger tips, temporary paralysis of one or more limbs, complete paralysis of the left arm developing within 3/4 of an hour after exposure, and disappearing within four hours, generalized motor weakness and mental depression.

In view of the futility of the symptoms described, they may rather be understood as psychic or psychopathic reactions to the violent irritation. In experiments on animals direct action of the product on the central nervous system could not be proved.

The effect of the vapor on the skin is not very severe, itching and reddening may occur. The substance directly applied to the skin causes pustules, keratosis and dermatosis.

Chronic arsenic poisoning may occur in industry and filling plants, but not in chemical warfare.

Prognosis: The resulting casualties are rather benign. Recovery may be expected in relatively short time, if acute intoxication was not caused by extreme concentrations.

Treatment is symptomatic. For the irritation, inhalation of a mixture of: alcohol, 40%; ether 20%; chloroform, 40% plus 5-10 drops NH_3 is recommended. Local anaesthetics such as anesthesine and menthol, and others are also useful.

DIPHENYLCYANARSINE German: 'Clark II"

Physical and chemical properties: It is a colorless crystalline substance. It is slightly soluble in water and forms foggy

vapors. It smells like a mixture of cyanic acid and garlic.

Formula	$(C_6H_5)_2$=As—CN
Molecular weight	255.05
Melting point	31.5°C
Specific gravity	1.45

Tactical properties: In 1917 and during the first months of 1918 most of the allied gas masks then in use were penetrated by this product. Its extreme irritant power makes it impossible to retain the gas mask. The troops so attacked were immediately put out of action and exposed to simultaneously shot toxic gases. This procedure was of great tactical advantage until adequate protection was provided to all troops.

Technical properties: The same as for diphenylchlorarsine.

Toxic properties: It is generally inhaled; direct affection of the skin is rare. *It is the most violent irritant known.*

Toxic concentrations: The irritative effect was studied in Berlin during the World War by "subjective experiments" (compare above) with the following results:

mg per m^3	time of exposure	effect
0.005		perceivable by smell
0.01	for about 10 minutes	tolerable
0.05	5-10 minutes	tolerable
0.1	2-5 minutes	tolerable
0.25	after 1-2 minutes	intolerable
1.0	½-1 minute	intolerable
2.5	immediately	intolerable

American sources confirm that 1 milligram per cubic meter causes immediate fighting inefficiency.[4]

Toxic concentration for men are not known.

[4] **Vedder, The Medical Aspects of Chemical Warfare (1925).**

	mg per m³	time of exposure	cxt	effect
cat	15	40 minutes	600	disease
	25	20 "	500	death after 5 days
	25	40 "	1000	death after 4 days
	50	40 "	2000	death after 4 days
monkey	50	40 "	2000	disease [5]

Effect on men: The irritation is overpowering, causing reflected and psychic reactions as already described. Acute disease resembles the phosgene type. If inhaled under special conditions, as occur in the field, for example, during unconsciousness by wounded men, longer lasting disease may follow. The violent irritation, however, predominates mostly and causes casualties of short duration. The irritant effects on the respiratory organs are absolutely predominant. Experiments on animals, however, prove that it is also absorbed and may cause protracted disease with all symptoms characteristic for arsenic. The cyanic group causes no specific effects.

Treatment, prognosis, prevention: compare the chlorides.

Detection is easy by smell and and irritation.

PHENYLDIBROMARSINE

Physical and chemical properties: A colorless liquid.

Formula:	$C_6H_5—As=Br_2$
Molecular weight	311.97
Boiling point	285° C. (545° F.)
Specific gravity at 15° C.	2.1

Tactical and technical properties: It was used like and in place of phenyldichlorarsine, for the first time in September, 1918, by the Germans.[6] The bromine product is more

[5] Wachtel, unpublished notes (1917).
[6] Prentiss, l. c., p. 168.

readily decomposed than the chlorine compound; through its low vapor pressure and volatility it is little effective in battle.

VINYLCHLORARSINE, LEWISITE, *"MI"*

Physical and chemical properties: The crude product which is used in practice is a mixture of the following components; it smells like geranium, it is soluble in organic solvents and readily hydrolyzed; with alkali it forms acetylene. The specific gravity of the crude product is 1.92.

	Molecular weight	Melting point	Boiling point	Vapor weight
b-Chlorvinyldichlorarsine $Cl—CH=CH—As=Cl_2$	207.36	—13°C	190°C	8.62
b-b^1-dichlordivinylchlorarsine $(Cl—CH=CH)_2=As—Cl$	233.37	—	113°/p.$_{11}$	9.71
b-b^1b^2 Trichlortrivinylarsine $(Cl—CH=CH)_3=As$	359.39	13°	138°/p.$_{12}$	10.79

Tactical properties: Lewisite was first isolated and described in 1917 by Dr. W. Lee Lewis and developed as a war gas by the American Chemical Warfare Service. But it was not used during the World War. It was also known to the German Gas Warfare Department without being practically used. But it may be used in future wars.

American experts assume "that Germany made a serious error is not employing Lewisite in the offensives of 1918." [7] It is considered a persistent vesicant, producing immediate casualties, and highly toxic.

However, American experts admit that Lewisite is more effective than, but of the same type as ethyldichlorarsine. Its use for offensive warfare in 1918 was a great disappointment for the Germans.

[7] **Prentiss, l. c., p. 191.**

The American assumption that Lewisite is superior to ethyldichlorarsine is based on the following facts: Ethyldichlorarsine is only 1/6 as vesicant as mustard gas and does not penetrate clothing. Lewisite acts quicker on the human skin than mustard gas and is said to be slightly more toxic. Its minimum irritant concentration is below its perceptibility through odor.

Through hydrolysis Lewisite is transformed into nonvolatile oxides according to the formula:

$$Cl \cdot CH{=}CH{-}As{=}Cl_2 + H_2O = 2HCl + Cl{-}CH{=}CH{-}As{=}O$$

These oxides are also highly irritant and vesicant and resist rain and moisture. They contaminate the ground for a long time.

Prentiss (l.c.p.191) refers to the publication of H. Wieland and A. Bloemer [8] as proving that Lewisite was synthetically manufactured in Germany in 1917. Indeed, I had tested Lewisite in 1916 as to its physiological effects. In collaboration with Flury and Haber we arrived at the opinion that it would not be a reliable war gas, its toxic effects were less lasting than those of mustard gas, the irritant effects could be realized by the adversary within a few minutes, while mustard gas is far more insidious. The men would be warned in time of its presence, the injuries caused through Lewisite are of shorter duration, all these were military disadvantages in comparison with the tactical procedure of 1918, which was called "Bunt schiessen," i.e. the simultaneous use of green, blue and yellow cross shells.

Wieland was one of the most outstanding chemists in Germany. He was called in to the Kaiser Wilhelm Institute in 1917 and got interested in the synthetic studies concerning arsenic compounds. Only through the weight of

[8] Liebig's Annalen der Chemie, vol. 451, p. 30.

his very impressive personality and through his persuasive power, did he succeed in having some of these arsenic compounds experimentally introduced at the front. Lewisite and also ethyldichlorarsine had been known and physiologically tested long before that time. Lewisite was discarded from practical use, before ethyldichlorarsine was used.

None of the German experts, then, had great confidence in the military effectiveness of Lewisite. In addition to the reasons mentioned above, Haber's method of determining toxicity figures is more reliable than other methods and it is mainly on this basis that I cannot believe in a superiority of Lewisite over mustard gas. It may be possible that under very special conditions (weather, climate, geography or special character of the tactical objective, etc.) Lewisite may prove effective. It will be highly interesting to see the first practical test in the second World War. Also in air attacks on civilian populations, everything that can be accomplished with Lewisite, can better be accomplished with mustard gas.

"Dr. Mueller [9] thinks Lewisite would have been a great disappointment to the Americans, had it been actually used on the Western Front in the World War." [10]

Toxic properties: Lewisite is a violent vesicant and highly toxic, but less persistent than mustard gas.

Toxic concentrations: Are recorded as follows:

0.8 mg. per m^3 is the minimum irritating concentration.
14 mg. per m^3 is perceivable by the odor of the product.
334 mg. per m^3 is the vesicant (blistering) concentration.
120 mg. per m^3 inhaled for 10 minutes is fatal.
48 mg. per m^3 inhaled for 30 minutes is fatal.

[9] **Ulrich Mueller, Die Chemische Waffe, 2nd Ed., Verlag Chemie, Berlin (1932).**

[10] **Quoted from Prentiss, l. c., p. 196.**

Effect on men: The period of latency and the duration of the disease are shorter than those caused by mustard gas. After absorption, symptoms are similar to those caused by phosgene. But the inflammation of the respiratory passages is more malignant insofar as it may become purulent very early. Lewisite may be absorbed through the skin and produce disease of the lungs within a few hours. Death may occur within a few hours, but generally within 3 to 5 days, according to the exposure.

The action of Lewisite on the human skin is described as follows:

in 5 minutes it is completely absorbed by the skin causing a slight burning sensation.

after 30 minutes the erythema (reddening) of the skin begins and gradually increases,

after 3 hours a surface of from 12 to 15 cm. diameter is affected,

after 13 hours numerous blisters of cherry size and smaller appear and gradually conflue into one large blister,

after 24 hours, one large blister which is surrounded by reddened zone.

The first reddening of the skin after mustard gas appears only after 2 hours and the affected area extends only over a surface of about 4 cm diameter.

Prognosis: If death does not occur within the limits mentioned, the prospects for convalescence and recovery are more favorable than with mustard gas, the duration of the recovery is shorter, and there is less chronic sequelæ.

Treatment: is the same as for irritant gases in general. The skin may be treated with a 5% solution of sodium hydroxide or caustic soda. This, however, would only serve to

render the adherent Lewisite inactive. A paste made from 1% glycerine and iron hydroxide freshly precipitated is also recommended.

DIPHENYLAMINEARSINE CHLORIDE British: "Adamsite," American: "DM"

PHENARSAGINE CHLORIDE

Physical and chemical properties: Adamsite is a yellow crystalline solid product, not soluble in and slowly hydrolyzed by water.

Formula	$(C_6H_4)_2HN{=}AsCl$
Molecular weight	277.50
Melting point	195° C.
Boiling point	410° C. (with decomposition)

Tactical properties: it is a violent irritant, but milder than diphenylarsinechloride. It is also toxic. It is more effective, when used as smoke, than in shells. Towards the end of 1918 the British intended to use it on the battlefield, but did not do so before the armistice. It is said that it is now used by police.

Technical properties: The technical product is dark green-brown and corrosive to iron, steel, bronze and brass.

Toxic properties: It irritates the eyes, mucous membranes, causes severe headache, nausea and vomiting. At certain higher concentrations the irritant effect of Adamsite lasts longer than that of diphenylarsinechloride, to which it is very similar in all respects.

APPENDIX: *ANTIMONY COMPOUNDS*

A number of antimony compounds which are homologous to the arsenic compounds mentioned in this chapter, were also investigated. The toxic effects resemble, it seems, in

every respect those of the homologous organic arsenic compounds.

No reason could be seen, therefore, for complicating the research by extending it too much.

We know, however, from other experiences, that the clinical effects of antimony compounds on men are somewhat different from those of arsenic compounds. Potassium stibyl tartrate is used in medicine and may cause intoxication which very closely resembles the clinical picture of dysentery. It is not impossible that a more thorough study of the antimony compounds would lead to products which could be used in gas warfare with advantage over similar arsenic compounds. A slight difference in physico-chemical and toxic properties may sometimes be of great importance.

CHAPTER IX:

THE SULFUR COMPOUNDS

The irritant effects of sulfuric acid, organic esters of sulfuric acid and other organic sulfur compounds were well known in 1914. Consequently, many compounds of this kind were examined for possible use as war gases. The inorganic compounds Cl_2S, sulfur dichloride and Cl - SO_2 - OH, sulfurylchloride or chlorosulfonic acid, were useful as smoke producers alone or in mixtures.

The toxic compounds of this group were introduced into actual warfare in the following order:

1915, June — Methylchlorosulfonate and ethylchlorosulfonate
September: Perchloromethylmercaptan
1917, July: Mustard gas.
1918, March: Thiophosgene.
September: Dimethylsulfate

These few poisons were selected from a few hundred of compounds the most important of which are listed at the end of this chapter. That list includes products which were examined in Germany from 1916 to 1917, but not all of them are mentioned in the American or other non-German scientific literature so far.

In this group two compounds are to be discussed in some detail, Dimethylsulfate, because its toxic action on the organism has been thoroughly studied and because such knowledge largely contributes to the understanding of the action

of other war gases; and mustard gas, because it is not only the most effective of all war gases, the "king of the battle gases," but it also implies many highly interesting problems, the study of which will be important for future advances in physiology.

Chemically, all these products are to be classified as esters of various acids of sulfur. The connections between chemical composition and physiological action which are already known make it probable that future advanced knowledge in this special field will not only lead to new war gases, but also to a more thorough understanding of the chemical nature of bacterial toxins. The reader may find some suggestions in this direction in the following paragraphs. However, problems of such general character exceed the plan of this book.

Here, it may suffice to mention the following facts: Esters and thio esters of this group, especially dimethylsulfate and thiodiglycolchloride (mustard gas) act on the organism simultaneously through both the undecomposed entire molecule and through the products of decomposition "in statu nascendi." Physical and physico-chemical properties of the products, like solubility in water and liquids, hydrolysis, etc., modify the physiological effect of individual compounds next to changes in their chemical composition.

It appears that the acid component of an ester mainly determines its toxic effectiveness. The esters of formic acid are more toxic than those of higher fatty acids. Halogenations increase the irritant effects of esters. Bromine and iodine substituting for chlorine atoms, increase the toxicity, simultaneously by decreasing the irritant effects. Thiodiglycol bromide acts more violently on the capillary vessels and on the ductless glands than the homologue chlorine compound mustard gas.

Those halogenated esters of formic acid which dissociate phosgene first are by far more toxic than other esters which directly dissociate hydrochloric, sulfuric and other acids, when in contact with the human organism.

The alcohols are seemingly of minor importance for the toxicity of esters. One should always remember that the action of the entire molecule is most essential.

It has become a rather general habit to classify certain war gases together as vesicants. This is quite correct from purely military viewpoints. For the chemist and physiologist it is more informative to consider the more complex and manifold variations of toxic effects in chemical groups of poisons. In this respect it is informative to read the following list of vesicants in descending order of their irritant effects on the skin:[1]

		Mortality product ext.
1.	Dichloroethylsulfide (mustard gas)	1500 (3)
2.	Lewisite	1200 (2)
3.	Phenyldichlorarsine	2600 (5)
4.	Methyldichlorarsine	5600 (7)
5.	Ethyldichlorarsine	5000 (6)
6.	Phenyldibromarsine	2000 (4)
7.	Dibromoethylsulfide	1000 (1)

This table shows that the same compounds form different orders, if arranged according to their vesicant or toxic properties. When we search for new war gases, the military experts must first determine which effect they wish to accomplish in the first line. For instance, Lewisite acts rather quickly, but causes fighting inefficiency for shorter periods only. The men return to their troops after rather short periods of absenteeism. On the other hand, mustard gas and, still more, dibromodiethylsulfide would cause fighting

[1] Prentiss, Chemicals in War, pp. 198 and 199 (1937).

inefficiency of equally large numbers of men for much longer periods of time, but less suddenly.

In total war, where the same compound may be used against civilian populations, mustard gas and dibromodiethylsulfide dropped in bombs or sprayed from aircraft would disable workmen in the defense industry for longer periods of time, than Lewisite would do. The latter would be more efficient, if used in shells, for the bombardment preceding attack.

METHYLCHLOROSULFONATE
METHYLSULFURYLCHLORIDE

Physical and chemical properties: A transparent liquid; it is not soluble in water and sulfuric acid, but miscible with alcohol, chloroform and carbon tetrachloride.

Formula	$Cl—SO_2—OCH_3$
Molecular weight	130.55
Vapor weight	4.5
Boiling point	133° — 135° C.
Melting point	—70° C.
Specific gravity	1.51
Volatility at 20° C.	60 mg. per lit.

Tactical properties: It was used in trench mortar bombs and hand grenades by the Germans in June, 1915 for the first time and for a short time only, after which it was replaced by the German "K-Stoff." 25% methylchlorosulfonate in mixture with 75% dimethylsulfate composed the German "C-stoff."

Technical properties: Methylchlorosulfonate is produced from methyl alcohol and sulfurylchloride. The shortage of methyl alcohol in Germany was the cause of this product not being used in artillery ammunition.

Toxic properties: It is mainly an irritant. In mixture with dimethylsulfate it diminishes the toxic effect of the latter. *Toxic concentrations*:

8 mg per m^3			minimum irritant concentration
50 mg per m^3	1 minute	:	limit of intolerability
2000 mg per m^3	10 minutes	:	lethal concentration

Effect on men: The irritant effect is violently felt in eyes, nose and chest. The toxic effects are irritation of respiratory passages and lungs, but played no part on the battlefields of the first World War.

ETHYLCHLOROSULFONATE

ETHYLSULFURYLCHLORIDE French: "Sulvanite"

Physical and chemical properties: Ethylsulfurylchloride is a colorless liquid with pungent odor, fuming on contact with moist air. It is insoluble in and decomposed by water, it is readily soluble in organic solvents, such as ether, chloroform, ligroin.

Formula	$SO_2 \begin{matrix} /OC_2H_5 \\ \backslash Cl \end{matrix}$
Molecular weight	144.57
Vapor weight	6.01
Boiling point	152—153° C.
Specific gravity	1.379

Tactical properties: The military value of the product is nil. It is of historical interest as one of the first lung irritants that were used in artillery shells. Grignard suggested its use for war, the French accepted it for a short period, because it irritates the skin; they mixed it with bromoacetone.

Toxic properties: It is an irritant, mainly acting on the upper part of the respiratory passages, because it forms rather rapidly, when in contact with the moisture of the air and the mucous membranes, hydrochloric and sulfuric acid, as intermediate product perhaps also ethyl sulfonate.
Toxic concentrations: are about equal to those of methyl-chlorosulfonate.

PERCHLOROMETHYLMERCAPTAN
CARBONTETRACHLORSULFIDE

Physical and chemical properties: A yellow, oily liquid with a pungent odor.

Formula	$CCl_3—SCl$
Molecular weight	185.91
Vapor weight	7.73
Boiling point	149° C.
Specific gravity	1.72

Tactical properties: Perchloromethylmercaptan was the first chemical to be used in gas shells, by the French[2] in September, 1915. It was also used by the Russians in mixture with Cl_2S. It is little toxic, and in addition, warns the enemy by its odor and is readily absorbed by charcoal.

Technical properties: In contact with iron the product is easily decomposed.

Toxic properties: It is inhaled. If absorbed, it acts as an irritant, causing edema of the lungs, causing also absorptive effects elsewhere.

Toxic concentrations: 10 mg per m^3 produces irritation of the eyes, 70 mg per m^3 is estimated as limit of intolerability. The mortality product, c x t, is about 30,000.

[2] Izard et al., "La Guerre aéro-chimique." Paris (1933).

Effects on men: The slightest exposures may cause nausea and vomiting by the terrible stench of this product. Small concentrations may cause irritation of the mucous membranes of the eyes and of the respiratory passages, also chest pain. Heavier exposures would cause edema of the lungs not unlike phosgene, but at the same time, slight absorptive effects on the nervous system may be present. Only very high concentrations, which hardly occur under field conditions, and which have not been observed so far in industrial cases, could cause affection of the central nervous system with convulsions and narcotic symptoms. No cases of this kind have been recorded so far.

THIOPHOSGENE — French "Lacrimite"

Physical and chemical properties: A yellow liquid with a pungent odor, fuming on contact with air.

Formula	$S=C\begin{matrix}/Cl\\ \backslash Cl\end{matrix}$
Molecular weight	114.98
Boiling point	73.5° C.
Specific gravity 15°	1.508
Vapor density	4 (air=1)

It is polymerized into dithiophosgene by the action of light and is rapidly decomposed by hot water and alkali.
Tactical properties: It was used on the battlefields in 1914—1918 by the Austrian and French armies, with no success.

DIMETHYLSULFATE — French: "Rationite"
German: "D-stoff."

Physical and chemical properties: A colorless oily liquid.

Formula	$CH_3O\diagdown$ SO_2 $CH_3O\diagup$
Molecular weight	126.19
Vapor weight	5.28
Boiling point	188° C
Specific gravity D_{18}	1.327

If pure, dimethylsulfate is almost without odor. Commercial products smell somewhat like lubricating oil. Dimethylsulfate is not soluble in water, but is readily decomposed by moist air and cold water, still more quickly by hot water, and instantaneously by acids and alkalis.[3]

In spite of its high boiling point, the volatility of dimethylsulfate is sufficient to cause dangerous concentrations at ordinary temperatures. At 20°C, the concentration of the atmosphere above the surface of liquid dimethylsulfate is 3,300 mg per m^3 — this is a fatal concentration by shortest exposure. At 50° the vapors of dimethylsulfate form fogs.

Tactical properties: It is highly toxic; in comparison with mustard gas it is less powerful as vesicant, also less toxic, but its immediate irritant action on eyes and mucous membranes is stronger. Its toxicity equals about that of phosgene insofar as acute injuries to the lungs are concerned. It is only little less toxic than mustard gas in view of the more chronic effects on men. Toxicologically it is the most adequate substitute for mustard gas. It is far less persistent than the latter, because it is speedily hydrolized by the moisture of the air. It was introduced by the French in September, 1918 and used in hand grenades and shells.

[3] Wachtel, Zeitschr. f. Exp. Path. & Ther., vol. 21, p. 1 (1920).

Technical properties: Dimethylsulfate is according to its tactical properties most adequate to substitute for mustard gas. This was one of the reasons for which the Germans did not use this product on the battlefield. The other reason was shortage of methyl alcohol. As dimethylsulfate could more easily be manufactured than mustard gas by the chemical industries of the Allies, careful investigations were made about the producing capacity for dimethylsulfate of France and Britain in 1916 and spring, 1917. Only after reports had been received that the Allies would not soon be ready to reply to the German use of mustard gas with mentionable amounts of dimethylsulfate, the former gas was decided upon for use on the battlefield for summer 1917. As mustard gas and dimethylsulfate were under consideration at the same time in Germany (1916) it was reasonable not to introduce dimethylsulfate and thus prematurely direct the attention of the Allies to this product. The fact that only France among the Allies thought of this gas and did so only very late in the first World War proves that the calculations of Haber on this subject were correct.[4]

I mention these details because they prove the fact that it is highly important for a country to have a man with the knowledge, skill and ability, as Haber had, on the German side. The Allies, frequently, believe too much in material superiority. Prentiss[5] says, "Throughout the war, with few exceptions, Germany maintained the initiative in chemical warfare, owing principally to her immensely superior chemical industry." And Lefebure[6] says, "As a general rule, where the German lag between the approval

[4] This answers the question raised by Prentiss, l. c., p. 153.

[5] Prentiss, Chemicals in War, p. 683 (1937).

[6] Lefebure, The Riddle of the Rhine. London (1921); as quoted by Prentiss.

of a substance and its use in the field covered weeks, our lag covered months. . . . The Germans used mustard gas in July, 1917. But the first fruits of allied production were not in the field for eleven months. British material was not used until a month or two before the armistice."

These facts and quotations make it rather clear that the superiority of the chemical industry was only one factor, the other factor for Germany's superiority in chemical warfare during the first World War was Fritz Haber's personal activity.

Toxic properties: Dimethylsulfate is inhaled. The liquid substance or solutions of it may act on mucous membranes and the skin directly. It is also absorbed through the skin, causing systemic disease after absorption, simultaneously with its local effects of irritation and corrosion.

The toxic mechanism is understood as follows: The undecomposed molecule is absorbed and gradually decomposed into sulfuric acid, methyl alcohol and possibly formaldehyde. This mechanism explains the irritative effects of the poison. It may be ascribed to the absorption and action of the undecomposed molecule that the blood pressure is lowered, and convulsions and paralysis of the central nerves develop. This action on the central nervous system is equally typical for other sulfur compounds and also for many organic esters [3].

It can also be proved that dimethylsulfate paralyzes the katalase of the blood "in vitro" at a concentration as low as 1—50,000 [3].

Toxic concentrations for men are of the same magnitude as those found for animals.

On account of the military and industrial importance of this product, a great number of animal experiments have been made, from which the following figures may be quoted:

	mm^3 per m^3	time of exposure	effect
For cats	10	30 minutes	fatal
" "	20	15 "	fatal
" monkeys	50	20 "	serious disease with partial recovery after 30 days
" "	100	40 "	fatal within 3 days

For men, the following figures may be derived from animal experiments:

mm^3 per m^3	time of exposure	effect
1	several hours	toxic
10	20 minutes	toxic, fighting inefficiency after a period of latency
50	20 minutes	fatal

Dimethylsulfate, therefore, is almost as toxic as mustard gas.[7]

Effect on men: The clinical picture is very similar to that caused by mustard gas.

Toxic exposures may cause a very slight or almost no initial irritation of the mucous membranes of eyes and nose. These effects develop within a few hours.

Salivation may sometimes occur as an initial symptom, During the latency period, which may last for eight hours or even from one to two days, the symptoms caused by absorption may develop according to the character of the exposure or to constitutional conditions. The clinical picture which develops may be of one of the following types:

1—*Phosgene type*—edema of the lungs is a predominating symptom. It may develop in the same way as described for phosgene.

[7] Wachtel, Unpublished experiments and l. c.

2—*Diphtheric type*—pseudo membranes and alterations of the respiratory passages may develop. The pseudo membranes may become very thick and may cause suffocation. Smaller concentrations may cause symptoms of bronchitis and pseudomembraneous changes of smaller degree.

3—*Affections of the circulatory system,* especially the vascular system of the heart may cause symptoms of circulatory insufficiency and heart failure without the presence of edema of the lungs or diphtheric appearances.

4—*Toxic cachexia* may develop, especially when very low concentrations are inhaled during protracted periods.

Symptoms falling under these four typical forms may be combined, thus causing a large variability of the clinical picture. In all cases, irritation of the eyes and the mucous membranes of mouth and upper respiratory passages may be present, the corneal epithelium may be lost and the alterations may be the same as described for mustard gas. Conjunctivitis may be very severe. Bronchitis, edema of the lungs may be combined with pneumonia or may be followed by bronchopneumonia caused either by direct action of the poison on the lungs, or by secondary infection.

Each one of the first three types of disease may be complicated by the simultaneous presence of toxic cachexia, so that the general weakness added to the more acute or local symptoms may delay or prevent recovery, and death may still occur after several weeks, and even later.

The clinical picture may vary from very acute forms, including cases with sudden deaths by heart failure, to subacute and very chronic suffering.

Pneumonia may develop in the beginning during the first days, as toxic pneumonia may cause fever and may end fatally.

In heavy cases, alterations of hemoglobin with jaundice and nephritis may occur. The functioning of the enzymes and hormones may be disturbed by very low exposures and play a role in the toxic cachexia.

It can be learned from animal experiments that after very small exposures, the blood sugar in rabbits is diminished.[8] Metabolic disturbances may, therefore, occur in dimethylsulfate poisoning, however, no detailed knowledge of these disturbances is available.

Treatment is symptomatic, and according to the type of disease, following the directions given for the treatment of phosgene and mustard gas, respectively.

Prognosis: Early appearance of heavy symptoms, especially fever and pneumonia during the first days are signs of bad prospects. Less heavy cases may always involve the possibility of more serious late sequelae. Even in such cases which seems to be apparently slight ones in the beginning, the prognosis should be given with great caution, as toxic cachexia may develop or become apparent in a later period of the disease. However, after the acute danger is overcome by the patient, complete recovery may be accomplished in most cases.

Prognosis for injury of the cornea largely depends upon the prevention of secondary infection and scars.

Detection and determination are made by gravimetric and titrimetric determination of the sulfur in the form of $BaSO_4$.

[8] Wachtel, Unpublished experiments.

DICHLORODIETHYLSULFIDE — THIODIGLYCOL CHLORIDE

(American: H S)
(English: Mustard Gas)
(French: Yperite)
(German: Gelbkreuz ["Yellow Cross"])

Mustard gas was the most efficacious war gas used during the World War. The pure compound was first synthetized in 1886 by Victor Meyer, who also described its toxic effects. During the World War, two German chemists, Lommel and Steinkopf proposed its use as war gas as early as in 1916. The German name "Lost" was formed from the first letters of the names of these two chemists.

The first laboratory experiments in September, 1916 confirmed the practicability of this proposition; but, the construction of technical equipment for approximately safe production, transportation of the dangerous compound, and filling equipment, took much time.

In the spring of 1917, the first filling station in Adlershof, near Berlin, was erected, and the first 1,200 7.7cm shells were filled, while some more tank cars stood in the vicinity. One evening, after the last worker had left the filling station, and only a few men of the military guard were present, an explosion occurred which blasted the 1,200 shells and destroyed the whole equipment.

The explosion was so violent that the windows were broken and roofs torn from houses for a distance of more than a mile; and yet, no intoxications occurred. The guards, fire brigade and military detachments that were immediately ordered to the place, were not injured in the least by the poison, with the exception of a young lieutenant who suffered from hysterical shock.

Then, the great majority of experts, including those in charge of the German anti-gas protection, who had been opposed to the use of the new gas (mustard gas) because the German gas masks, at that time, were no protection against it, persistently opposed its use in the field, remarking, sarcastically, that it might be the best means for killing cats, but that it was no war gas at all.

However, the results of laboratory experiments on animals were so convincing, that the toxicologists[9] took the entire responsibility upon themselves. The negative result of the explosion was explained by the fact that the heat of the explosion forced the entire gas cloud upward so rapidly that no person was affected. Great quantities of chloride of lime, applied for the degassing of the debris and the soil, eliminated the danger from sprinkled drops of mustard gas in liquid form.

Laboratory and field experiments were continued, while the filling station was repaired. During the summer of 1917, a field experiment was made covering a certain area, where several hundred cats and dogs were exposed; 500 shells were shot. Soon after this experiment, the first attack, with *Gelbreuz* ("Yellow Cross"), mustard gas, were made at Ypres, Nieuport and Armentières (July, 1917), the result of which is well known.

Mustard gas has proved to be the most efficacious war gas. It has been stated that Germany produced about 4,800 tons of this gas; France, 2,500 tons; United States during 1917 and 1918, 645 tons.[10]

[9] **Flury & Wachtel.**

[10] **Fries and West, Chemical Warfare. New York and London (1921).**

Prentiss [11] estimates the total quantity of mustard gas used during the first World War at 12,000 tons, which caused a total of 400,000 casualties. The average amount of mustard gas per one casualty is accordingly 60 pounds (compared with 230 pounds of lung injurant agents and 650 pounds of arsenic compounds) (German blue cross ammunition).

The French production of mustard gas shells is recorded as follows: [12]

75 mm shells	2,160,000
105 mm shells	91,000
155 mm shells	141,000

On July 12 and 13, 1917, 77 mm and 105 mm gas shells filled with mustard gas (yellow cross) were used against the Ypres area held by the French. The bombardments were continued each night until the end of the month July, 1917. Especially heavy bombardments were directed on Armentières and Nieuport during the nights following July 20 and 21, 1917.

German attacks of this kind were continued throughout the war until July, 1918. After that time mustard gas shelling diminished. It has been assumed that this diminution of mustard gas shelling was due to a shortage of the product on the German side. This assumption is not quite correct. The German general staff had planned a general offensive against the Allies for the spring and summer of 1918. As mustard gas is a defensive weapon, the German front was supplied with offensive gases (blue cross and green cross) according to plans. However, the Ger-

[11] Prentiss, Chemicals in War, p. 199 (1937).

[12] André Meyer, Gaz de combat, p. 17 (1938).

man offensive of 1918 did not succeed and led to the final failure and defeat of the Germans.

Physical and chemical properties: The pure substance is a colorless oily liquid. Its odor resembles somewhat that of lubricating oil. The commercial product as used in shells is yellowish to dark brown in color. It contains various sulfur compounds as impurities. Its odor has been compared with that of mustard, garlic, decayed cabbage and similar materials.

Formula	$S\begin{matrix}/CH_2—CH_2—Cl \\ \backslash CH_2—CH_2—Cl\end{matrix}$
Molecular weight	159.05
Liter weight	6.61
Melting point	13.5°
Boiling point	215.5
Specific gravity D_{20}	1.26

Its volatility at different temperatures is given in the following table:

At 14°	345 mg per m^3	[13]
" 15°	401 " " "	[14]
" 18°	422 " " "	[13]
" 20°	625 " " "	[14]
" 20.5°	541 " " "	[13]
" 22°	719 " " "	[13]
" 35°	2,135 " " "	[14]
" 39°	2,980 " " "	[13]

The low vapor pressure combined with its relatively high stability allow it to persist in the field, undecomposed, for relatively long periods.

[13] Flury, Zernik-Schädliche Gase, p. 363. Berlin (1931).

[14] Vedder, Medical Aspects of Chemical Warfare (1925).

It is slightly soluble in water; but readily soluble in fatty oils and lipoids, and organic solvents. At ordinary temperatures, water saponifies 25% within 2 hours 35% within 6 hours; 60% within 24 hours.

Thiodiglycolchloride is produced from thioiglycol and concentrated hydrochloric acid, or from ethylene and S Cl_2 or S_2 Cl_2.

With chlorine, chloride of lime or chloramine it is transformed, by chlorination or oxidation into less toxic compounds that are practically without danger. Chloride of lime and chloramine, therefore, are used for decontamination of men, objects and soil.

Tactical properties: Mustard gas is a vesicant. The vapor and the droplets penetrate the clothing, uniforms and boots and cause blisters by their action on the skin after a period of latency. The protective effect of gas masks is thus frustrated. For its persistency, it is most adequate for defense actions. Areas contaminated with mustard gas by shelling, sprays or by special devices which gradually release mustard gas after delays of varying lengths of time cannot be immediately occupied by the troops which pursue the retreating adversary.

Mustard gas dropped in bombs or sprayed from aircraft would contaminate inhabited areas or factories making work impossible, until decontamination is made, which requires time, special decontamination squads and large quantities of chloride of lime.

According to the type of solvent used, the exploding shell may form gas clouds, finely dispersed mists, or sprays of droplets. The gas clouds are practically not visible and remain effective for periods from 6 hours in open country, to 24 hours in terrain protected against wind and sun. The fine droplets adhere to the clothing and penetrate boots made

of both leather or rubber. Through such contamination, the gas is carried into closed rooms, shelters, first aid stations, etc., and injures the people unaware of its presence at locations far distant from the immediate target of the gas shelling.

Technical properties: Mustard gas is a liquid at ordinary temperatures but solidifies at about 14°C. (57°F.) The ballistic behavior of the shells is subjected to changes, when their contents change between solid and liquid with the change of temperature. To avoid this difficulty, mustard gas was used in solutions. As solvents, were added, from 10 to 25% carbon tetrachloride, chlorbenzene or nitrobenzene by the German and French armies. The Americans used chlorpicrin for the same purpose, considering it an advantage that the latter is also a toxic war gas. However, chlorpicrin is also an irritant. Such shells, containing chlorpicrin, act, therefore, less insidiously. The enemy is warned in time of the presence of gas, puts on his masks and is thus protected, against the insidious action of the odorless and non-irritant mustard gas.

Toxic properties: Mustard gas is a very insidious and violent general cell poison, affecting epithelium, capillary vessels and nervous cells.

Toxic concentrations (For Monkeys) [15]

Variety	Concentration mg per m^3	Time in minutes	Product cxt	Effect
Macacus	1	150	150	Slight disease lasting one day
Macacus	2·5	200	500	Keratitis, bronchitis, recovery

[15] **Flury, Wachtel and collaborators, Zeitschr. f. exp. Med., vol. 13, p. 400 (1921).**

Macacus	5	150	750	Slight disease, recovery
Cercopithecus	20	25	500	Vomiting keratitis, laryngitis, bronchopneumonia lasting for two weeks, followed by slow recovery
Cercopithecus	50	10	500	Keratitis, bronchopneumosia, disease lasts for one month, then recovery with permanent impairment of sight
Rhesus	50	20	1000	Death after 8 days. Autopsy: keratitis, hemorrhage, bronchopneumonia, pseudomembranes in larynx, trachea and broncho.

Equal exposures to carbon monoxide, even if continued for many hours would have no injurious effect. All concentrations to which the monkeys were exposed can easily be obtained on the battlefield.

Toxic concentrations for men:

Mg per m³	*Time of Exposure*	*Product cxt*	*Effect*
1	8-10 hours	480-600	Fighting inefficiency [16]
1.2	45 minutes	54	Eye and skin disease [16]
2.5-5	30-60 minutes	75-300	Skin disease [16]

6.5	60 minutes	390	Serious disease of the lungs [17]
70	30 minutes	2100	May be fatal [17]
100-200	Few seconds	—	Itching of the skin for several weeks [18]

Effects on men: Mustard gas is inhaled. Its droplets may act directly on the skin. It is also absorbed through the skin. It is a powerfully irritant gas, acid in character, and a destructive poison affecting the epithelium, capillaries and nervous system after absorption.

Its effects are most complicated and complex. It is soluble in fats and lipoids, has an acid effect, combined with the high reactivity of the ethyl sulfide group in statu nascendi. Its affinity to the nervous system, its effect upon the blood and enzymes,[19] are among the principal chemical explanations for its efficaciousness.

Anatomically, the epithelium of every organ affected by it, including the capillary walls, is subjected to its destructive power. It appears justified to call it a general cell poison.

Every attempt to give a satisfactory explanation of the mechanism of the poisonous effect of this product has been unsuccessful. It remains one of the most baffling problems of general pathology, why mustard gas is able to cause such deep seated alterations within the organism only after a period of latency, long enough to admit the assumption that at the time, when the grave and chronic symptoms appear, the molecule itself must have been completely decomposed.

[16] Reed, Journal Pharm. and Exp. Therapeutics, vol. 15, p. 71 (1920).

[17] Vedder, Medical Aspects of Chemical Warfare (1925).

[18] Flury & Wieland, Zeitschrift Exp. Med., vol. 13, p. 370 (1921).

[19] Wachtel, unpublished notes (1917); partly reported by Flury; Zeitschr. f. Exp. Med., vol. 13, pp. 431, 556, 572 (1921).

What are the alterations, chemical or biological, within the skin that can explain, not only the symptoms that recur again and again for weeks and months in unchanged severity, but also the fact that the content of the skin pustule of one patient can cause the same symptoms on the skin of another patient at a time, when there is no trace of the substance present and, logically, cannot be in existence any more? A chemically well determined and simple substance produces effects, which, otherwise and elsewhere, are observed only as effects of certain bacteria.

Mustard gas, primarily and directly, causes pronounced alterations within the blood.

These effects are very similar, in fact, almost identical, to those caused by infections. The following alterations may be distinguished:

1st phase: Increase of neutrophile leucocytes, decrease of monocytes and lymphocytes, disappearance of eosinophile cells

2nd phase: Increase of monocytes

3rd phase: Increase of lymphocytes, reappearance of eosinophile cells.

Small concentrations cause a decrease of blood sugar in rabbits before other symptoms become apparent.[20]

The blood of dogs and rabbits poisoned by mustard gas, on microscopical examination in the dark field, showed changes of the normal process of the coagulation (clotting) and alterations of the surface properties of the red cells of the blood. The red cells of these dogs and rabbits which normally appear with a distinct sharp margin under the microscope showed a certain very fine unevenness of their cir-

[20] Wachtel, unpublished notes (1935).

cumferential lines which could be understood as a roughening of the surface. Other changes became apparent inside the red cells. The coagulation of normal blood as observed under the microscope begins with the formation of very finely interlaced filaments. In the blood of the animals poisoned with mustard gas there initial formations of fibrin were short and thick, rather chubby, blunt and broad.[21] The significance of these findings for the clinical picture of mustard gas poisoning is not yet fully understood.

Clinical Symptoms: From experience on hundreds of thousands of cases that came under observation during the World War, and from experiments made upon several hundred animals, the clinical symptoms may be understood as mixtures or transition forms of three essentially different, well limited basic types of disease. The three types also occur in their simple form, but much less frequently than they do in their mixed forms.

(1) The first typical disease which may be caused by mustard gas is that of *edema of the lungs.* This type of disease may occur in its simplest form, but usually it is accompanied by absorptive symptoms.

(2) The second type of disease is characterized by pseudo-membranous (fibrinous, croupous) pharyngitis, laryngitis, tracheitis and bronchitis. Aside from these symptoms, there is *no* edema of the lungs. These pseudomembranes may be so thickened that only a knitting needle is able to pass the lumen that remains. In such cases, edema of the glottis, inflammation of the regionary lymph glands of the throat and lungs, tumor and hyperaemia of the spleen may occur.

[21] **Wachtel, notes on unpublished research (1917), in collaboration with W. Scheffer, partly reported by Flury and Wieland, Zeitschrift f. exp. Med., vol. 13, pp. 401 and 431 (1921).**

(3) The third type of disease is characterized by a general destruction of cells and tissues, and can be understood, at least to a certain extent, as having a specific effect upon the capillaries.

Primarily, there is often a predominating heart disease of a very serious nature present. French writers, especially, emphasize this group of symptoms. Heart failure may prevail under certain conditions. Anatomically, the heart muscle is dilated and dark, showing degenerative changes, as well as hemorrhagic punctuations which are also found in the epicardium and endocardium. The kidneys also show hemorrhagic changes, edema and injury to the epithelium. It may be mentioned here that, in experiments on animals, hemorrhagic changes of the parenchyma, and below the capsule of the suprarenal glands occurred. The latter symptoms were particularly evident after intoxication with the homologous bromine compound:

$$\begin{matrix} CH_2\,Br - CH_2 \\ CH_2\,Br - CH_1 \end{matrix} \Big\rangle S, \qquad \text{Thiodiglycolbromide.}$$

It may also occur that no particular symptom predominates. In such cases, the general effect produced by mustard gas takes the form of *toxic cachexia,* general weakness, diminished resistance against injurious influences of any kind —infections, and the like.

The central nervous system may also become involved, and manifests itself through coma and convulsions. These symptoms appear in the most serious cases.

The essential symptoms may sometimes be overshadowed by affections of the eyes and skin. The destruction or degeneration of the epithelium of the *cornea* may result in scars or blindness.

The skin is inflamed, itches and burns. The epithelium

degenerates and is destroyed, and scales off. Often pustules are formed, which contain a serious liquid that will affect healthy portions of the patient's own skin, as well as that of other's (Nurses) through direct contact. To a certain extent the pustules resemble those caused by combustion.

An overwhelming majority of the cases show a combination of these numerous symptoms, thus forming multifarious variations of the clinical picture.

Variations and Complications: Mild cases may only show irritation of the skin, conjunctiva, and respiratory passages; hoarseness and slight cough. In the more serious cases, these symptoms, as well as all the others that have been described, may occur in varying degree from the slightest to the severest forms. Secondary infections may, of course, complicate the condition, such as infections of the lungs and eyes, as well as inflammation of the skin.

The effect of a preexisting pulmonary tuberculosis upon the intoxication may be illustrated in the case of a monkey that had a slight tuberculosis of the lungs. It died after 10 hours during an exposure to only 2.5 cmm per m^3 of mustard gas.

When the eyes and the respiratory tract are protected by gas masks, the only symptom may be an irritation of the skin, but it must be borne in mind, that mustard gas may be absorbed through the skin, and that external irritations may be followed by absorptive symptoms.

A research worker, after slight exposure to an unknown concentration of mustard gas, exhibited bright red elevated areas, scarlatiniform plaques, and a bright red inflammation of the throat and pharynx—a symptom complex frequently occurring in infections, but in this case, without fever or general disturbances. The symptoms disappeared, when the patient avoided exposure to mustard gas.

Prognosis: The prognosis in respiratory intoxications, aside from eye and skin injuries, should be made with caution. Severe, sudden gassing may cause death within a few hours as a result of heart failure. The affection is much more protracted than affections produced by other irritant gases. Death may occur after one week, but also within three or four weeks. The course is always uncertain. Only in obviously slight cases, can a favorable prognosis be made.

Meakins and Priestley [22] established statistics on 4,575 cases of mustard gas intoxication that occurred during the World War; they found the

Duration of the disease longer than 9 weeks in....17.2%
Duration of the disease longer than 4 months..... 1.6%
Permanently disabled 0.08%

Such statistics are not quite satisfactory insofar as the conditions and circumstances at the time of the intoxication are too little known; particularly during war, when it can never be ascertained, whether pure mustard gas was the only toxic agent or a mixture of different war and explosive gases.

Mustard gas causes disease and temporary disability for protracted periods. The French compiled the following statistics [23] on the duration of the disabilities caused through mustard gas artillery attacks at Verdun during the months of August and September, 1917. The absolute figure of the gas poisonings is not recorded, the table records the number of days within which the men returned to their regiments:

[22] Vedder, Medical Aspects of Chemical Warfare, p. 250 (1925).
[23] Hanslian, Der Chemische Krieg, p. 147 (1937).

Returned within 30 days:	0%
45 days:	13%
60 days:	35%
70 days:	17%
Total	65%

Results from these figures show that mustard gas is a very humane weapon insofar as it causes a low mortality (2.2 to 3%), but it is also militarily efficient, as it causes long lasting disabilities.

During the three weeks of mustard gas shelling at Ypres from July 12 to August 1, 1917, the Allies (British)

counted ..... 14,275 casualties
including about ..... 500 deaths.

The total number of casualties due to gas during the period from July 21, 1917 to November 23, 1918 registered in British clearing stations was 160,970
including fatal cases ..... 1,859.

These figures include about 10% of cases due to dichlorethylarsine and 10% due to phosgene, diphosgene and chlorpicrin.

The following table contains a list of mustard gas attacks on the British and the number of casualties and deaths caused in each attack. It is apparent that the mortality was not only low but also rather even at all times.

The last figures of the table concerning the time after armistice show that the mortality was relatively higher than before that time. It may be assumed that these cases were caused not by direct attacks but by the exposure of troops in contaminated areas left by the Central Powers and occupied by the Allies who were unaware of the exposure and

therefore remained unprotected and unwarned. These exposures must have been accordingly protracted.

British gas poisonings caused by German mustard gas shells.[24]

Week end		*Total Casualties*	*Killed*
1917			
July	.....	10,911	188
August	7.....	2,887	67
"	14.....	1,664	16
"	21.....	1,913	9
"	28.....	848	2
September	4.....	312	1
"	11.....	1,413	3
"	18.....	1,760	15
"	25.....	876	5
October	2.....	1,389	13
"	9.....	1,507	16
"	16.....	1,124	18
"	23.....	2,653	40
"	30.....	1,328	19
November	6.....	3,003	28
"	13.....	1,614	16
"	20.....	1,187	8
"	27.....	744	14
December	4.....	1,550	35
"	11.....	804	92
"	18.....	414	15
"	25.....	278	6
1918			
January	1.....	387	2
"	8.....	441	1
"	15.....	176	—
"	22.....	146	—
"	29.....	189	—
February	5.....	536	1

[24] Hanslian, l. c.

(*Continued*)

Week end		*Total Casualties*	*Killed*
"	12.....	234	1
"	19.....	307	1
"	26.....	486	—
March	5.....	306	1
"	12.....	601	1
"	19.....	4,783	17
"	26.....	4,401	40
April	2.....	2,031	18
"	9.....	1,851	5
"	16.....	5,456	56
"	23.....	3,488	55
"	30.....	4,414	96
May	7.....	2,127	45
"	14.....	2,389	59
"	21.....	2,621	219
"	28.....	3,103	131
June	4.....	2,393	51
"	11.....	1,503	24
"	18.....	849	16
"	25.....	559	18
July	2.....	519	29
"	9.....	480	30
"	16.....	276	8
"	23.....	262	2
"	27.....	798	21
August	3.....	1,835	28
"	10.....	1,668	19
"	17.....	2,384	29
"	24.....	3,588	75
"	31.....	5,243	50
September	7.....	3,751	41
"	14.....	2,914	71
"	21.....	3,114	60
"	28.....	1,858	47
October	5.....	2,409	41
"	12.....	1,170	35
"	19.....	2,002	25

(*Continued*)

Week end	*Total Casualties*	*Killed*
" 26.....	1,666	72
November 2.....	1,157	53
" 9.....	1,060	43
" 16.....	403	28
" 23.....	117	12
" 30.....	32	5
December 7.....	30	—
Total	124,702	2,308

It can be seen from these tables that, after the introduction of mustard gas, the number of gas poisonings increased remarkably. Yet, at the same time the percentage of fatalities due to gases decreased from 6 to 2.2%.

This is especially illustrated by the following table:

Period 1918	Casualties	Killed	Killed in percent[25]
September 15 to 21.....	4,172	95	2.3
September 22 to 28.....	2,578	24	0.9
September 29 to October 5....	4,315	80	1.9
October 6 to 12.....	2,206	62	2.8
October 13 to 19.....	4,407	106	2.4
October 20 to 25.....	2,568	66	2.6
October 27 to November 2....	2,162	69	3.2
November 3 to 9.....	1,561	34	2.2
November 10 to December 7..	394	4	1.0
Total	24,363	540	2.2

Treatment: The treatment is symptomatic as described elsewhere in this book. For the treatment of the respiratory and circulatory symptoms, compare also the section on phosgene.

[25] Hanslian, l. c., pp. 125, 126.

In eye injuries, showing only a conjunctivitis, the treatment is the usual one. If there is loss of corneal epithelium, special treatment should be given by an experienced ophthalmologist; corneal transplantation may be found necessary.

Skin affections are treated with a soothing ointment, vaselinum album purisimum. Severe injuries to the skin should not be treated with ointments or powder, because secondary infection is favored by the formation of a scab. Antiseptic moist dressings are indicated. Pustules should be carefully opened and their contents properly disposed of. *Protection and decontamination*: Chloride of lime or solutions of chloramine will clean objects contaminated with mustard gas. They should be left within these solutions (which may be warmed) for 24 hours. Thiodiglycolchloride easily penetrates rubber gloves. The skin may be cleaned with warmed suspensions of chloride of lime as soon as there is any suspicion of their having come in contact with mustard gas.

To protect against inhalation, military gas masks are needed.

Detection: is possible by a number of unspecific reactions, such as decolorization of 0.003% solution of potassium permanganate and others or by the fairly specific reagent of Grignard, which contains sodium iodide and copper sulfate. Strictly specific is Schroeder's method: 0.01% gold chloride solution or 0.05% palladium chloride solution forms a colloidal turbidity with mustard gas. The sensitivity of this method is said to be 10-12 mg per m^3 of air.

Other halogen derivatives of organic sulfur compounds.

A large number of halogen substitution products of organic sulfur compounds were prepared, and studied for possible use as war gases. Such products may also occur as inter-

mediate or by products during the preparation or production of chemical compounds in industry.

Dibromodiethylsulfide is heavier and more steady than mustard gas itself. It causes subcapsular hemorrhages and intraparenchyamatous hemorrhages in the suprarenal and other ductless glands. It acts qualitatively like mustard gas in most respects, but is a more violent poison.

The toxic and lethal action of the thio-compounds is slow —a latency period may always be observed. The lethal effect may occur within several days, or even after several weeks. Many more thio compounds are known as highly toxic. Some products of this group will most probably be used as war gases in the future.

The following list of some halogenated organic sulfur compounds contains formula, name, toxic and fatal doses derived from experiments on cats, dogs, and in some cases, monkeys, according to the principles developed by the research in the Kaiser Wilhelm Institute in Berlin, Germany, during the World War, and not published elsewhere. These doses are in cxt products, where c is the concentration in mm^3 per m^3 and t the time of exposure in minutes. The cxt products for all compounds of this group are constant as even the lowest concentration of 1 mm^3 per m^3 would still be toxic or fatal, if the exposure is extended for a correspondingly long time.

SULPHOXIDES

Formula	*Name*	*Toxic Dose cxt*	*Fatal Dose cxt*
$\begin{matrix}Cl-CH_2\\Cl-CH_2\end{matrix}>S$	Dichlorodimethylsulphide.....	1500	4500
$(Cl_2CH)_2=S$	Tetrachlorodimethylsulphide...		< 1000
$\begin{matrix}Br-CH_2\\Br-CH_2\end{matrix}>S$	Dibromodimethylsulphide.....		300
$\begin{matrix}Cl-C_2H_4\\Cl-C_2H_4\end{matrix}>S$	Dichlorodiethylsulphide.....	300	600
$\begin{matrix}Cl_2-CH-CH_2\\Cl_2-CH-CH_2\end{matrix}>S$	Tetrachlorodiethylsulphide....	300	500
$\begin{matrix}Cl-CH_2-CH_2\\CH_3-CH_2\end{matrix}>S$	ω-chlorodiethylsulphide.....	250	500
$\begin{matrix}Br-CH_2-CH_2\\CH_3-CH_2\end{matrix}>S$	ω-bromodiethylsulphide.....	100	250
$\begin{matrix}Br-CH_2-CH_2\\Br-CH_2-CH_2\end{matrix}>S$	Dibromodiethylsulphide.....		250
$\begin{matrix}Cl-CH=CCl\\CH_3-CH_2\end{matrix}>S$	αβ dichlorovinylethylsulphide..	1500	....
$\begin{matrix}Cl-CH_2-CH_2\\C_6H_5\end{matrix}>S$	β chloroethylphenylsulphide...	500	1000
$\begin{matrix}Cl-CH_2-CH_2\\Cl-CH_2-CH_2\end{matrix}>SO$	Dichlorodiethylsulphnoe	400	800
$\begin{matrix}Cl-CH_2\\CH_3\end{matrix}>SO_4$	ω-chlorodimethylsulphate.....	300	500
$\begin{matrix}Cl-CH_2\\Cl-CH_2\end{matrix}>SO_4$	Dichlorodimethylsulphate.....	....	500
$\begin{matrix}Cl_3\equiv SC\\NC\end{matrix}>S$	Perchloromethylrhodanide	< 300	300
$\begin{matrix}Cl-C_2H_4\\NC\end{matrix}>S$	Chloroethylrhodanide.....		< 1000

CHAPTER X:
CYANOGEN COMPOUNDS

The poisons of this group, hydrogen cyanide and cyan derivatives, are systemic poisons.

Those compounds which dissociate hydrogen cyanide after absorption within the human organism are more toxic than other compounds which dissociate other radicals. The halogenated cyan derivatives are more irritant than toxic. Bromobenzylcyanide is almost not toxic but a very powerful irritant. At least it causes no effects which are specific for the cyan group. For this reason it was not classified here, but with the aromatic irritant poisons.

Cyanogen derivatives have not been very important as war gases thus far. Yet research in this field has largely contributed to advance in other fields; cyclon is one of the best insecticides for agricultural purposes, and in our defense against typhus, plague and other infections. It may well be that further research will lead to new poisons that may be useful in war or peace.

The main gases of this group appeared on the battlefields of the first World War in the following order:

1916,	July	Hydrogen cyanide
	September	Cyanogen bromide
	October	Cyanogen chloride
1917,	May	Phenylcarbylaminechloride

HY. ROGEN CYANIDE French: "Vincennite" "Manganite"

HYDROCYANIC ACID

Physical and chemical properties: A colorless gas, lighter than air.

Formula	HCN
Molecular weight	27.02
Vapor weight	1.12
Boiling point	26.5° C
Melting point	15° C
Specific gravity	0.697

Tactical properties: Hydrogen cyanide was selected for chemical warfare at an early date by the French, certainly for the only reason that it was known as the most effective of the "traditional poisons." The experience in the field was utterly disappointing. The conditions are explained in detail in Chapter VI. One week before the French gas appeared on the battlefield, the German gas mask was improved to protect against it.

Technical properties: As a gas of high toxicity hydrocyanic acid is difficult to handle in filling plants. Its reactivity and tendency to polymerization makes storage for any length of time impracticable. For its high volatility it had to be mixed with other products which also prevent the polymerization. Such admixtures were arsenic tetrachloride[1] and tin tetrachloride. "Vincennite" contained: hydrogen cyanide 50%, plus arsenic trichloride 30%, plus tin tetrachloride 15%, plus chloroformium 5%. The French produced 4,160 tons of Vincennite during the first World War, enough to kill 20 billion men, had it been used in closed

[1] "Manganite" was composed of hydrogen cyanide and arsenic trichloride.

rooms and at adequate concentrations, which could not be accomplished on the battlefield.

Toxic properties: Hydrogen cyanide paralyzes the respiratory and other enzymes. This reaction is reversible. As long as the heart of a poisoned person continues functioning, recovery can be accomplished by artificial repiration and other means of treatment. If a patient recovers, no protracted or permanent disability of any kind results. As fatal concentrations cannot be obtained on the battlefield, casualties of military importance do not occur either.

Toxic concentrations:

1: 1 mg hydrocyanic acid per kg body weight is fatal if inhaled, swallowed, or absorbed through the skin. (Gettler recently estimated this dose being about 1.4 mg per kg body weight for men.)

2: The effects of inhaled doses on men are the following:

mg per m^3	time of exposure	effect
50		Complaints of headache, nausea, vomiting and cardiac symptoms. The symptoms disappear after removal of the exposure [2]
100	within a few minutes	Toxic [2]
100	60 "	Fatal [2]
300	6 "	Fatal [2]

Concentrations below 40 mg per m^3 cause no symptoms on cats, dogs and monkeys exposed to them for not more than about 30 minutes. It can be estimated that the toxic figures for hydrocyanic acid inhaled are of the same magnitude for cats, dogs, monkeys and men. Rabbits and other rodents

[2] Flury-Zernik, Schadliche Gase, p. 404 (1931).

are less sensitive. This experience has been derived from numerous experiments made in the Pharmacological Department of the Kaiser Wilhelm Institute in Berlin during the World War. These experiments were made in connection with accidents which occurred in the gassing of ships and buildings for the extermination of insects. In several of these accidents, the concentrations of hydrocyanic acid were determined by chemical analysis of the atmosphere. The figures found in these experiments confirmed the older figures as published by Lehman and his collaborators in 1903 and 1905. There can be no doubt that these toxicity figures are reliable.

3. Individual sensitiveness to hydrocyanic acid is variable in men, animals and insects. Insects may acquire a higher resistance by repeated gassings. Rats are more resistant than mice; still less sensitive are rabbits; least sensitive are guinea pigs. Pigeons, cats, dogs and monkeys do not show exactly the same sensitiveness as men, but the differences are not great. The principal reactions of these animals may well be compared to those of men. In the experimental intoxication of animals, the exposure which causes lateral posture as a very characteristic symptom can be used for the comparison of the toxicity figures. The following table shows concentrations and time of exposure which are just sufficient to cause lateral posture:

	Time of Exposure		
mg per m³	cat	dog	monkey [8]
50	25 minutes	15 minutes	
100	7.5 "	3 "	
150	5 "	6½ "	12 minutes
200	3 "	8 "	
430	2 "		
700	1 "		
1,000	55 seconds		

[8] Flury-Zernik, Schadliche Gase, p. 403. Berlin (1931).

4: As concerns war gases, it is important to remember that only high concentrations have fatal effects. Smaller concentrations may cause transitory disturbances of short duration without fatal or toxic effects. This means that soldiers exposed to smaller concentrations, do not fall ill for long periods, nor do they lose their fighting efficiency.

Heavy concentrations, under field conditions, are practically impossible because hydrocyanic acid is specifically light and does not, therefore, exercise any long-lasting effect. The following figures may illustrate these conditions;

The lowest concentration that causes fighting inefficiency is about 100 mg per m^3. This concentration is extremely difficult to maintain under field conditions for periods longer than a few minutes. It is easier to achieve in closed rooms, in bombardments of buildings, fortifications and battleships, if the gas is used in heavy bombs with delayed ignition. The ordinary artillery shell does not, however, produce a concentration of 100 mg per m^3 and does not, therefore, under field conditions, cause fighting inefficiency or disease.

The German Army was scarcely affected by the hydrocyanic shells used by the Allied Armies during the World War. The Germans, themselves, used hydrocyanic compounds in their shells, but they did so with full knowledge of the unsatisfactory effects. They were forced to use the hydrocyanic compounds on account of a shortage in other, more efficient war gases in Germany. The compounds were also used as a means of dilution with the more powerful gases, again on account of a shortage.[4]

[4] It is easily understandable why German textbooks do not mention this fact. Even Flury and Zernik in Schädliche Gase, Berlin (1931), make no reference to it. The chapter on hydrocyanic acid contains no reference to its use as war gas, while other German and foreign war gases are discussed in detail.

5: The observation mentioned above is not only important for the use of cyanic compounds as war gases, but also for the criticism of a number of medical remedies which have been recommended as specific ones by toxicologists and clinical physicians. Additional data, therefore, concerning the toxic concentrations should be discussed. These data, and the foregoing facts as well, have been determined by the use of Haber's formula, which is discussed in the chapter on toxicity figures. It was mentioned that hydrocyanic acid is a typical example of a poison with an unconstant ct product. This may be illustrated by the following table, which contains some results of experiments on cats made in 1917, and which establish a basis for a better understanding of the conditions in question:

c mg per m^3	t minutes	c x t	effect[5]
250	2	500	fatal
125	6	750	fatal
125	6	750	fatal
100	5½	550	fatal
100	5½	550	fatal
62	300	5,000	survives
62	300	5,000	survives

This table clearly illustrates that the limit of danger or fatal concentration is between 62 and 100 mg per m^3. Any

[5]Flury & Zernik, Noxious Gases, p. 401 (1931), and Flury & Heubner, Bioch, Zs. 95, p. 249 (1919) refer to the same experiments. Their figures are twice as high as those given above. The difference may be explained by the considerations given in annotation elsewhere in this book. The increased figures of Flury & Heubner correspond about with certain American figures as given by Vedder. This discrepancy, however, does not affect the fact that is to be proven by the table. The importance of the concentration instead of the c x t product would equally result from the doubled figures as given by Flury & Heubner.

concentration, whatever, above 100 mg per m^3 is fatal at a ct product as low as 500. Any concentration below this limit is not fatal, even if exposure is protracted over 5 hours with a resulting cxt product of 5,000.

In practical cases of accidental intoxications, the exact concentration which caused the accident is generally unknown. For this reason, it is almost always impossible to decide, whether certain "specific" medical remedies have a curative effect or not.

6: The concentrations of hydrocyanic acid that are used for the extermination of insects and parasites are the following:[6]

	Concentration mg per m^3	Time in hours
Rats, mice (in ships)	1,500— 5,000	2— 6
Bedbugs, fleas (in buildings)	5,000—15,000	12-24
roaches, lice		
Lice on orange (by night) trees	13,600	¾

These concentrations exceed, by far, the danger limit for men.

Effect on men: Fatal concentrations cause sudden breakdown. The man collapses, sometimes with the so-called "hydrocephalic" cry. Under convulsions death results in a few seconds or a few minutes.

Smaller concentrations may first cause irritation of the eyes, headache, nausea, sensation of peculiar taste, oppression, dizziness, accelerated and deepened respiration, heart symptoms, asthmatic attacks, convulsions, and finally asphyxia with resulting paralysis of the respiration.

[6] Flury & Zernik. Schädliche Gase, p. 536. Berlin (1931).

If aid can be given even in a very advanced stage of this development by removal of the patient from the contaminated atmosphere, by artificial respiration and oxygen inhalation, recovery will be obtained in most cases. The same symptoms occur in the opposite sequence, according to the reversible character of the intoxication, when the patient gradually improves.

Treatment: Insofar as it can be applied by laymen and first aid squads is mentioned above. Medical preparations, such as lobelin and cardiacs, amyl nitrate, intravenous infusion of sodium thiosulfate, methylene blue, colloid sulfur, glucose, dioxyacetone and blood transfusion belong to the exclusive domain of the physician and of the hospital.

Protection: Ordinary gas masks do not protect against hydrogen cyanide. One should therefore carefully read the instructions which are attached to each canister, military or civil, in order not to be surprised by lack of preparedness.

As hydrocyanic acid is readily absorbed by clothes, the gas mask should not be taken off immediately after leaving the contaminated atmosphere.

The gas is also absorbed through the skin. Therefore, even persons equipped with gas masks or respirators should not stay longer than is necessary in contaminated rooms. *Detection* of hydrocyanic acid through its smell is not safe, because certain individuals are not sensitive to it. The reaction of iodine solution or a special reagent containing copper acetate and benzidine acetate are most sensitive.[7]

CYANOGEN CHLORIDE French: "Vitrite" "Mauguinite"

Physical and Chemical Properties: A mobile liquid. Its

[7] Sieverts and Hermsdorf, Zeitschr. f. angew. Chemie, vol. 34, p. 3 (1921).

odor is pungent and irritating. It is little soluble in water, readily soluble in organic solvents.

Formula	CNCl
Molecular weight	61.47
Vapor weight	2.56
Boiling point	15.8°
Melting point	-7°
Specific gravity	1.2

On standing, it forms the polymeric product *cyanuric chloride*:

Formula	$(CNCl)_3$
Molecular weight	184.41
Boiling point	190°
Melting point	145°
Specific gravity	6.35

Tactical properties: Cyanogen chloride is one of the long series of cyanic compounds which combine the irritant properties of the halogen with that of the cyano-radical. It was used by the French Army. It is heavier than cyanogen chloride. Its odor warns the attacked troops of the presence of gas.

Technical properties: It polymerizes on storage forming a less effective product $(CNCl)_3$. Addition of arsenic trichloride makes the product more stable and was for this reason a component of the French "Vitrite" shells.

Toxic properties: At low concentrations it acts more like phosgene, as an irritant; at higher concentrations the action is more similar to that of hydrogen cyanide.

Toxic concentrations:[8]

mg per m³	time of exposure	effect
50	1 minute	Tolerability limit for men[9]
100	18 minutes	Fatal for cats within 9 days after exposure[10]
300	3 minutes	Fatal for cats during exposure[9]
300	8 minutes	On dogs, causes heavy disease with following recovery[11]
800	15 minutes	On dogs, fatal
2,500	3 minutes	On goat, fatal after 70 hours

CYANOGEN BROMIDE

Austrian: "CE"

British: "CB"

Italian: "Campiellite"

Physical and chemical properties: A colorless, crystalline mass.

Formula:	CNBr
Molecular weight	105.92
Liter weight	4.40
Boiling point	61.5°
Melting point	52°
Volatility	155 gram per m³ at 16° C

Tactical and Technical and Toxic properties: Cyanogen bromide is somewhat less irritant and a little more toxic than cyanogen chloride. On storage it polymerizes, it decomposes in contact with metals which it corrodes. It was used during the World War by the Austrian Army. The "CE" shells contained 25% cyanogen bromide plus 25% bromaceton plus 50% benzol. In peacetime it served as an insecticide.

[8] According to Flury-Zernik, Schädliche Gase, p. 410 (1931).

[9] Flury, Zs. exp. Med., vol. 13, p. 567 (1921).

[10] Ibid, p. 588 (1921).

[11] Reed, Journ. Pharm. and Exp. Therap., vol. 15, p. 301 (1920).

Toxic concentrations:

mg per m^3	Time of exposure	effect
85	1 minute	Tolerability limit (according to German research)[12]
35	within a few seconds	Fighting inefficiency (according to American sources)[13]
710	within 1 minute	Toxic dose (according to American sources)[13]
140	within 1 minute	Toxic concentration (according to Austrian research)[13]

METHYL AND ETHYL CYANOFORMATE:

Physical and Chemical Properties: The methylester is a colorless liquid.

Formula	CN—CO—O—CH_3
Molecular weight	85.03
Liter weight	3.53
Boiling point	97°
Specific gravity	1.08
Volatility	187 grams per m^3 at 21° C.

The ethyl ester is also a colorless liquid.

Formula	CN—CO—O—C_2H_5
Molecular weight	99.05
Liter weight	4.12
Boiling point	116°
Specific gravity	1.014
Volatility	65 grams per m^3 at 16° C

[12] Flury, Zs. exp. Med., vol. 13, p. 567 (1921).
[13] Vedder, The Medical Aspects of Chemical Warfare, p. 70 (1921).

"Cyclon" is a technical product containing a mixture of both substances with an addition of about 10% of the esters of the chloroformic acid. This mixture has a boiling range of about 80-100° and a content of hydrogen cyanide of about 30%.

Tactical and technical properties: The technical product was used during the World War as admixture to other war gases by the German army. The product was called "Cyclon." It is very useful as an insecticide and as a fumigant and was largely used in occupied Poland and Russia to destroy the lice which spread typhus among the civilians and troops in 1917 to 1919. This product was composed during the World War by the German War Department for different reasons. Its boiling point is far superior to that of hydrocyanic acid. Its volatility is correspondingly lower, but sufficiently high to assure effective concentrations under field conditions. It is, therefore, preferable to hydrogen cyanide as a war gas for tactical use in the open field. Furthermore, it combines the effect of cyanic compounds with the irritating effect of the chlorinated products that are contained in it. However, the toxicity of this mixture is not sufficient to make it useful as a war gas by itself. It was, therefore, used by the German War Department as a means of dilution for other gases of which there was a certain shortage. At the same time, physiological research confirmed that such mixtures of several war gases, for instance, cyclon combined with mustard gas, were at least not less toxic than the single components. Such mixtures also served somewhat different tactical purposes.

Toxic concentrations: The combination of the cyan group with the esters causes the ct product to be more constant than is the case for hydrocyanic acid. This may be illustrated

by the following tables which contain the toxic concentrations for cats:[14]

mg per m³	Time of exposure	c t	effect
	methylcyanoformate		
10	60 minutes	600	Fatal after 3-13 days
50	10 "	500	Fatal after 6 days
	ethylcyanoformate		
10	60 minutes	600	Fatal within 4-19 days
50	20 "	1,000	Fatal within 14 days
5	100 "	500	Fatal within 14 days
5	200 "	1,000	Fatal within 7 days

These tables prove that even the smallest concentrations of cyclon are effective as gaseous poisons. The product, therefore, is much more suitable for practical use as a war gas than is hydrocyanic acid.

Effect on men: The clinical picture is principally that of an irritant gas as caused by phosgene. If the exposure is sufficiently high to cause death, the disease takes a course analogous to an intoxication by phosgene, and death occurs as a result of edema of the lungs and pneumonia. Only extremely high and sudden exposures cause the typical effects of hydrocyanic acid. After medium and lower exposures, the typical characteristic effects of the cyan group are subordinate to the prevailing symptoms of irritation.

Treatment is symptomatic.

Prevention: Gas masks with special filters which protect against cyanic compounds are necessary.

PHENYLCARBYLAMINECHLORIDE

Phenyl Iso-Cyano Chloride German "K 2-stoff"

[14] Experiments in 1917 cp. Flury & Hase, Munich, Med. Ws., p. 779 (1929).

Chemical and physical properties: A colorless liquid.

Formula	$C_6H_5NCCl_2$
Molecular weight	173.97
Liter weight	7.23
Boiling point	210°

Tactical properties: As a lung irritant, it is an offensive gas. It is more persistent than all the other lung irritants. It was first used in battle by the Germans in May, 1917, only two months before blue cross and yellow cross appeared in the field. Phenylcarbylaminechloride through its persistency could have exhausted the gas mask canisters then in use, had it been used in bigger quantities. Indeed, it was less effective as a lung irritant than phosgene, as lachrymator it was mediocre, therefore, "the reason for its use by the Germans is not apparent"[15] to American experts. About 700 tons of phenylcarbylaminechloride were used by the Germans from May, 1917, until the end of the war. In fact, nobody on the German side expected great results from the use of this gas. It was one of the products that should cover certain shortages in the field of chemical economy, that existed at that time at which all economic and technical and industrial efforts were directed on the production of blue cross and yellow cross ammunition for the great defensive in the then coming summer of 1917.

It was the German plan at that time to increase the part of the gas ammunition to one-half of the total ammunition output of Germany. As this could not be accomplished with the highly effective gases, other less effective products had to be used to such extents as could be produced by the chemical industry without serious disturbances of the needs of other fields of chemical production.

[15] Prentiss, l. c., p. 164.

Probably it was not considered desirable to give the Allies more complete information on this problem. Their laboratories, certainly, spent at least some efforts in research in such fields that offered no prospect of success. Other German writers on chemical warfare had no insight into the economic conditions or could not know the reasons for which decisions were made in 1916 and 1917, because they were not admitted to the meetings in the War Ministry and had to find possible explanations in the literature just like the scientists on the side of the Allies.

Toxic properties: Phenylisocyanochloride is inhaled and acts as a violent irritant on the mucous membranes, like phosgene, but may also produce more general effects after absorption.

Toxic concentrations:

mg per m^3	Time of exposure	c t	effect
30	1 minute		Tolerability limit [16]
800	immediately		Toxic [17]
50	20 minutes	1,000	Fatal for cats
15	30 "	450	Toxic for cats

Effects on men under field conditions are similar to those caused by phosgene.

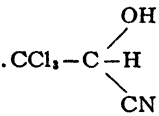
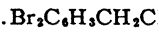
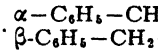
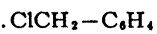
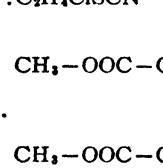
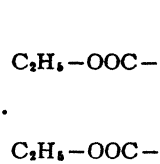
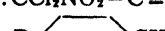
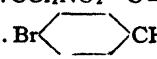
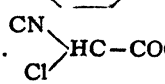
Other Cyan Derivatives

A great number of organic cyan compounds have been investigated as to their usefulness as war gases, before those practically applied at the various fronts were introduced. The following list contains the formulas and fatal doses

[16] Flury. Zs. exp. Med., vol. 13, p. 567 (1921).

[17] Vedder, The Medical Aspects of Chemical Warfare, p. 70 (1925).

for cats resulting from experiments made by the author during the World War in 1917 in the Kaiser Wilhelm Institute in Berlin (Germany) which were not published elsewhere.

Name	*Formula*	*Fatal Dose for Cats (CT)*
Chloral cyanohydrate		>3,000
Dibromobenzylcyanide		>3,000
Cyanoethylbenzol		>3,000
p-Chloromethyliso-cyanophenyl-chloride		<1,500
Chloroethylrhodanide		<1,000
Furoxandiformicacidmethylester		>3,000
Furoxandiformicacidethylester		<3,000
Furyl nitroethylene		>3,000
Dichloronitroacetonitrile		c. 2,000
Bromobenzylsulfurcyanide		c. 1,500
Methylcyanochloroacetate		c. 1,000

Mixtures of Gases in Chemical Warfare

Most of the technical products which are filled into shells are not pure chemical compounds. In addition, for tactical purposes various gases are simultaneously shot in many cases. The resulting casualties are, accordingly, combined intoxications and the effects on men which we observe in field hospitals are more complicated than can be explained in a book. These conditions were not overlooked at the proper time. A great number of animal experiments with combinations of various gases were made in 1917. Not much has been published about it. In some cases the toxic effect of a mixture is increased; in other cases it is decreased in comparison with the toxicity of the components. Chlorine and nitrous oxide,[18] sulfur dioxide and nitrosyl chloride,[18] carbon monoxide and hydrogen cyanide,[19] carbon monoxide and nitrous fumes,[20] irritant gas and hydrogen sulfide,[21] carbon monoxide and hydrogen sulfide,[21] are combinations with increased toxicity, i.e., the combined intoxications are more violent or death occurs at lower concentrations or sooner. Sometimes only half of the fatal doses of the single components is needed to obtain the fatal effect in mixtures.

It is, therefore, reasonable that the British Gas Defense takes into consideration the possibility that hydrogen sulfide may appear among the future war gases.[22] It is, however, insufficient to expect only one such gas combination.

[18] Zechinsen, Arch. ne'erl. Physiol., vol. 7, p. 146 (1922).

[19] Hofer, Arch. exp. Path. & Pharmak., vol. 111, p. 183 (1925).

[20] Wirth, Arch. exp. Path. & Pharmak., vol. 157, p. 264 (1930).

[21] Flury and Zernik, Schädliche Gase, p. 462 (1931).

[22] The British employed a mixture of 35% hydrogen sulfide and 65% chlorpicrin in shells during the First World War.

There may be many more. If I only review a few of my notes on such research, I feel safe in saying that increased toxicity and also new unexpected effects will certainly be met with in future warfare. It is certainly wrong to assume that there will be no new gases on the battlefield of the future.

CHAPTER XI:

EXPLOSIVE GASES AND FUMES

Some of the most effective war gases, such as chlorine, phosgene, hydrogen cyanide and others, are also largely used in peacetime industry. On the other hand, many industrial poisons which cannot be considered as war chemicals, because they are not specifically used for attack or defense, may occur under special circumstances during war and expose the men of the armed forces or civilians to the hazard of intoxications. For detailed information on the effects of such peacetime poisons the reader must be referred to the volume dealing with occupational diseases. However, a brief and by far not complete discussion of wartime exposures to peacetime poisons shall be given in the following paragraphs.

In 1917 a group of soldiers at the Western Front fell ill with symptoms which could not be explained by the physicians at the front. They reported that a new and mysterious gas had been used by the enemy. The investigation by toxicological experts revealed that the patients had acquired intoxications from trinitrotoluol, the well-known explosive. They had been in contact with the contents of shells which they had to handle; none of the officers were aware of the fact that all nitrated products are toxic and none of the precautions usually applied for the protection of workmen in the explosive industry had been observed. Such intoxications are rare in peacetime, especially in countries with highly developed safety regulations. The aver-

age physician has little opportunity to see such cases in his practice. No wonder, if he does not think of the right diagnosis, if the cases occur "somewhere at the front."

More frequent are exposures to the explosive gases of shells and bombs which burst in closed rooms. High concentrations of such toxic gas mixtures occur through delayed explosions in shelters, houses, naval vessels and in bomb craters, if atmospheric conditions keep the gas cloud close to the soil. In gun towers of land fortifications and naval vessels, such gases originating from the explosions of the cartridges may cause frequent and fatal intoxications, if the ventilation is insufficient and no gas masks or respirators are used.

The most toxic components of such gases are carbon monoxide, carbon dioxide and nitrous fumes.

The same gases are the components of smokes which originate from fires, caused by explosive or incendiary projectiles.

Carbon monoxide is the mother substance of a number of toxic products which contain the bivalent carbon atom; they have the general formula: $C = C\begin{matrix}/X \\ \backslash X\end{matrix}$

The halogen derivatives of acetylene are spontaneously inflammable, unstable and toxic: dibromoacetylene, $CBr_2{=}C$, is very toxic, causes violent headache and general debility.[1] Diiodoacetylene, $CI_2{=}C$, is irritating and toxic. The products are too unstable to be used in chemical warfare.

Carbon monoxide is formed from explosives in the following amounts:

[1] Lawrie, J. Am. Chem. Soc., vol. 36, p. 490 (1906).

1 kg	black powder	yields	279	liters	CO at	O°C
1 kg	nitro glycerine	"	713	"	" "	"
1 kg	picric acid	"	828	"	" "	"
1 kg	gun cotton	"	859	"	" "	"

In rapid combustion, Black powder forms about 10% CO

Powder B	forms	33%	CO
Dynamite	"	35%	"
Gun cotton	"	40%	"
Trinitrotoluol	"	55%	"

Carbon dioxide may cause headache, dizziness and other nervous symptoms, if it exceeds about 4% in atmosphere air. Such conditions occur in overcrowded and insufficiently ventilated air shelters. As a component of explosive gases, smokes and exhaust gases, carbon dioxide represents another toxic agent which acts on the organism through its suffocating power.

The nitrous fumes are mixtures of nitrogen oxides which are formed by the combustion of dynamite, nitrocellulose, other explosives, celluloid and films. Their effect on the human organism is very similar to that of phosgene. The presence of nitrous fumes in gas mixtures with carbon monoxide and dioxide forms a very serious complication insofar as the two latter gases act as asphyxiants on the oxygen metabolism, while the nitrous fumes simultaneously irritate the respiratory organs directly. The action of such gas mixtures is more complex than the action of one pure poison alone.

Fire brigades are trained to deal with such gas mixtures in peace time. This training must be extended to all people in modern war, when incendiaries form one of the most largely used weapons.

Incendiaries

The historical remarks in the first chapter made it clear that fire has always been one of the main weapons in war. Tar and pitch and oils are equal components of ancient weapons, such as the "Greek fire," and of modern incendiary bombs and flame throwers as well. Through new technical devices, through the use in artillery shells and air bombs, the effects of incendiaries are increased, yet defense against them is also correspondingly more effective.

During 1914-1918, incendiaries were rather largely used by both sides.

The most widely used American and British incendiary projectiles were known by the symbol "WP", because they contained white phosphorus as the incendiary agent. As soon as white phosphorus gets into contact with air, after and through the explosion of the shell or bomb, it begins to burn. Inflammable material is easily ignited by such bombs. Its particles may also injure men and cause very deep burns. By absorption, white phosphorus causes highly dangerous intoxications. To increase the effect of these incendiary bombs on targets that are not readily ignited, white phosphorus was combined with inflammable liquids which contributes to the spreading of the fire.

At an early period attempts were made to use a solution of phosphorus in carbon disulfide which is highly inflammable. This solution is dangerous to handle, because it is very volatile. It is also dangerous during storage. The properties of the solution could be improved by the addition of other less volatile inflammable liquids with lower flash points, such as crude benzene, fuel oil, gas tar oil, and nitrated toluenes. Through quantitative and qualitative variation of the components, mixtures of incendiaries

can be composed which are adapted to special requirements, as may occur during the war. The liquid may be combined with absorbent substances such as cotton waste to form a plastic or solid mass which can easily be handled. Solidified oil mixtures of this kind are sometimes called: "solid oils", and may be filled into shells, mortar bombs or Liven projectors.

Incendiary projectiles of this kind were well studied but were not ready for the front before the armistice of 1918.

Thermite Projectiles

Little use was made by Germany of incendiaries containing white phosphorus, because there was a shortage of this material there. Instead, the thermite incendiary bomb was developed. This type very well satisfies the tactical requirements of modern warfare:

1. The temperature of burning thermite is so high that the flames emitted by it set afire material of the lowest inflammability.

2. The time of burning is also sufficient to cause an effective fire.

3. The burning thermite cannot be quenched by water.

4. The flames are formed at the target. Even if early ignition should take place, the temperature and heat production is so tremendous that the flames cannot be extinguished by the air during the flight.

5. The alloy electron that forms the body of the projectile is melted and inflamed by the ignition of the thermite. The bomb, therefore, carries no inflammable material and is almost 100% efficient.

6. Storage and handling of thermite projectiles are without particular danger.

7. As the entire weight of the projectile serves the purpose of spreading fire, very small projectiles can be used. Thermite bombs of ½ or 1 kg weight can be carried by the hundreds and even thousands by one airplane. Thousands of fires can thus be started by a relatively small number of airplanes.

8. There is no technical difficulty to manufacture heavy thermite bombs or to use them with delayed ignition or combined with explosives.

Thermite is a mixture of aluminum powder (24%) and magnetic iron oxide (76%). If this mixture is ignited, the following reaction takes place:

$$8Al + 3\ Fe_3O_4 = 4Al_2O_3 + 9Fe,$$

which produces 758,000 calories per gram molecule and a temperature of 3,000°C.

It seemed advantageous for military use to combine thermite with some inflammable substance which spreads over the target and assures its inflammation. All kinds of inflammable materials from sulfur to celluloid, fuels, tars, etc., have been tried. The British "baby incendiaries" at the end of the first World War contained 3 parts by weight of aluminum, 6 parts barium nitrate and 8 parts hammerscale (Fe_3O_4). The materials are finely powdered and then compressed under a pressure of 12,000 pounds per square inch.

Thermite in its various and manifold modifications can be used in hand grenades, trench mortar bombs, artillery shells and in bombs dropped from aircraft.

To improve the original thermite bombs, a great number of modifications have been recommended. A French mixture under the name "Daisite" contained aluminum, magnetic iron oxide and sulfur but did not prove satisfactory. Other mixtures contain 2 parts by weight magnesium plus 17 parts barium peroxide or 1 part magnesium plus 9 parts red lead or 1 part aluminum plus 15 parts red lead or 28 parts magnesium plus 64 parts barium nitrate and 8 parts linseed oil. Other inflammable materials such as petroleum oils, products of the distillation of wood, pitch, celluloid, resins, etc., may also be combined with thermite.

Flame Projectors

The first flame projectors were used by the German army near Verdun. These weapons had a range of a few yards only and developed a tremendous wave of smoke. The attack was made by about one batallion of infantry and special engineers on a small sector of the front in the direction of Malancourt. The surprise effect of the attack was satisfactory. This attack warned the Allies; later attacks were accordingly less effective. The distrust of military circles against new technical developments deprived the Germans of the exploitation of this then new weapon; the same had been the case with respect to the first cloud gas attack at Ypres in April, 1915. The same happened on the side of the Allies, when the first tanks were used against the Germans. Then, too, the first attack was not sufficiently well prepared to exploit the surprise effect.

Before the first flame projectors were used by the special engineer troops at Malancourt, the infantry of the sector, where the attack was planned, was to become familiar with the new weapon.

Flame projectors may be classified mainly as casualty weapons. In a modern mechanized army, there are few objects that can be inflamed. Advancing German tanks equipped with flame projectors that have a range of 100 yards or more were able to silence concrete machine gun nests of the French in 1940 more successfully than by any other weapon.

The inflammable liquid is projected from the weapon by high pressure which may be produced in various ways, mostly by a compressed gas. The ignition of the liquid should take place easily and readily, yet the combustion should not take place, before the liquid has reached the target. The technical problems are similar to those discussed in connection with the inflammable liquids used in incendiary bombs. Through adequate mixtures of various products such problems can be solved easily. Compositions used in flame projectors contain crude benzene, benzene heads, water gas tar and similar oils and fuels. The resulting mixtures may have lower or higher flash points according to the range of the projector in which they are used.

Artificial fogs and smokes may be used to conceal objects in the field. Such smoke screens may be used on the battlefield or at sea for purely military purposes. They may also be applied to large parts of the country to camouflage whole towns, or to change the aspect of the countryside in order to deceive attacking airplanes, to disturb their orientation, or to prevent them from finding the objects of their attack. Insofar as the latter purpose is concerned, areas, inhabited by civil population, may be put under smoke.

It is obvious that, for this purpose, only fogs that are

not poisonous can be used. On the other hand, artificial fogs which are used for purely military actions may contain substances which are, at the same time, either toxic or able to penetrate the gas masks of the enemy.

As has been explained previously, for the latter purpose, the physical structure of the fog is important.

Artificial fogs may be formed by exploding shells or bombs, or by igniting the contents of cans containing smoke mixtures. They may also be formed from the exhaust pipes of motor cars, tanks, or airplanes.

The navies of all nations used smoke to camouflage movements and produced it by reduction of the amount of air which is normally needed for the fire under the boiler. Smokes produced from sulfuric acid and chlorsulfuric acid were used by the German Navy in 1906.

Smoke screens in fighting on land are used to camouflage infantry and tank attacks, the crossing of rivers and in conjunction with gas attacks. On April 22, 1915, the extension of the first gas attack was camouflaged by smoke clouds produced at both ends of the gas cloud.

The French added smoke-producing agents to their gas shells, especially chlorsulfonic acid, arsenic trichloride, tin tetrachloride, silicon tetrachloride and titanium tetrachloride to make the gas cloud visible. This was an advantage for the control of the artillery action, but it decreased the content of effective gas in the shells. In addition, it makes it equally easy for the attacked troops to detect the presence of gas very early. The insidious action of gases of the type of mustard gas is thus advertised to the enemy and he is warned in time to take measures for protection.

The following statement of an outstanding American expert is correct: "While the Germans took and held the initiative in the use of gas throughout the World War, the

Allies excelled the Germans in the use of smoke, both from a qualitative and quantitative standpoint." [2]

The total obscuring power (T.O.P.) of a smoke is determined by the area in square feet covered by the smoke produced by 1 pound of material, in which area the filament of a 40-watt standard lamp is obscured. Temperature, humidity and the rate at which the particles of the smoke fall downwards influence the qualities of smokes.

Smokes formed from colloidal carbon particles are produced from crude oil by its partial combustion and evaporation. This smoke is stable to humidity, not corrosive, but may contain carbon monoxide which is injurious to health under certain conditions. In all navies this form of smoke is in use. Two ounces of crude oil produce 1,000 cubic feet of standard smoke.

British S mixture in "Smoke Torch, Mark I, Type S" contained 45% potassium nitrate, 12% sulfur, 30% pitch. 9% borax, 4% glue; the smoke was brown yellow, its screening power was low and unreliable.

White phosphorus forms phosporus pentoxide and phosphoric acid in the proportions 1 :2.33.3.23 by weight. It is the most efficient smoke producer, at the same time it is an incendiary. It is, however, difficult to handle and to store. It was largely used by the Allies in 1914-1918. Germany is short of phosphorus.

The various acids of sulfur are known as smoke producers. Sulfur trioxide SO_3, oleum ($SO_3 + H_2SO_4$), chlorsulfonic acid ($HCl\ SO_3$), sulfuryl chloride (SO_2Cl_2), and sulfur trioxide-chlorsulfonic acid mixture are largely used in peacetime industry.

(SO_3+SO_3HCl), American "FS," like the other sulfur compounds, forms dispersions of fine droplets by the

[2] Prentiss, Chemicals in War, p. 224 (1937).

combination of nuclei of sulfur dioxide or trioxide with the moisture of the air. The American "FS" mixture is the standard liquid smoke agent of the United States Army and Navy. It is, however, corrosive to the metal parts of ships and airplanes.

Chlorosulfonic acid was used as a smoke producer by the Germans and the French. The latter used it in September, 1915, in smoke shells ("obus spéciaux au chlorosulfure de carbone") and later as admixture to dimethylsulfate in shells ("Rationite").

While arsenic trichloride that was used in French shells as a smoke producing agent is toxic, the following three tetrachlorides produce practically harmless smokes.

Tin tetrachloride, $SnCl_4$ (British: "KT"; French: "Opacite"), forms a dispersion of stannic hydroxide and hydrogen chloride which is not corrosive but less dense than the sulfur smoke. It was used in mixture with phosgene and chlorpicrin in French shells.

Silicon tetrachloride ($SiCl_4$)), forms a dispersion of silicon hydroxide and hydrochloric acid. In combination with vapors ammonia it forms smokes that resemble natural fog to camouflage troops or ship movements at land and at sea. Silicon tetrachloride was sometimes used also in French gas shells, to make the clouds visible.

Titanium tetrachloride ($TiCl_4$), (German. "F-stoff"; American, "FM"), forms a dispersion of titanic acid hydrate and hydrogen chloride. This smoke, too, can be made more dense by combination with ammonia vapors. It is preferably employed by airplanes which lay smoke screens. It was also used in artillery and trench mortar smoke shells.

The fine smokes were introduced into the practice of war by the French "engins fumigènes" named after the French chemist, Berger. They were used in units of 4½

kg and 40 kg and contained carbon tetrachloride (CCl_4), metal oxides and powdered aluminum. A mixture, composed from 25% zinc dust, plus 50% carbon tetrachloride, plus 20% zinc oxide, and 5% kieselguhr, reacts according to the folowing formula:

$$2\ Zn + CCl_4 = 2ZnCl_2 + C$$

Candles formed from this mixture can easily be handled and stored, the resulting smoke is not injurious to health. Ignition and burning are slow, the mixture, therefore, cannot be used in shells and bombs.

The Berger mixture was later improved by the United States Bureau of Mines; sodium chlorate was added to obtain complete combustion of the carbon.

28% 50% 22%

"HC mixture" ($Zn + C_2Cl_6 + ZnO$) is probably the most successful improvement of the Berger principle, O.12 ounces of this mixture producing 1000 cu. ft. of standard smoke.[3]

The French "Verdier engines" have a weight of 150 kg and form smokes from liquid ammonia and a fumigant. Other chemicals which form hydrogen chloride like the tetrachlorides of tin, silicon and titanium, were also used in combination with ammonia. Ammonium chloride forms white fogs which blend naturally with the horizon. Such smokes are very valuable for most military and naval purposes. It is, however, a disadvantage that more complicated engines are needed for ammonia under high pressure or in the liquified stage.

The discussion shows that there are no technical difficulties in producing smokes of manifold qualities and for all military needs.

[3] U. S. War Department, Chemical Warfare Service Field Manual, vol. I, Tactics and Technique, Washington (1938).

Usually smoke screens are formed by the candles or engines. Artillery may produce and maintain smoke screens and smoke barrages or rolling smoke barrages for protracted periods. Trench mortars may also be used for this purpose within the limits of their firing range.

It may be interesting to mention that toward the end of the year 1917 Germany suffered heavily from the Allied tanks. As the German industrial capacity was entirely filled by orders for construction and repair of submarines, it was then impossible for Germany to build tanks for defense. To facilitate the control of artillery fire against the Allied tanks, experiments were made to add smoke in different colors to the charge of 77 mm anti-tank (field) gunshells. The results of these experiments were not very satisfactory and of little practical value. No doubt, the problem could be solved. It may certainly be useful, if on the battlefield each battery could distinguish and exactly control the location of its own shells in regard to the target.

Artificial smokes may be useful for many technical purposes. However, the economic problems involved must also be considered. It has been calculated that a smoke covering the city of Berlin (Germany) for from two to three hours would require about 120 to 180 metric tons of smoke producing chemicals.[4] If such a tremendous quantity of chemical products is used for aggresive tactics, instead, it would be of incomparably greater military value.

Chemical Warfare and the Navy

Chemical warfare is subjected to special considerations insofar as the Navy is concerned. The climatic conditions at sea are very unfavorable for the application of gas shells.

[4] Militaerisches Wochenblatt, No. 40, April 25, 1925.

On the other hand, warships of all kinds offer very special conditions in case the gassing succeeds.

The gas cloud is formed from the exploding shell in a closed room and thus kept concentrated for a long time. Furthermore, the gas may penetrate through the ventilation ducts and thus reach important positions far distant from the place where it exploded. The same may happen, not only with specific gas ammunition, but also with explosive shells. When such explosions take place inside the ship there is not sufficient oxygen present. The explosive gases, therefore, do not only contain nitrous oxide, which may act as an irritant, but also much higher amounts of carbon monoxide than when the explosion takes place in the open air. The concentrations of carbon monoxide, thus produced, are sufficiently high to cause deadly intoxications, even at far distant places. Ordinary gas masks do not protect against carbon monoxide. For use in the Navy, special provisions are to be made for this purpose.

There are, again, different conditions to be considered in submarines. A lack of oxygen may occur, when the boat is under water for a protracted period. More injurious than a lack of oxygen, however, is the increase of carbon dioxide that occurs under the same conditions. While normally, under industrial conditions, the content of carbon dioxide in the air should not go above 0.07%, the crews of submarines should be trained to sustain contents up to 2% carbon dioxide for several hours. If the content of carbon dioxide is increased above this level, injuries to the crew may occur, if the special ventilation appliances are not put into effect.

Other dangers from gases occurring in submarines originate from the storage batteries. Sulfuric acid spray may be

developed and escape into the air to such a degree that serious irritation takes place. At the same time, hydrogen is developed. This, in itself, would not produce poisonous conditions, but there is danger of explosion which must be taken into consideration. The content of hydrogen in the air of submarines, therefore, must be controlled. Insofar as it exceeds 2%, it must be burned in special lamps equipped with catalysts. A content of 4% hydrogen in the air is inflammable; higher percentages are explosive. Under special conditions, if sea water enters, perchance, the storage batteries, chlorine may be developed by electrolysis. If metals, containing arsenic, are used in the accumulators, arseniuretted hydrogen may develop, thus putting the crew into serious danger.

In the American Navy special reagent papers with mercury chloride or bromide are used to test the content of arseniuretted hydrogen in the air of submarines. It is destroyed by the same lamps with catalysts as is hydrogen.

Other dangers occur from the motor gases in submarines, and from fires, which frequently occur as the result of a short circuit. If rubber and other insulation materials are ignited, carbon monoxide may be formed. Improper handling of the motors, when the hatch is closed, may cause an excessive use of oxygen, leading to suffocation.

Problems of these various kinds, which occur in submarines, may very frequently occur under industrial conditions in peace time. The doctor should be familiar with them. He should be aware of the alterations of the atmosphere which may occur under irregular conditions, in order to understand and explain the various, and sometimes surprising casualties.

The above only represents a very short enumeration of the most frequent occurrences of gas dangers in the Navy.

CHAPTER XII:

TREATMENT AND PROTECTION AGAINST GAS POISONING

Typical Clinical Pictures

More than 300 different poisons had been studied in experiment on several thousand animals, monkeys, dogs, cats, rabbits and pigs, not counting experiments on rats, mice, frogs, fishes and the like, before May 1, 1917. Many thousands of human cases of gas poisoning on the battlefields and in the manufacturing industries had occurred during the same period. It was the greatest toxicological experiment in the history of mankind and medical science.

Based on this tremendous material I was able to establish some of the fundamental facts and experiences in a report on the observations concerning the pathology of war gas poisoning, submitted to the Medical Section of the German War Ministry (June 1, 1917).[1]

In spite of the great chemical and physical differences between so many various poisons, certain clinical symptoms and pathological findings occurred so regularly that it was possible to establish a small number of *typical clinical pictures* which always reappear in individual cases of gas poisoning, whatever may be the single agent or the mixture of gases that cause the individual intoxication.

[1] **Some parts of this report were published by Wachtel, Zeitschr., exp. Path. & Therap., vol. 21, p. 8 (1920), other parts appeared in various papers by Flury, Zeitschr., exp. Med., vol. 13 (1921), and elsewhere.**

This fact is of great practical importance, because the medical treatment of gas poisoning can be understood and organized along general principles. It is not necessary to apply special procedure of medical treatment for every specific intoxication, except for a few specific symptoms.

The training of physicians for gas service and the training of first aid squads are equally more simple than if very special measures of treatment would be required for every special war poison. In addition, on the battlefield it is usually impossible to know, at all times, which specific gas or mixtures of gases caused an individual casualty.

It is, therefore, a highly fortunate circumstance that the knowledge of only a few clinical types of gas poisoning is required in order to found medical treatment, first aid and protection against war gases on a reasonable understanding of relatively few and simple scientific facts.

It seems that the human organs answer to a very great number of different and manifold irritations with only a very small number of biological reactions which are generally the same or very similar. We know that similar conditions prevail in infectious diseases, where different specific toxins may produce a great number of clinical appearances which are more or less common to all infections.

We know that arsenic compounds may produce a great variety of clinical pictures in occupational intoxications: acute, subacute, chronic diseases with either respiratory or digestive or nervous disturbances or any combination of various of these symptoms in addition to dermatosis and allergic reactions. The same chemical compounds produce far more uniform clinical pictures, when they are used as war gases, because:

(1) The concentrations to which troops attacked by gas are exposed vary within relatively narrow limits; minimum

concentrations of O, 5—1, 0 mg per m^3 are encountered in contaminated areas. In cloud gas attacks the maximum concentrations occurring on the battlefield may be from 100 to 200 mg per m^3. The same concentrations may occur in gas clouds resulting from bursting gas shells. Heavy trench mortar bombs or Livens projectors may produce higher concentrations for very limited lengths of time.

(2) The time of exposure to gases on the battlefield is relatively short in comparison with industrial exposures. If gas clouds are maintained for protracted periods of time by continuous bombardments, the troops thus exposed are relieved at regular intervals, hardly ever extending over more than several days.

(3) The troops on the battlefield are alert to the gas danger at all times and are usually warned to use gas masks immediately, when the danger occurs. Many intoxications occurring in industry are due to negligence rather than to unavoidable conditions. Military discipline in the field makes the protection in the field more effective, even if the same gas masks are used on both the battlefield as in industry.

(4) In war the men exposed to the gas are selected for their physical fitness, they are in perfect health and represent more or less exclusively a limited age group. The men between 21 and 35 years of age possess a higher resistance than the younger and older parts of the population.

When gas is used against civil populations, the clinical pictures may become more complicated on account of the co-incidence of gas poisoning with other diseases. The disabilities of old age, its lowered resistance, like that of babies, children and adolescents, pregnant women, tuberculous infections and circulatory diseases of individuals would nat-

urally change the uniformity of the clinical pictures with which we mainly meet in military conditions.

Other factors which contribute to the relative uniformity of war gas intoxications may be found in the biochemical field.

The toxic mechanism which causes the effect on men is the same for many different chemical compounds.

(5) A great number of war gases dissociate acid groups, when in contact with the liquids of the human organism. All irritant effects of war poisons can be explained in this way, what the dissociated acids may be (HCl, HBr, HI, H_2SO_3, H_2SO_4, H_2S, H_3AsO_3 or $HAsO_2$ and others, always "in statu nascendi").

(6) Practically all war gases paralyze the enzymes, especially the action of the oxidative enzymes which are essential for the normal function of respiration. The paralyzing effect of mustard gas on enzymes was first discovered[2] and later it was found that arsenic compounds and other gases act in the same way. For the systemic poisons, especially hydrogen cyanide, this kind of action was known before the beginning of chemical warfare.

(7) War gases which are highly effective are also soluble in lipoid substances.

(8) The three factors mentioned above, acid action, paralytic effect on enzymes and solubility in lipoids are equally contributory to the injurious action of war gases on the blood and on the epithelium of the skin, of the cornea and of all mucous membranes or of the capillary vessels in general.

[2] Wachtel, Zeitschr.. exp. Path. & Therap., vol. 21, p. 1 (1921).

(9) The destruction of the epithelium of the alveolar walls in the lungs, the destruction or alterations of the walls of the capillary blood vessels and the paralysis of the respiratory enzymes are various factors which either each by itself or two or more of them combined cause anoxemia through lack of oxygen within the blood and in the tissues of the organs. The internal respiration of the organs, the entire oxygen metabolism is thus seriously impaired. Anoxemia is the most outstanding symptom of all war gas poisonings, it develops, as well, after chlorine, phosgene, chlorpicrin and other irritant and vesicant gases, dimethylsulfate, mustard gas, Lewisite, etc., as after the systemic poisons, hydrogen cyanide, carbon monoxide and others. The physiology of anoxemia has been thoroughly studied since the first World War.

The typical clinical pictures which chiefly occur in gas poisoning are the following:

1. The *phosgene type* is a gradually developing disease of the lungs, during which a plasma-like liquid originating from the blood penetrates into the alveolar spaces of the lungs. The liquid decreases the respiratory surface in the lungs and causes mechanical asphyxiation. The patient is drowned from within.

2. The *pseudo-diphtheric type* is characterized by the formation of pseudo-membranes in pharynx, larynx, trachea and broncho. The resulting clinical picture somewhat resembles that of diphtheria (there are, of course, no diphtheria bacteria and toxins, nor increased temperature). The pseudo-membranes are formed by the destruction, necrosis and desquamation of the superficial layers of epithelium of the organs mentioned. These membranes may grow so thick

that they fill the entire lumen of the respiratory passages. In some autopsies, it was hardly possible for a knitting-needle to pass through the trachea. The lung tissue is not affected in cases of this type. Death is caused through mechanical asphyxiation.

3. *Circulatory failure* is the characteristic symptom of the third type. There is no affection of the respiratory organs involved. It may be assumed that very low concentrations of the more insidious war gases pass through the lungs without causing local alterations. Only after absorption of the gas changes occur in various organs; a general affection of the organ tissues, and, most probably, specific injuries to the wall of the capillary vessels are the main causes of this type of disease. Clinically, heart disturbances predominate. In autopsies the heart muscle is degenerated, cloudy swelling of the heart muscle fiber and punctiform hemorrhages may frequently be found in the myocardium and under the epi- and endocardium. Such cases were first observed in 1916 and 1917 in the chemical factories in Hoechst (Germany), where several chemists suffered from cardiac symptoms without disturbances of the respiratory organs after exposure to phenylcarbylaminechloride. A similar case occurred on October 19, 1916, in my laboratory through diphosgene which caused sudden fainting and heart failure of the injured soldier; there was no edema of the lungs. More than one year later French authors emphasized the importance of this type of disease on the basis of observations at the fronts. Not much attention is paid to this type of war poisoning in the German, British and American literature. The reason for this neglect of a very frequent and very important form of disease is not quite understandable.

4. *Toxic cachexia,* general debility, may result from the

same kind of toxic mechanism as described for circulatory failure. There is the difference that the poison after absorption exerts a still slower action on various organs so that no acute symptoms appear. It is evident that this form of disease preferably occurs after protracted absorption of very low concentrations which is rather infrequent in chemical warfare in the field, but may occur in the manufacture of war chemicals.

5. *Systemic poisonings* through hydrogen cyanide, paralysis of the respiratory center of the nervous system and of the respiratory enzymes and carbon monoxide poisoning through impairment of the respiratory function of the hemoglobin are of great military importance. The physiological mechanism of these intoxications is discussed elsewhere.

6. *Mixed or transition types* are more frequent than the typical cases. In one patient symptoms belonging to two or several of the afore described typical clinical pictures may be combined. In mixed types, edema of the lungs, if present, is never so extremely developed or predominant as in typical phosgene poisoning. Most frequent are clinical pictures combining symptoms of the first four types. The more the symptoms of the fourth type prevail in a case, the more protracted and insidious is the course of the disease. Mixed types with predominant symptoms of absorptive injury to the organ tissues in general cause *disabilities of longer duration,* as occur after mustard gas. Predisposition to secondary infection is frequent in these cases.

As these types of disease occurred not only after gases that were used on the battlefields of the past but also in experiments with several hundred other poisons, one may assume that most of the new war gases of the future may be covered by this presentation. One should not forget,

however, that poisons of very different character may possibly be used in the future. The types of gas poisoning cover only those groups of war gases which are expected to reappear or to appear in modified forms in future warfare. This assumption would be correct if we accept that the Chemical Warfare Field Manual of the United States War Department, edition of 1938, and similar publications of other nations, cover the future developments of gas warfare. It would be safer to be prepared, both scientifically and practically in the military field, for surprising events in the very near future.

General Treatment and First Aid

The principles of medical treatment of gas poisoning will be easily understood if we remember the principle factors of the toxic mechanism, as explained before. The medical aid based on such understanding should always be logical according to knowledge of the scientific facts combined with common sense.

For the sake of chemists and physicians it must be said that no specific antidote nor specific treatment exists. The poisons act too quickly and intensely with the liquids and tissues of the organism so that the application of a chemical antidote, for example of an alkaline product, in order to neutralize an acid poison, like phosgene, after inhalation, always comes too late to be of any real use.

To neutralize poisons which are in contact with the human skin is, however, possible if it is done within the shortest possible time. If applied later than three minutes after the contact takes place, any neutralizing measure would be practically useless. Only if the contamination is very heavy, it may be tried later in order to remove that part of mustard gas, Lewisite or other persistent products which are not yet

absorbed. This late application will certainly diminish the effect but not neutralize that part of poison that is already absorbed.

Every general or special treatment of gas poisoning is symptomatic, i.e. it aims at the improvement of or recovery from single symptoms. No specific elimination or neutralization of the causative agent itself is possible.

Chemically speaking, all war gas poisonings are irreversible biological reactions with the only exception of hydrogen cyanide and carbon monoxide and dioxide poisoning. If in these intoxications a very effective ventilation of the lungs is applied in time by artificial respiration, oxygen inhalation and chemical irritation (through lobeline or CO_2) of the nervous centers that regulate the respiration, we may be able to reverse the reaction and remove parts of the inhaled poisons before they act injuriously on organs causing irreversible alterations.

The reader will now understand the following recommendations for the first aid treatment of injuries by chemical agents:

(1) Remove the patient from the contaminated atmosphere.

(2) Loosen clothing and put patient at rest in a reclining or semi-reclining position.

(3) Remove contaminated clothing and equipment.

(4) Apply warmth to the body.

(5) Neutralize that part of the chemical which is not yet in irreversible combination with the organs of the body.

(6) Keep the patient absolutely quiet. Do not permit him to talk unnecessarily or to move. The object is to conserve his strength and to minimize the amount of oxygen which the body requires.

(7) Remove the patient to a hospital by litter or by

ambulance. No transportation is allowed during the "gray-stage asphyxia" in cases of the "phosgene type."

(8) Oxygen should be given from the beginning, even while the symptoms of asphyxia and anoxemia are absent or not grave. Oxygen is never injurious. Omission of oxygen treatment in due time may be fatal.

Oxygen should be given, before a patient is transported, and should be available during transport.

If there is a shortage of oxygen, continuous inhalation may be replaced by periodical application, according to the seriousness of the case. In slight cases, 5 minutes oxygen inhalation per hour may be sufficient.

As an average a patient suffering from phosgene poisoning needs 300 liters oxygen per hour. Other war gases require lesser amounts of oxygen.

(9) Artificial respiration is strictly prohibited in intoxications caused through irritant gases.

Artificial respiration is to be applied in intoxications caused through hydrogen cyanide, other cyan derivatives, carbon monoxide, carbon dioxide, asphyxiant gases like methane, sewer gas, exhaust gases, but only if it is certain that these gases were not combined with irritant gases. In the field, it is always safe to apply oxygen, if there is any doubt as to the nature of the toxic agent.

(10) The gassed patient should keep his gas mask on as long as he is in areas contaminated by gas, as long as his clothing is not removed or decontaminated and during transport through gassed or contaminated areas.

If no gas mask for the patient is available, his head should be wrapped in cloths moistened with alkaline solutions.

(11) Injuries to the eyes caused through gas or droplets of chemical should immediately be treated with thorough

washing with 3% boric acid solution. If nothing else is available boiled water containing a teaspoonful of salt per pint may be applied. After washing purest white vaseline containing 1—2% sodium carbonate may be used. The eyes should be slightly covered for protection against light. Atropin or anesthetics may be given by the physician only.

(12) Injuries to the skin through mustard gas, Lewisite and other vesicants can be prevented, if the contaminated area of the skin is immediately and thoroughly treated with chloride of lime, sodium hypochlorite solution or chloramine. Kerosene, gasoline, which must not contain lead tetraethyl, soap solutions in alcohol or water are less reliable for prevention. If injuries develop, dressing with boric acid, mild unguents and anesthetics may be used.

Individual Protection

For their own protection the first aid and the medical personnel must be well trained in the use of the equipment for protection against the war gases. The measures and equipment needed for this purpose are the same as those used for the protection of the fighting troops and of the civil population.

In this chapter only the most indispensable information shall be mentioned briefly. More detailed advice on special problems and on the planning and organization of first aid and medical aid in mass poisoning will be found in the volume on civil air defense.

For protection against gases the following regulations should be carefully obeyed:

1. No single person, even if correctly equipped with protective apparatus, should enter a gassed area. Two persons forming a first aid squad should never lose sight of one another while in contaminated areas. They must be prepared and trained to communicate with one another by

signals. They should be equipped with belts and cords, when they enter closed rooms, shelters or difficult terrain.

2. The protection equipment, gas mask, gloves, goggles, protective clothing, respirators, should be carefully examined and tested, before the squad enters the gassed area. The selection of the most adequate protective means must be correct.

3. Military gas masks provide safe protection against all war gases, "such as lachrymatory gases, phosgene, chlorpicrin, chloracetophenone, chlorine, mustard gas, diphenylchlorarsine (DA) and diphenlyaminechlorarsine (DM)." The canister should always contain a special cellulose filter to protect against toxic smokes and dusts. Special canisters are needed for carbon monoxide, hydrogen cyanide and cyan derivatives.

4. If there is any doubt, whether respirable air will be available in a gassed room, shelter or the like, no canister-type gas mask should be employed. Also if the concentration of gas is extremely high, only a self-contained oxygen breathing apparatus should be used.

5. As protection against persistent vesicant gases like mustard gas and Lewisite, protective clothing is necessary. Mustard gas penetrates even protective clothing material such as rubber, only not so quickly. The stay in these clothings and in the contaminated area or rooms should therefore be as short as possible.

6. As soon as possible the protective equipment must be removed, all precautions must be observed that the contaminated outer surface does not contaminate any object or person. Decontamination of the clothing and gas masks must take place without delay.

7. After that, careful and thorough decontamination of the entire body of the personnel should follow. Thorough washing under a warm shower with soap, followed by a water shower. The special regulations concerning decontamination for specific gases are to be applied reasonably and conscientiously.

The Gas Mask

The gas mask is composed of the following parts;

The *face piece* is a flat rubber surface in contact with the face. It is kept in place by elastic, adjustable headbands. Persons with perforations of the tympanic membrane need face pieces which cover the ears or separate protection for the ears. Otherwise they would inhale gas via the middle ear and Eustachian tube.

The *eye lenses* should be made of strong shatter-proof safety material in fog proof construction or with some kind of a fog preventing device.

The *exhalation valve* through which the exhaled air escapes should be protected against deformation, should function in all postures which the carrier of the mask may be forced to undergo. The valve must not become corroded. In cold weather no ice which would disturb the regular function of the valve should be formed by freezing of the moisture that is contained in the exhaled air.

The *tube* through which the mask communicates with the canister should be non-collapsible and should permit free movements of the head in all directions without harassing other activities.

The *canister* is held in position by a carrier with easily adjustable harness. The canister contains charcoal and other

chemical agents which filter out or neutralize such amounts of various gases as may occur on the battlefield.

Special canisters are needed for protection against hydrogen cyanide, cyan derivatives and carbon monoxide. Canisters must carry labels which plainly indicate the names and amounts of gases against which they provide protection.

THE SELF CONTAINED OXYGEN BREATHING APPARATUS may be used in combination with the face piece of the gas mask. This apparatus provides oxygen for respiration from a steel cylinder. The oxygen in the steel cylinder is under high pressure and sufficient for one half hour, one hour or two hours in cylinders of different sizes. Through a reducing valve the oxygen is reduced to about atmospheric pressure before it is inhaled. The exhaled air passes through a regenerator which removes carbon dioxide and returns the purified air into a rubber breathing bag; then through the automatic action of the admission valve enough fresh oxygen is added from the steel cylinder in order to keep the air in the bag at a content of not less than 21% oxygen.

The self contained oxygen breathing apparatus provides complete protection in oxygen-deficient atmospheres or in any dangerous concentrations of gases against which the canister gas mask would be insufficient.

CONCLUSIONS

If we can believe the publications of the War Departments in various countries, the principles of chemical warfare are still the same as they were in 1918. There are still the cloud gas attacks from steel cylinders, the trench mortar bombs or Liven's projectors, the artillery shells and airplane bombs and sprays.

The United States Chemical Warfare Service Field Manual of 1938 contains the following list of chemical weapons:

The portable chemical cylinder contains about 32 pounds of phosgene.

The Liven's projector has a range of 1450 yards. They are usually installed in batteries of 25 and fired electrically. Each shell carries 28 pounds of phosgene or other non-persistent agents. 800 Liven's projectors carry a charge of 11 tons of gas covering from 50 to 100 squares with effective gas concentrations.

The 4.2 inch chemical mortar has a range from 600 to 2400 yards. It may fire from 5 to 20 rounds per minute. Its shells weigh about 25 pounds each, carrying 6 pounds of chemical agent. A chemical company of eight mortars, firing at the maximum rate can place nearly a ton of chemical agent on its target in a period of 2 minutes.

Field artillery uses gas and smoke shells. Each 75 mm shell for guns and howitzers contains 1.3 to 1.8 pounds of persistent agents or smoke and covers about 15 yards in diameter.

A land mine (1 gallon can) contains 8.5 lb. mustard gas, covers about 20 yards, when exploded in place.

United States airplanes carry electrically controlled tanks for spraying chemicals; each tank has a capacity of 22 gallons. The action of spraying is best carried out at altitudes from 50 to 150 feet; one tank covers a belt of about 500 yards long and 100 to 150 yards wide. Each plane carries two tanks.

The 30 pound chemical bomb (MI), carries about 9 pounds of agent and covers about 40 yards in diameter.

Gas hand grenades contain 2.9 to 4 oz. of various irritants.

Smoke hand grenades contain 20.6 oz. HC and burn for 3 minutes.

The chemical agents which are listed in the United States Field Manual were all known in 1918 and are classified according to the following table which contains the United States Chemical Warfare symbols and a few more data.

CHEMICAL AGENTS

	CWS Symbol	Persistency Summer	Persistency Winter	Tactical Classification	First Aid
a. Vesicants					
(1) Mustard	HS	3-4 days in open 1 week in woods	several weeks	casualty agent	Wash with kerosene or gasoline then with strong soap and hot water, rub dry, rinse with hot clean water. Act within 3 minutes.
(2) Lewisite	MI	24 hours in open 2-3 days in woods	1 week or more	casualty agent	Wash with oil, hot water and soap. Dry. Act at once.
(3) Ethyldichlorarsine	ED	1-2 hours in open 2-6 hours in woods	2-4 hours in open 12 hours in woods	casualty and harassing agent	Wash with warm sodium carbonate solution.
b. Lung Irritants					
(4) Phosgene	CG	5-10 minutes	5 to 10 minutes	Casualty agent	Keep patient quiet, administer heart stimulants; give oxygen in severe cases. Treat like pleurisy.
(5) Chlorine	Cl	5-20 minutes		Casualty agent	Keep patient quiet, warm and treat for bronchial pneumonia.
(6) Chlorpicrin	PS	1 hour in open 4 hours in woods	12 hours in open 1 week in woods	Harassing and casualty agent	Wash eys with boric acid. Keep patient warm and protect throat from infection.

c. Irritants					
(7) Adamisite.....	DM	5 minutes in open from candles		Harassing agent	Breathe low concentration of chlorine from bleaching powder bottle.
(8) Diphenylchlorarsine.....	DA	5-10 minutes		Harassing agent	The same as above.
(9) Chloracetophenone.....	CN	Solid. Several days to weeks; burning mixture: 5-10 minutes		Harassing agent	Wash eyes with boric acid. Wash skin with warm sodium carbonate solution.
(10) Chloracetophenone solution.....	CNS	1 hour in open. 2 in woods	6 hours in open 1 week in woods	Harassing agent	Same as above.
(11) Brombenzyl-cyanide.....	CA	Several days	Several weeks	Harassing agent	Wash eyes with boric acid.
d. Smokes					
(12) White Phosphorus.....	WP	10 minutes or less		Screening agent	Apply 2-5% Copper sulfate solution. Pull out solid particles and treat like ordinary burn. Keep burns part under water if no $CuSo_4$ is available
(13) Hexachlorethane.....	HC	While burning		Screening agent	None needed.
(14) Sulfur trioxide solution...	FS	While operating		Screening agent	Like an acid burn.
(15) Titanium tetrachloride...	FM	10 minutes		Screening agent	Wash with sodium bicarbonate solution, then with warm water and treat like an ordinary burn.

This is the information on which the training of the United States Army is based. It is correct to assume that this training is about identical with that of European Armies. It is adequate to prepare the American troops for gas attacks which were usually made in 1918. The training is planned along general lines, which is a good principle.

There is, however, no anticipation of possible new developments. Sartori[3] has composed a list of war gases which were prepared or studied at the end of the war or immediately after the war.

	Chemical Warfare Symbols of the		
	American	English	French
Nitrobenzylbromide			
Bromobenzylcyanide	CA		Carnite
Chloroacetophenone	CN		
Bromoacetophenone			
Bromopicrin			
Tetrachlorodinitroethane			
Dibromoethylsulfide			Bromlost
Diiodoethylsulfide			
Chlorovinyldichloroarsine	MI	Lewisite	
Dichlorovinylchloroarsine			
Bromovinyldibromoarsine			
Chlorostyryldichloroarsine			
Diphenylbromoarsine			
Phenarsazinechloride	DM	Adamsite	
Phenarsazinebromide			
Phenarsazinecyanide			

This list contains only 16 compounds. Many more products are mentioned in this book. In addition, during the more than twenty years between the two World Wars hundreds of chemists in the countries of the European conti-

[3] Sartori, The War Gases, p. 340 (1939).

nent have synthetized and studied new compounds to be used for chemical warfare. It is certain that new gases will be used later during the war. It is not certain that the new gases will be of the same types as were the gases that are known. Everybody understands that the newest achievements in gas warfare are not made public. The people of each country wish to believe that their own chemical warfare service possess the most effective gas.

On both sides the distrust of the professional soldier against new technical development has spoiled the effects of new weapons during the war of 1914-1918. This fact proves that distrust against the scientist is not confined to one nation, but rather a characteristic quality of professional officers of all armies and navies. Undoubtedly, the technical training of these men has increased and improved between the two World Wars in all countries, but not everywhere to the same extent.

It should be a rule that no officer who has not a thorough training in engineering and chemistry should be admitted to responsible positions in the higher staffs of army, navy or air force.

Planning of chemical production should take place in view of the future requirements and developments of chemical warfare. Such planning must be made in close connection with the strategical intentions of the general staff. It may be easier for European countries to plan for the campaign of the next year than for the United States. Even though no expeditionary force be ever sent to Europe or Asia, nevertheless plans could be made, conditionally. Different gases would be needed for either Europe or Asia, also different kinds of gas ammunition. Wars cannot be improvised, but are planned for years in advance. The date when a future

war shall begin must be at least approximately fixed several years in advance by the aggressor, and must be foreseen as correctly as possible by the nation that will be attacked. The nerves of the people are usually protected against the strain that would result from such knowledge. But the governments must be prepared. When I arrived in Moscow in 1935, to advise that government of problems of civil air defense, I was clearly informed that war was not expected before 1938, and plans for civil air defense should be made accordingly. The results of Britain's and France's lack of preparedness were Munich, 1938, and the second World War one year later. Only preparedness can prevent war. There are no Munichs for governments that are alert.

New developments in the field of chemical warfare must be studied by a special research institute. The chemical warfare service of the army is fully occupied with the training and military preparations in practice. Research of new developments should be separated from the routine work. The special duties and tasks of the research institute are largely discussed in chapter

Future Developments of Chemical Warfare

The manifold efforts of the War Departments and war industries of the different countries aim at making chemical warfare still more effective than it has been in the past. As not only the general press, but also scientific articles report, from time to time, the fantastic discoveries in this field, it might be useful to outline the possibilities that can be expected in order to give a more realistic view of the toxicological developments of the future.

1: *Offensive gases*

Offensive gases may be developed in the future along different lines:

a: Compounds, or other means, may be found, the fatal doses of which are lower than those of the most effective poisons already known. The probability of success in this direction is not extremely high in so far as the fatal dose of the most effective gases is already so low, that a diminution of it would not alter the magnitude.

b: It may be conceivable that the fatal effect of new poisons, still unknown, in a dose of the same magnitude, as mentioned before, might be achieved within a shorter time or even momentaneously.

c: The dose which causes disease may also be diminished by further progress, or new products may be developed which cause disease, or militarily speaking, fighting inefficiency, more promptly than the gases now known. A suggestion, unpublished up to now, concerns the development of products like atropin or eserin, in order to contract or enlarge the pupils of the eyes of the enemy, thus causing fighting inefficiency by disturbance of the sight. This has not yet been put into practice. It is very easy to see that such developments may further complicate the toxic effects in future warfare. As it is impossible to foresee every possible development, this one example may suffice.

d: As a future war will be a total war, it will be of extreme importance, not only to attain momentary

fighting inefficiency of the soldiers, but also prolonged, chronic disease, in order to put out of service as large a number of soldiers as possible for as long a time as possible. In this respect, one may refer to poisons causing chronic intoxications to a far larger extent than was the case during the World War. Far-reaching results may be expected in this direction. The use of compounds like mustard gas and arsines represents only a beginning.

2: *Mask Penetration*

The most essential progress in the future of chemical gas warfare that may be expected is the development of mask penetration compositions. The principle in question is discussed above. If results are achieved, this would hardly concern the toxicological aspect of the disease provoked, but rather the number of casualties which may occur.

3: *Effects of chemical warfare on animals and plants*

More emphasis may be laid in a future war on the destruction of animals and edible plants. This may lead to the diminution of the food supply in such countries where importation of food, during the war, is not feasible. In so far as intoxications of cattle and other animals are concerned, the principles to be applied are the same as mentioned above. The problems arising from such a development of future warfare are of an economic character. Problems of food hygiene, decontamination of poisoned foods, arising in this field, would belong to the domain of the physician. Similar problems are already familiar to the physician in the field of fumigation of steamers, mills, etc., for the purpose of extermination of insects. The problems, of course, would be more complicated.

4: *Bacteriological warfare*

Infections, artificially provoked, and occurring in a future war among the soldiers or the civil population would place a tremendous burden upon the medical service. It can only be mentioned here that this aim would be attained by the spreading of germs or toxins inside the country. The principal possibilities are:

a: Infection of the water supply.

b: Infection of animals, rats, mice, insects may prove useful in the spreading of contamination and in the direct infection of cattle and horses. This would, indirectly, also affect the food supply, especially the milk supply.

c: Infections may also be used to diminish the harvest and destroy the edible agricultural products by spreading parasitic plants and insects all over the country by means of sabotage or special mechanical means, such as special bombs hurled from airplanes, or sent with the wind, or by automatic means.

5: *Defensive gases*

It seems that the greatest development may be expected in the field of defensive gases which exercise a long lasting after-effect in the field. The prototype of these gases is mustard gas, which does not only act if inhaled, but also acts directly on the skin. It is, therefore, the most effective of the defensive gases. The quantitative toxicity of this product can hardly be expected to be surpassed. It might be possible to find products with a still more prolonged after-effect. It may be mentioned that the gases in this group

which are defensive gases only on the battlefield, are very suitable for attack on the civil population because they permit the making of an area uninhabitable for a long period of time, provided that no decontamination takes place.

This outline may prove that toxicological dangers in a future war will be of the same nature as is already known, or may introduce new effects. Continued systematic production and storage of enormous quantities of poisons for a future war may, however, concern the attacked people because of an enormous mass poisoning of the civil populace. What can be done against such a danger lies in the field of organized defense and protection and is discussed in the volume on civil air defense.

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