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**GAS MASKS FOR GASES MET IN
FIGHTING FIRES**

BY

ARNO C. FIELDNER, SIDNEY H. KATZ
and SELWYNE P. KINNEY



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GAS MASKS FOR GASES MET IN FIGHTING FIRES.

By ARNO C. FIELDNER, SIDNEY H. KATZ, and SELWYNE P. KINNEY.

INTRODUCTION.

The Bureau of Mines has tested and used many types of self-contained oxygen breathing apparatus in fighting mine fires and in rescuing miners trapped in poisonous gases resulting from fires or from explosions in mines. Similar devices have been used by city fire fighters but have never been considered entirely satisfactory owing, largely, to their weight, to the time necessary for adjusting them to wearers, and the constant care required to maintain the apparatus in good working condition. Hence there has long been need for a light, easily adjusted, and dependable breathing apparatus for protecting fire fighters from irritating and poisonous gases and smokes.

As a result of the war the gas mask, which uses a chemical filter for removing poisonous gases and fumes from air, has been developed to a high state of perfection. The mask used by the United States Army is capable of giving complete protection against all the deadly gases that have been met on the battle field, but it does not protect against all the gases or atmospheres encountered in mines and in the industries and in fire fighting.

The dangers from gases that city firemen face and the need of standardized methods of protection against them have been pointed out by Chief John Kenlon,¹ of the fire department of New York City, who also mentioned the knowledge firemen should have of gases. The need of such knowledge has been especially emphasized by over-confidence in the capacity of the Army type of gas mask to protect the wearer against industrial gases, an assurance that has probably arisen because soldiers were taught that the United States Army gas mask would protect them against all the gases they might encounter. This statement, true for the battle field but not true for all industrial gases, including products of combustion, has been brought back by soldiers and spread generally among workers. Furthermore, city firemen and mine operators have been circularized with letters and advertisements of Army gas masks offered for sale by certain persons

¹ Proceedings of International Association of Fire Engineers, Fire and Water Eng., vol. 66, July 30, 1919, p. 239.

who made unreserved statements, probably through ignorance, that the masks would protect wearers in mines and burning buildings. The falsity of these statements was evident to the Bureau of Mines, which took steps immediately to notify the public that Army gas masks had serious limitations, especially when used in fire fighting or in any place where unusually heavy amounts of poisonous gas are present. This warning has been verified by the actual experiences of some city firemen who have tried Army masks. On the other hand the excellent qualities of the masks have also been demonstrated at fires.

The work described in this paper was undertaken to obtain information regarding the use of the Army type of mask for fighting fires and for doing rescue work in mines and the mineral industries. Incidentally, the results may be of interest to city firemen, insurance underwriters, state officials, property owners, and others who are interested in protection of property from fire.

There have also been included herein descriptions of breathing apparatus other than gas masks, descriptions of most of the gases met in the industries, of their physiological effects when inhaled, and of methods of treating persons who have been gassed.

ACKNOWLEDGMENTS.

The authors wish to express their grateful appreciation of the many suggestions and valuable criticisms received from George S. Rice, chief mining engineer of the Bureau of Mines, who suggested an investigation of the application of Army gas masks to industrial uses, and from E. A. Holbrook, assistant director of the Bureau of Mines, whose aid and encouragement were never lacking. Acknowledgment is also made to Yandell Henderson, O. P. Hood, D. J. Parker, and J. W. Paul for criticisms and suggestions which were incorporated.

EXPERIENCES OF FIRE FIGHTERS WHERE MASKS WERE INADEQUATE.

New York City, pier fire.—Two men wearing Army masks were overcome while putting out a fire on a pier where sulphur was burning.

Chicago, rag-shop fire.—One fireman while wearing an Army gas mask was overcome by products of combustion at a fire in a rag shop. He had been in the shop about 30 minutes and his condition was such that he was sent to the hospital.

Detroit, celluloid fire.—Gas masks were found to give inadequate protection to firemen in a fire in a varnish factory in Detroit, Mich. Celluloid in the burning building gave off carbon monoxide and oxides of nitrogen.

Experiments by the Bureau of Mines have shown that when celluloid burns in insufficient oxygen the gaseous products contain rather

high percentages of carbon monoxide and oxides of nitrogen. If the supply of air is cut off entirely, the combustion may be continued by means of the combined oxygen contained in the celluloid itself. Chemical fire extinguishers are of slight value in fighting celluloid fires; water serves as well as anything. The Army gas mask will absorb the oxides of nitrogen, but not the carbon monoxide in the gases produced.

Rochester, N. Y., basement fire.—The Rochester Democrat and Chronicle of June 19, 1919, described a fire at which firemen wearing Army masks were overcome. Firemen who entered the basement found that the dense smoke was mixed with ammonia from the refrigerating plant and with illuminating gas from a broken pipe leading to a gas meter. Illuminating gas contains considerable proportions of carbon monoxide. Several men were overcome and one was so badly affected that he was taken to the fire house in an ambulance. About 20 men suffered from the effects of the gas in the basement, but most of them recovered shortly after they came out into the air. No one seems to have been seriously affected.

EXPERIENCES WHERE MASKS WERE USEFUL.

Pittsburgh, Pa., fire in waste-paper plant.—In contrast to the foregoing citations, masks of the Army type have proved useful at some fires, as was witnessed by one of the authors at a fire in the warehouse of the Pennsylvania Paper Stock Co., in Pittsburgh, Pa., July 1, 1919. The building had four stories, was of fireproof brick construction, and contained large quantities of baled scrap paper and rags. Twenty-one firemen were injured, most of whom were overcome by smoke and required hospital treatment. The building was ventilated by breaking nearly all the windows. Under these conditions firemen wearing commercially produced gas masks of the Army type, equipped with filters in the canisters for removing smoke, were able to work in the worst part of the building, in shifts of 25 to 30 minutes each, for a period of five to six hours. Under the same conditions men without masks would work for five minutes, come to fresh air to rest and recuperate, and return to the work in the building for another five minutes, when they would come out with eyes swollen nearly shut by the smoke and so weakened that hospital treatment was necessary.

Spring Lake, N. J., garage fire.—Four firemen wearing gas masks were able to work in a garage filled with smoke.²

New Brunswick, N. J., cellar fire.—At a very smoky cellar firemen wearing Army gas masks entered, ventilated the building, and located and extinguished the fire.³

² Letter of Chief C. H. Waters: Fire and Water Eng., vol. 65, Apr. 16, 1919, p. 876.

³ Letter of Chief H. J. Francis: Fire and Water Eng., vol. 65, Apr. 16, 1919, pp. 876-877.

Camden, N. J., fire in wall-paper factory.—At a fire in the Hitchner wall paper plant, February 18, 1919, gas masks were used to get at the fire, and resulted in a saving of thousands of dollars.⁴

Moline, Ill., fires in storerooms.—Two fires occurred in storerooms which filled with heavy thick smoke. Firemen wearing gas masks were able to enter the building and work with a line of hose.⁵

Duluth, Minn., fire in wooden dwelling.—The fire started in the basement of a wooden dwelling and had spread into the walls on the second story when the fire department arrived. An unprotected man was unable to enter the second story because of the smoke. The assistant chief, wearing an Army gas mask, entered the second floor, ventilated the place, and thus enabled the other men to work there.⁶

DISCUSSION OF THE EXPERIENCES.

At the pier fire where sulphur was burning the firemen may have encountered sulphur dioxide gas in concentrations greater than the canisters could absorb completely. Besides this instance of the failure of an Army gas mask to protect its wearer against a high concentration of a gas that is readily absorbed in lower concentrations, the Army masks are shown to give no protection against carbon monoxide and ammonia.

Altogether, the examples show the wide variety of situations in which the gas masks have been used. An early discussion of the use of gas masks for fire fighting stated⁷ that firemen are entering smoke-filled areas every day without the use of appliances, and, therefore, the gas masks offer protection of some value, as they are adapted for use in the great majority of fires. The instances cited previously where the gas mask has proved useful are few, but are varied enough to show the many different situations where gas masks are proving valuable aids to firemen. Probably thousands of gas masks are in use among the many fire departments of the country, so undoubtedly their usefulness has greatly increased. On the whole, the incidents show the usefulness of the gas mask to fire fighters, but demonstrate also that undue risks should not be taken with them.

THE CHEMISTRY OF COMBUSTION.

Probably the best way to analyze the value and limitations of the gas mask for fire fighting is to consider the process of combustion, the effect on man of the various products that are formed, and the action of the mask on these products. Ordinary pure, dry air consists chiefly of oxygen and nitrogen in the proportion of nearly four

⁴ Letter of Chief P. B. Carter: *Fire and Water Eng.*, vol. 65, Apr. 16, 1919, p. 877.

⁵ Letter of Chief J. Q. Hawk: *Fire and Water Eng.*, vol. 65, Apr. 16, 1919, p. 878.

⁶ Letter from First Assistant Chief C. W. Wilson: *Fire and Water Eng.*, vol. 65, Apr. 16, 1919, p. 878.

⁷ Anon., *Is the Army gas mask safe for fire fighting.* *Safeguarding America Against Fire*, vol. 11, March, 1919, p. 8.

volumes of nitrogen to one volume of oxygen. The nitrogen is an inactive gas and takes no part in combustion or in supporting life. It merely serves to dilute the oxygen and to reduce its activity.

The important constituent of air is oxygen; without it there could be no life or combustion. Burning or combustion is the rapid union of oxygen with substances, the process being accompanied by the production of heat and usually of flame. If a lighted candle is placed in a glass fruit jar and the cap is closed air-tight, the flame will gradually become weaker and finally go out. Chemical analysis of the air left in the jar will then show a different composition from that of pure air. The percentage of oxygen will have decreased from 21 to about 16 or 17 per cent, and in place of the consumed oxygen there will be from 3 to 4 per cent of another gas, carbon dioxide.

A man placed in a small, tightly closed chamber will finally suffocate, like the candle in the jar, but he will retain consciousness until the oxygen is reduced to 12 or 13 per cent, if he is working, or to 10 per cent if he is at rest. Both the man and the candle flame require oxygen, and both give off carbon dioxide in its place. The oxygen combines with carbon, forming carbon dioxide and giving off heat by the union. In the wax or fat of the candle there is also hydrogen, which burns by uniting with the oxygen of the air and forms water vapor. Therefore, the products of combustion of a candle burning freely with plenty of air are carbon dioxide and water vapor.

PRODUCTS OF COMPLETE COMBUSTION.

These two gases—carbon dioxide and water vapor—are the products of complete combustion not only of a candle but also of most of the common inflammable materials such as petroleum, natural and artificial gas, coal, wood, and paper. Coal, of course, contains some sulphur, which as it burns forms with oxygen a pungent suffocating gas called sulphur dioxide. No smoke is given off in absolutely complete combustion; neither are there any irritating or very poisonous gases when the burning material is ordinary coal, wood, paper, or similar material.

PRODUCTS OF INCOMPLETE COMBUSTION.

Complete combustion without any visible smoke is infrequent. In the ordinary fire, especially before it gets well under way, there are many particles of carbon, in the form of soot and tar, which escape before they are burned. Smoke consists of these fine particles. Some of these tars are very irritating to the eyes and respiratory passages, and produce coughing and choking when inhaled.

A much more serious product of incomplete combustion is a highly poisonous gas called carbon monoxide. This dangerous gas is like carbon dioxide, a combination of carbon and oxygen, but contains

only half as much oxygen. Hence, it is most likely to be formed when the supply of air to the fire is restricted, as in smoldering fires of closely packed materials in a basement or closed room where the air can not get at the fire. Although dense smoke oftentimes indicates dangerous quantities of carbon monoxide, it is by no means a sure guide. Many very smoky fires give off but little of this poisonous gas.

Carbon monoxide is also produced by the distillation of coal, wood, and many other combustible materials. Such distillation may be seen when fresh coal is thrown on a hot fire. While the coal is heating, but not hot enough to burn, smoke and gas are seen coming off. One of these gases is carbon monoxide and the smoke is largely particles of tar. As the fresh coal becomes hotter, or when flame strikes the gases that are being distilled off, these gases ignite and burn. The carbon monoxide burns to carbon dioxide, the product of complete combustion. If a grate fire were kept smoldering without bursting into flame, and the fumes were allowed to discharge into a closed room, enough carbon monoxide would soon be generated to overcome a man.

PROPERTIES AND EFFECT ON MAN OF VARIOUS PRODUCTS OF COMBUSTION.

CARBON DIOXIDE.

Carbon dioxide is a colorless and odorless gas, approximately one-half heavier than air. It is the principal product of complete combustion of carbonaceous materials and is also produced in the tissues and organs of the body when the carbon in the body, which comes originally from the food, unites with the oxygen of the air inhaled. A man's breath contains about 4 per cent carbon dioxide. The flue gas from a boiler furnace contains from 8 to 14 per cent of this gas, and smaller proportions are found in the smoke from all fires. A resting man can breathe 2 per cent carbon dioxide in otherwise pure air for a period of several hours without ill effects. Three to four per cent carbon dioxide cause an oppressive feeling, and produces shortness of breath or panting, especially if a man is working. Five to six per cent produces stronger panting, headache, flushing of the face, and, in fact, will soon exhaust a man so that he can not continue work. No subsequent ill effects, however, result. Higher percentages are asphyxiating.

These data indicate that a man can withstand a considerable percentage of carbon dioxide, probably more than a fireman is likely to encounter in the smoke from any fire. The maximum percentage of carbon dioxide found in any of the experimental fires,

which are described in a subsequent part of this paper, was 4.3 per cent. This amount would not be serious unless breathed for periods of 30 minutes or more, and, furthermore, the Army gas mask or any similar mask containing a soda-lime canister would remove some of the carbon dioxide from the inhaled air.

CARBON MONOXIDE.

The following statements are taken from a paper by Dr. Henderson.⁸

Carbon monoxide is formed by the incomplete combustion of carbonaceous materials. It is extremely poisonous and is responsible for more deaths in civil life than all other gases combined. To it are chiefly due the poisonous effects of illuminating gas, producer and blast-furnace gas, the afterdamp of explosions in coal mines, and the products of combustion of fires. It has no odor, taste, or color, nor does it give any warning by irritating the eyes or throat. It is poisonous because it combines with the red coloring matter (haemoglobin) of the blood more readily than oxygen does, and oxygen is thus excluded. Consequently the victim dies of suffocation just as if his supply of air were shut off. A few breaths of air containing 2 per cent carbon monoxide will cause unconsciousness and death almost as quickly as drowning.

The effect of carbon monoxide on a man is proportional to the amount in the air and the length of time it is inhaled. A very low percentage breathed for a long period of time may saturate the blood to the same extent as a high percentage for a short time. Death is likely to ensue when a man breathes air containing 0.2 per cent carbon monoxide for four or five hours, or 0.4 per cent for one hour. These are rough figures only, as a man working vigorously breathes three to nine times as great a volume of air as a man at rest, and will, therefore, be overcome sooner. Different men also vary somewhat in their susceptibility to carbon monoxide poisoning. Burrell⁹ states that he was very sick for eight hours after exposing himself for a period of 20 minutes to an atmosphere containing 0.25 per cent of this gas. Relatively short exposures for 20 to 30 minutes to any percentage above 0.10 per cent must be regarded as dangerous to a man, even when he is not working.

During the hasty and vigorous exertion of fighting fires, the volume of breathing may increase to even eight times that during rest, and thus saturate the blood much faster with carbon monoxide. The firemen must, therefore, regard as dangerous an atmosphere containing percentages as low as 0.10 per cent, especially if he

⁸ Henderson, Yandell, Carbon monoxide poisoning: Jour. Am. Med. Assoc. vol. 67, 1916, pp. 580-583.

⁹ Burrell, G. A. and Seibert, F. M., Gases found in coal mines: Miners' Circ. 14, Bureau of Mines, 1916, p. 20.

breathes this atmosphere for more than 10 minutes. The ordinary Army gas mask affords no protection from carbon monoxide. Special canisters capable of absorbing low percentages, up to 3 or 5 per cent, may become available in the near future.

SYMPTOMS OF CARBON MONOXIDE POISONING.

According to Foster and Haldane,¹⁰ and to Henderson,¹¹ the symptoms of carbon monoxide poisoning are much the same as those produced by air from which the oxygen has been burned out, and differ according to the degree of saturation of the blood with the gas. With 20 per cent saturation, the only symptom is a slight tendency to dizziness and shortness of breath on exertion. As the saturation increases, however, the symptoms of want of oxygen become more and more pronounced, until at 50 per cent saturation a person is scarcely able to stand, and even slight exertion causes loss of consciousness. The effects of carbon monoxide are insidious. At first only a slight shortness of breath and palpitations are noticeable with hardly any discomfort; the senses and the power of judgment and of movement are commonly much impaired before the person is aware that anything is wrong. Sometimes the victim becomes much excited, but often he is simply drowsy and stupid. The symptoms are in some respects similar to those produced by alcohol. One curious fact is that in carbon monoxide poisoning, as in alcoholic poisoning, sudden exposure to cool, fresh air may greatly increase the symptoms. In many cases death seems to have been brought about immediately by muscular exertion, as in attempts to escape up ladders or inclines. If death is gradual, the haemoglobin (red coloring matter of the blood) is usually found to be 80 per cent saturated with carbon monoxide. Persons rescued in an unconscious state, after long exposure to carbon monoxide, often die later from damage to the system during exposure.

The process of freeing the blood from carbon monoxide sets in when a man reaches fresh air, and if he breathes vigorously relief may proceed rapidly. The ill effects, however, do not pass off so rapidly, but may persist for hours, days, weeks, or throughout life. Most of the harm has been done before the man reaches fresh air, and the ill effects may be manifest later. For this reason it is better to send fresh men into a place where carbon monoxide is suspected rather than men who have previously breathed the gas.

DETECTION OF CARBON MONOXIDE.

Mice and birds, preferably canary birds, are used by the Bureau of Mines rescue parties for detecting carbon monoxide, because these

¹⁰ Foster, C. L. N. and Haldane, J. S., *The investigation of mine air.* London, 1905, pp. 146-7.

¹¹ Henderson, Yandell, *Carbon monoxide poisoning.* Jour. Am. Med. Soc., vol. 67, 1916, pp. 580-583.

creatures are much more sensitive to the poisonous action of the gas than men. If an exploring party cautiously enters a suspected atmosphere with birds, it will be able to escape safely if it leaves promptly when the birds begin to show signs of distress.

SOOT, TAR, AND SMOKE VAPORS.

The choking, irritating effect of smoke is due to the finely divided particles of soot and tar and to certain smoke vapors, similar to formaldehyde, that have an extremely irritating action on the eyes and throat. None of these substances are poisonous in the amounts in which they are found in smoke, but their immediate action on the throat, eyes, and lungs is so strong that they may easily disqualify the fireman from performing any effective work, and, in extreme cases, may so interfere with his breathing as to produce unconsciousness.

An Army type gas mask equipped with a canister containing cotton pads and activated charcoal will furnish protection against soot, tar, and smoke vapors, provided there is no carbon monoxide nor a deficiency of oxygen. The cotton pads filter out the soot and tar particles, and the charcoal absorbs the irritating smoke vapors.

OTHER POISONOUS AND ASPHYXIATING GASES ENCOUNTERED BY FIREMEN.

In addition to the common products of combustion of ordinary fires, a city fire department often has to contend with poisonous and asphyxiating gases and fumes from chemicals, broken illuminating gas mains, ammonia from refrigerating plants, and many substances such as motion-picture films, varnishes, and lacquers, that give off when burning large quantities of unusually dangerous fumes.

OXIDES OF NITROGEN.

When strong nitric acid acts on organic matter or certain metals in the presence of air, a reddish brown, insidiously poisonous gas is given off, a chemical combination of nitrogen and oxygen, called nitrogen peroxide. Several other oxides of nitrogen contain oxygen in different proportions, as, for example, nitrous oxide, which is the common "laughing gas" used by the dentist for the painless extraction of teeth. This gas has a marked anaesthetic effect when inhaled in considerable quantity but is not very poisonous. The fire fighter is concerned chiefly with the brown nitrogen peroxide and the vapors of nitric acid, as these are the substances he occasionally encounters.

Nitrogen peroxide is very likely to be met in a burning chemical plant or warehouse where nitric acid or certain nitrates are stored. Burning dynamite, nitro powders, motion-picture films, and celluloid

give off large quantities of these poisonous brown fumes. Thompson¹² describes the following accidents in which men were overcome from nitrous fumes:

A few years ago, a number of workmen were unloading from a vessel at a dock in New York carboys of nitric acid, some of which became accidentally broken. Their contents flowed over the wooden floor, producing dense clouds of acid vapor. The workmen were immediately overcome with suffocation, and in a few hours intense capillary bronchitis developed, which was fatal in several instances. The action of nitrous compounds upon wood evolves large quantities of vapor very rapidly.

An unusual accident occurred in the Gunnison tunnel in 1911. A blast was exploded and 13 men inhaled the smoke at some distance. In less than three days nine of these men died from acute inflammation of the lungs. It was found that nitrous fumes, consisting of nitrogen peroxide, had been developed from the powder smoke.

Haldane¹³ exposed mice to a concentration of 0.05 per cent of nitrogen peroxide for one-half hour. Death followed in 24 hours. Guinea pigs and rabbits have been killed after six to eight minutes' exposure to high concentrations.

Hamilton¹⁴ states that pneumonia may follow a case of poisoning in 1 to 30 days. Quickly fatal cases do not usually develop pneumonia, but autopsy generally shows congestion of the finer bronchioles and air vesicles.

Regarding nitrogen peroxide gas, Oliver¹⁵ says:

During inspiration of this gas there is a painful burning of the throat, which ceases when the fits of coughing have rejected the poison from the lungs. A few hours afterward, when it would seem as if all symptoms had ceased and all fear of possible complications had passed away, the individual who has breathed the gas begins to complain of severe compression of the chest and of inspiration being painful. There is profuse, foamy, yellow expectoration, the face becomes pale, the temperature elevated, the pulse frequent and small, and the patient succumbs without loss of his intellectual functions. After death, the lungs are found to be gorged with dark liquid blood, and are the seat of patchy hemorrhages, the bronchial tubes contain bloody foam, and the heart is filled with dark liquid blood.

SULPHUR DIOXIDE.

The burning of sulphur or brimstone in air produces a strongly irritating and pungent gas called sulphur dioxide. This gas is a chemical combination of sulphur and oxygen and is not nearly so poisonous as carbon monoxide or nitric fumes. There is very little danger from sulphur dioxide poisoning, because the fumes are so irritating to the eyes and throat that the victim is compelled to seek air at once. In very strong fumes, when the victim can not avoid breathing them, death may result from respiratory spasms and as-

¹² Thompson, M. D., and Gilman, W., *The occupational diseases*. New York, 1914, p. 374.

¹³ See Irvine, R. G., *Gassing accidents from fumes of explosives*: *Brit. Med. Jour.*, vol. 2, 1916, pp. 162-163.

¹⁴ Hamilton, M. A., *Industrial poisons used or produced in the manufacture of explosives*: U. S. Bur. Labor Stat., Bull. 219, 1917, 141 pp.

¹⁵ Oliver, Thomas, *Diseases of occupation*. London, 2d ed., 1908, p. 277.

phyxia. Ordinarily, however, exposure to mild fumes merely produces headache, coughing, smarting of the eyes, and later constriction of the chest and bronchitis.

Most persons detect sulphur dioxide by the smarting of the eyes and irritation of the throat, when the proportion present is only 5 to 20 parts in a million parts of air; 500 parts to a million parts of air, or 0.05 per cent sulphur dioxide, is so acutely pungent as to cause a sensation of suffocation, even with the first breath.

Sulphur dioxide fumes are likely to be met in sulphite paper mills, sulphuric acid plants, smelters, chemical plants and stores. Most persons can recognize the gas by its odor, with which they have become familiar through the use of burning sulphur for fumigation or disinfection. The Army mask affords good protection, unless the fumes are very dense, as in the previously cited fire on the docks in New York City (p. 4), where large quantities of sulphur burned. At this fire, it was reported that the fumes penetrated the Army masks. There are now on the market, however, masks provided with special acid-gas canisters that are more effective than the original Army canisters.

AMMONIA.

The widespread use of ammonia refrigerating plants make it necessary that city fire departments have adequate protection from this irritating gas, not only to cope with fires in buildings containing refrigerating plants, but also to enter rooms in which ammonia is escaping, and to shut off the valves of the container or apparatus from which the gas is leaking.

In the pure form, ammonia is a colorless gas and has a sharp, penetrating odor. Under high pressure it can be condensed to a liquid. When the pressure on a tank of liquid ammonia is released the liquid evaporates into a gas again. Much heat is absorbed in the process of evaporation and the cooling effect is utilized in refrigerating and artificial-ice plants. The temperature of liquid ammonia when exposed to the air is 37° F. below zero, so if any part of the human body comes in contact with the liquid it may be frozen. Should a leak occur in the ammonia-piping system of a refrigerating plant, the ammonia, being under pressure, would escape and fill the room with gas. As the gas is very soluble in water, it may be removed from the air of a room not easily ventilated by spraying the air thoroughly with water. In ammonia gas a handkerchief or cloth wet with water and used as a respirator over the mouth and nose of the fireman, if he is caught without other protection, serves to remove much of the gas from the air breathed. The spraying of water from a hose over the neighborhood of the leak also absorbs much of the gas and gives protection.

Ammonia is not considered very poisonous, as it does not often produce death when inhaled. It is, however, quite irritating to the eyes, throat, and lungs in concentrations less than 1 part of ammonia to 1,000 parts of air. According to Lehman,¹⁶ 0.03 per cent ammonia in air can be inhaled from one-half to one hour without producing serious disturbances. Under the same conditions, 0.3 to 0.5 per cent is considered dangerous. The inhalation of larger percentages may cause a spasmodic closing of the glottis and asphyxiation of the victim.

Experiments at the American University experiment station show that the average man will detect the odor of ammonia when only 0.005 per cent is present in air; the eyes are irritated when the percentage is over 0.07 per cent and throat irritation begins at 0.04 per cent; coughing is produced by 0.17 per cent. These percentages differ for different persons, as individual sensitivity is not the same.

The standard Army gas mask as issued for military purposes does not provide sufficient protection from ammonia for industrial use or for fire departments. Special ammonia canisters, however, that give complete protection to the eyes and the lungs can now be purchased from commercial supply houses. In fact, a fireman wearing an approved ammonia mask need have no hesitancy in entering any atmosphere containing ammonia fumes which is bearable as regards skin irritation. Two per cent ammonia is about the maximum strength that a man's skin will endure; more than this has an intolerably irritating action on the tender parts of the body, which increases with the concentration. Perspiration accentuates the effect. Exposure of the skin sufficiently long will cause blistering.

TREATMENT FOR AMMONIA POISONING.

For alleviating the effects of ammonia on the skin use lint or linen or washed muslin wet with picric acid or the picric acid gauze supplied with first-aid outfits.

To treat the eyes first pour a saturated solution of boric acid into the eyes, or use the solution with an eye cup. Have the patient open and close the eyes rapidly to bring the solution in contact with the entire inner surface.

When ammonia gas has been inhaled, dip a handkerchief or gauze, folded once, into vinegar, wring out lightly, and lay loosely over the mouth and nose.¹⁷ If liquid ammonia has entered the nostrils, sniff up some diluted vinegar and apply sweet oil to the inner surface of the nostrils. If ammonia has been swallowed, have the patient suck lemons, or give diluted vinegar, and follow with four teaspoons of sweet oil, milk, or the whites of three or four eggs and ice. If vomiting occurs, aid it with liberal draughts of lukewarm water.

¹⁶Lehman, K. B., Table of poisonous gases, in Koberts' *Praktische Toxikologie*. Stuttgart, 1912. p. 45.

¹⁷ National Ammonia Co., New York, N. Y.

CHLORINE.

Chlorine was the first poisonous gas used on a large scale in the World War. Great clouds of this suffocating gas were sent against unprotected Canadians at Ypres with terrible effect. At ordinary temperatures chlorine is a greenish-yellow gas. However, it can be liquified by compressing it into steel cylinders similar to those used for transporting oxygen gas for welding and cutting iron and steel. Considerable quantities of liquid chlorine are transported in this form for commercial uses, especially for treating city water supplies to kill bacteria, for recovering tin from scrap tin plate, for bleaching linen, cotton, and paper, for use in laundries, and for manufacturing disinfecting agents and many other chemicals.

If exposed to fire, a cylinder containing liquid chlorine would be very likely to blow out a fusible metal plug on its stem. This would release the gas to add to the difficulties of fire fighters, as the suffocating action of the chlorine is intolerable, even in very small amounts. The breathing of air containing only 0.004 to 0.006 per cent chlorine for a period of 30 minutes to 1 hour is dangerous to life. A few deep breaths of air containing 0.1 per cent chlorine is likely to prove fatal. Lehman¹⁸ gives 0.0004 per cent, or four parts of chlorine in a million parts of air, as the maximum percentage that a man can inhale for 30 minutes to 1 hour without serious effects.

Chlorine, when inhaled, even in small quantities, has a strongly irritating action on the mucous membrane of the lungs and respiratory passages. In cases of severe poisoning, the lungs become congested and the victim develops a condition similar to that of pneumonia. Death may result several days after exposure to the gas.

As chlorine is more than twice as heavy as air, firemen should observe especial care in entering basements of buildings in which this gas has been released. If there are no strong air currents, chlorine gas will flow to the lowest places and fill depressions in much the same way as water.

The ordinary Army gas mask affords excellent protection against chlorine in the concentrations likely to be encountered in burning chemical plants or warehouses.

ILLUMINATING GAS.

Broken illuminating or artificial gas pipes sometimes add to the dangers of fire fighting, an excellent illustration being the Rochester, N. Y., fire previously described in this paper (p. 5), where a number of firemen wearing Army gas masks were overcome. In this fire the dangerous constituent of the gas which penetrated the mask was probably carbon monoxide. Practically all artificial illuminating gas contains carbon monoxide. The percentage varies from 6 to 35

¹⁸ Lehman, K. B., Table of Poisonous Gases, in Kobert's *Praktische Toxikologie*. Stuttgart, 1912, p. 45.

per cent, according to the proportions of coal gas and water gas that are put into the gas by the manufacturer. Pure water gas contains about 35 per cent carbon monoxide, pure coal gas about 6 per cent.

The Army type of gas mask and the ordinary commercial smoke masks do not protect against carbon monoxide. For this purpose, an oxygen-breathing apparatus should be used, at least until the new carbon monoxide mask that is being developed by the Government is available.

Where unconsciousness occurs from the breathing of illuminating gas or carbon monoxide in any form, resuscitation by the Schaefer method should be used.

GASOLINE AND PETROLEUM VAPORS.

As regards fire fighting, gasoline and other petroleum vapors are of interest chiefly because of their great inflammability and the fact that only $1\frac{1}{2}$ per cent of gasoline vapor mixed with air will explode on ignition. The explosive range is 1.4 per cent to 6 per cent. Firemen will be interested, however, in the facts regarding the danger from inhaling these vapors, as they may be called upon to rescue some one who has been overcome on entering an empty gasoline tank.

Benzine and gasoline are the more volatile parts of crude petroleum. Owing to their low boiling points, these liquids evaporate very quickly on exposure to air. The air space of a closed gasoline tank having some liquid gasoline left in the bottom contains much gasoline vapor mixed with the air. If the day is very hot, or the sides of the tank become heated, the percentage of gasoline vapor in the air becomes high enough to render unconscious quickly a man who breathes it. Men have thus been overcome on inhaling air from open trapdoors in the top of crude oil or gasoline storage tanks. Similar danger from petroleum gases attends the cleaning out of empty tank cars and storage tanks. A considerable quantity of gas may be left in the car or tank, especially if much sludge must be stirred up in cleaning, thus setting free more gas. To get rid of these irrespirable gases, in common practice, tanks and stills are thoroughly steamed out before workmen are sent into them. Even after this has been done, frequently so much gas is left that men can work only in short shifts, usually not longer than 10 minutes.

The inhalation of benzine, gasoline, and other volatile vapors given off from petroleum, causes headache, dizziness, and frequently an intoxication in which the victim becomes excited and hysterical. Experiments carried out by the Bureau of Mines¹⁹ have shown that the odor of gasoline is noticeable in inhaled air at a concentration of 0.03 per cent; a man who breathed gasoline vapors in air, increasing in concentration from 0.07 to 0.28 per cent for $14\frac{1}{2}$ minutes, felt dizzy at

¹⁹ Fieldner, A. C., Katz, S. H., and Kinney, S. P., Permeability of oxygen breathing apparatus to gasoline vapors: Technical Paper 272, Bureau of Mines, 1921, 24 pp.

the end; a concentration of 1.13 to 2.22 per cent for three minutes made a man so dizzy that he had to hold to a table to stand; with a concentration increasing from 2.22 to 2.60 per cent a man became dizzy after only 10 or 12 breaths. Lehman²⁰ gives 15 to 25 milligrams of gasoline to a liter of air, corresponding to 0.13 to 0.71 per cent, as the maximum that can be inhaled from 30 minutes to one hour without serious disturbances. High concentrations of gas quickly overcome the victim, causing complete insensibility and occasionally death. In most cases, however, the patient recovers as soon as he is removed to fresh air. The Schaefer prone pressure method of resuscitation should be used if breathing is shallow. Recovery is usually accompanied by severe headache and sometimes nausea.

Ordinary Army gas masks afford some degree of protection against low concentrations of petroleum vapors and gasoline for such short periods of time as five to ten minutes. A canister filled with activated charcoal has a higher capacity for these gases and is, therefore, safer to use than the Army canister, which has only 60 per cent charcoal. But even with this canister tanks should be entered cautiously as the gas may be too concentrated for any gas mask. An air helmet or oxygen breathing apparatus affords better protection than gas masks.

Recent experiments in the Bureau of Mines laboratory have shown that many of the thin, rubberized-cloth breathing bags on oxygen breathing apparatus are permeable by gasoline and similar vapors. Low concentrations of gasoline vapor, such as are found in tanks containing ordinary motor gasoline, are not likely to penetrate the bags enough to be dangerous during periods of 15 to 30 minutes; but high concentrations, such as the vapors of more volatile distillates or casing-head gasoline, may permeate some bags fast enough to cause dangerous quantities of the vapor to accumulate in the breathing bag. Breathing bags of the thick rubber type have proved quite impermeable in a two-hour test.

At certain refining plants, the Tissot type of gas-mask face pieces attached to a long, flexible hose leading to pure air have been successfully used. A description of this type of air mask appears on page 21 of this bulletin. All things considered, it may be the best form of apparatus for use in gasoline vapors. Whether such an air helmet or an oxygen apparatus is used, the wearer should always have a stout rope attached to his person so that he can be removed immediately from the irrespirable atmosphere if anything goes wrong with his apparatus.

²⁰ Lehmann, K. B., Tabelle der kleinsten Mengen schädlicher Fabrikgase, welche noch giftig sind und der Mengen, welche allenfalls ertragen werden: in book by Rudolf Kobert, Kompendium der praktischen Toxikologie zum Gebrauche für Ärzte, Studierende und Medizinalbeamte. Stuttgart, 1912, p. 45.

ACID AND MISCELLANEOUS CHEMICAL VAPOURS.

Fires in industrial plants that use acids and other chemicals, and in warehouses where such materials are stored, present many hazards to the firemen who have to enter the fume-laden atmosphere. The fumes from the two most common acids, hydrochloric, sometimes called muriatic acid, and sulphuric, although choking and irritating in the concentrations likely to be found in fires, are seldom fatal. Hydrochloric-acid gas is described on page 19. Nitric acid gives off highly poisonous brown fumes, which have been discussed under "Oxides of nitrogen" (p. 11). In general, inhalation of strong acid fumes corrodes the delicate mucous membranes that line the respiratory passages and the lungs, and if the corrosive action on the lungs is strong, death may follow from pneumonia.

The Army type gas mask affords good protection against all ordinary concentrations of acid fumes. Failure or exhaustion of the mask is readily detected by irritation when the fumes penetrate the canister.

Another class of gases, called the organic vapors, are similar in many respects to the vapors of gasoline and petroleum. They are absorbed by gas masks fitted with canisters that contain activated charcoal, providing the concentration is not excessive. The chief organic vapors that firemen may meet are those of benzene, carbon disulphide, carbon tetrachloride, formaldehyde, turpentine, and solvent naphthas. These liquids are largely used in the manufacture of rubber, explosives, dyes, paints, varnishes, and chemicals. Like the vapor of gasoline, organic vapors are generally inflammable, and when mixed with air may cause violent explosions.

Other organic vapors than those mentioned above may sometimes be encountered. Among these are acetone, alcohols, aniline, chloroform, ether, and toluene. The Army gas mask affords protection against these.

GASES FROM CARBON TETRACHLORIDE FIRE EXTINGUISHERS.

At ordinary temperatures carbon tetrachloride is a volatile, sweet-smelling, colorless liquid. It readily vaporizes and the vapor is colorless and heavy; 7 to 9 per cent of the vapor mixed with air will extinguish fires. The heavy vapor tends to settle to the bottom of a room and form a blanket over the floor. This blanketing effect of the vapor on any material wet with carbon tetrachloride excludes air and so aids in extinguishing fires. Small fire extinguishers, holding about a quart of carbon tetrachloride, are widely used for extinguishing small or incipient fires and are very effective.

There is danger from inhaling the gases formed by carbon tetrachloride when sprayed on heated materials. Experiments by the

Bureau of Mines, which are described later, have shown that the decomposition products of carbon tetrachloride may consist of phosgene, chlorine (sometimes), and hydrochloric (muriatic) acid gas. In addition, high concentrations of carbon tetrachloride itself are produced. Death may be caused by breathing the gases for only a short time. Danger is greatest when the fire is in a closed or confined space. The Army gas mask protects the wearer in any concentrations likely to be met.

Of the gases produced by carbon tetrachloride on fires, chlorine has been described previously. The others, phosgene and hydrochloric-acid gas, are considered below.

PHOSGENE.

Phosgene, as one of the gases most used in warfare, has been studied quite thoroughly. Aside from that formed from carbon tetrachloride in fires, firemen are not likely to meet phosgene, for its use in the chemical industry is small.

It has been found²¹ that three parts of phosgene in a million parts of air, irritate the throat; five parts cause coughing; six parts can be detected by smell; 25 parts per million is the approximate deadly concentration for an average man when exposed for 30 minutes.

HYDROCHLORIC-ACID GAS.

Hydrochloric-acid gas has a pungent, biting odor, and although it irritates the respiratory passages, it is not considered very toxic; but brief exposure to a concentration of 1,000 parts per million, or 0.1 per cent, of the gas has been known to cause death.²²

Hydrochloric-acid gas, besides being produced from carbon tetrachloride in fires, is one of the acids most used in the industries, where it is commonly known as muriatic acid, which is a solution of large quantities of the gas in water. When heated, the gas is driven off from the solution. As muriatic acid is widely used, firemen may encounter the gas at many fires. The Army gas mask offers effective protection.

CARBON TETRACHLORIDE.

Undecomposed carbon tetrachloride vapor arising from the use of the liquid in fire extinguishers when encountered in a small confined space will probably produce unconsciousness by its anaesthetic effect. The commercial product usually contains some carbon bisulphide, a

²¹ Chemical Warfare Service, American University experiment station, Washington, D. C.

²² Thompson, W. G., *The occupational diseases.* 1914, p. 370.

residue of the carbon bisulphide used in the manufacture. Waller and Veley²³ found that the presence of carbon bisulphide vapor with that of carbon tetrachloride greatly increased the toxicity, but comparatively large amounts of the carbon tetrachloride vapor must be breathed before the effects become dangerous. For this reason, the more serious danger in the use of carbon tetrachloride lies in the products formed from it rather than from the vapor itself.

Lehman²⁴ states that 159 parts per million (0.016 per cent) will cause slight symptoms when breathed for several hours; 3,980 parts per million (0.4 per cent) may be inhaled for about one hour without very serious effects; 23,850 parts per million (2.4 per cent) are dangerous in 30 minutes.

An employée of the Bureau of Mines was overcome while using a carbon tetrachloride fire extinguisher on an automobile burning in the open air. Two employées of the Navy Department died as the result of breathing fumes from carbon tetrachloride that had been used when the clothes of one of them caught fire while the men were working in a very small compartment.

The Army gas mask will protect the wearer against carbon tetrachloride, and its use is recommended when a fire extinguisher of this type is used in a small, unventilated space.

TYPES OF BREATHING APPARATUS.

SELF-CONTAINED OXYGEN BREATHING APPARATUS.

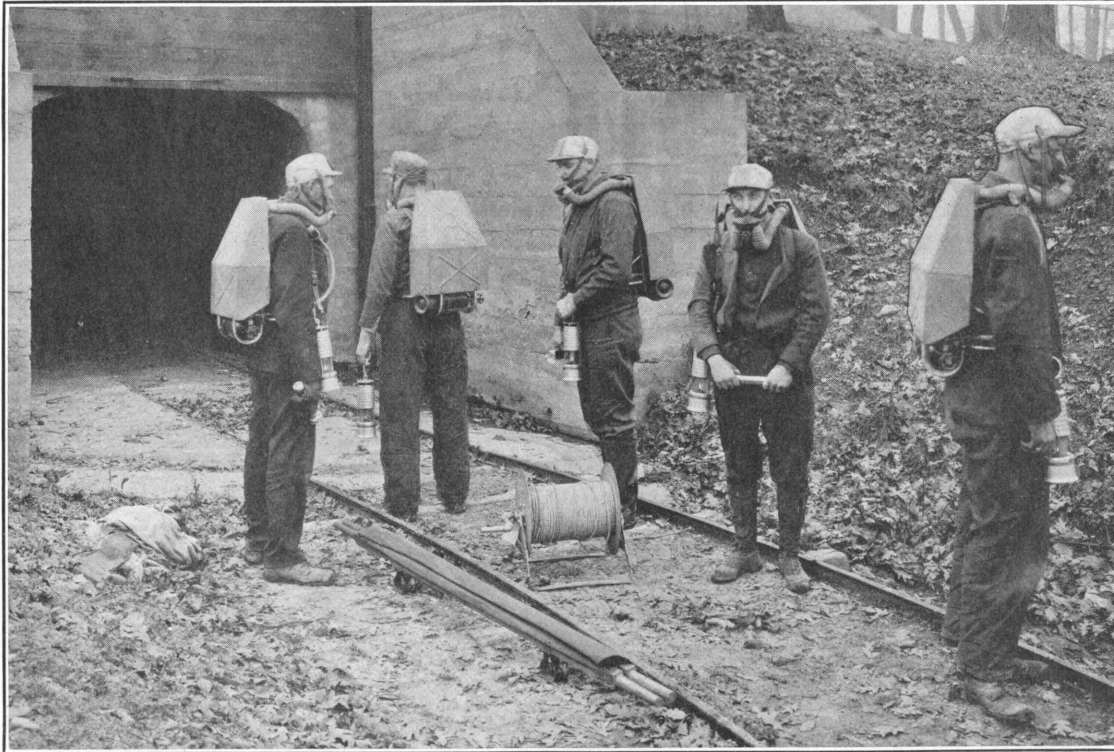
Self-contained oxygen breathing apparatus have been used extensively by the engineers of the Bureau of Mines in fighting mine fires and in rescuing miners trapped by fire or by the poisonous gases resulting from fires and explosions. J. W. Paul,²⁵ describes these devices and the care that is necessary to keep them in serviceable condition. Plate I shows the Gibbs apparatus developed by the Bureau of Mines. It weighs about 34 pounds, and contains oxygen enough to supply a man at work for two hours or more. Plate II shows the Fleuss or Salvus light apparatus, which weighs about 15 pounds and holds oxygen enough to supply a man for about one-half hour.

These apparatus will support life and enable one to work in any gas that does not attack the skin. Goggles are worn to protect the eyes. As the apparatus supply their own oxygen, the wearers are not dependent on the surrounding atmosphere.

²³ Waller, A. D., and Veley, G. A., Relative toxicities of chloroform and carbon tetrachloride: Jour. Am. Med. Asso. vol. 53, Aug. 28, 1909, p. 9.

²⁴ Lehman, K. B., Table in Koberts Praktische Toxikologie, Stuttgart, 1912, p. 45.

²⁵ Paul, J. W., The use and care of mine rescue breathing apparatus: Miner's Circular 4, Bureau of Mines, 1912, p. 24. See also Oxygen mine rescue apparatus and physiological effects on users, by Henderson, Yandell, and Paul, J. W., Tech. Paper 82, Bureau of Mines.



GIBBS APPARATUS, DEVELOPED BY THE BUREAU OF MINES; SUPPLIES OXYGEN FOR TWO HOURS OR MORE.



SALVUS LIGHT APPARATUS; SUPPLIES OXYGEN FOR HALF AN HOUR AND WEIGHS ABOUT 15 POUNDS.

"PIG SNOUT" RESPIRATORS.

Plate III, *A*, shows a "pig snout" respirator, which contains a moistened sponge through which the inhaled air passes. Chemical solutions for absorbing gases may be used in the sponge, which also acts as a filter to remove some dust and smoke particles. It is doubtful whether this type of respirator is more effective than a moistened handkerchief tied over the mouth and nose, or certain homemade respirators of muslin or cheesecloth, several layers deep and fashioned to fit the face.²⁶ Plate III, *B*, shows a similar respirator, which contains a paper filter, through which the air passes. This respirator filters out some dust and smoke, but will not remove any gases.

AIR MASKS AND HELMETS.

Air masks and helmets, which provide the wearer with fresh air through a long hose somewhat after the fashion of divers helmets, are made in many forms. Plate IV shows a mask that covers the face only. Pure air at some distant point is forced by a pump through the line of hose that leads into the mask. The hose is fastened to a belt which takes the pull necessary to move it after the wearer. The air, which enters the mask, passes out through a valve that prevents passage in the reverse direction. Also, with a Tissot face piece it is possible to use, instead of the absorbent canister, a noncollapsible hose leading to pure air. A $\frac{3}{4}$ or $\frac{1}{2}$ inch hose fitted with a check valve near the mask may be used without an air pump, provided the length of hose does not exceed 50 feet. In longer lengths the resistance becomes too high.

Such use of a Tissot type gas mask with a line of hose replacing the absorbent canister is described by J. D. James,²⁷ safety inspector of the New Jersey Zinc Co., Palmerton, Pa.

Tissot masks connected up with 50 feet of $\frac{3}{4}$ -inch rubber hose, having a 6-inch funnel held in pure air on the other end, were according to Mr. James—

Thoroughly tried out at the blast furnaces and gas producers of the New Jersey Zinc Co. plant at Palmerton with good results. One of the tests was to throw a 3-foot slide damper on the main gas line, where thirty-six $\frac{3}{4}$ -inch bolts had to be removed before the slide could be opened to clean out the gas line. After cleaning the gas line the slide was closed and the 36 bolts replaced, tightened, and the joints sealed all around with clay. This test was made by two men who were enveloped with carbon monoxide about 45 minutes. After the job was completed both men declared that they were not affected in the least with gas, and continued their regular routine of work. Several tests have been made with the same very gratifying results.

²⁶ Anonymous, A simple and inexpensive respirator for dust protection: Bull. 90, Division of Industrial Hygiene, Department of Labor, State of New York, December, 1918, 10 pp.

²⁷ James, J. D., Experiments with the Tissot gas mask: Safety Eng., vol. 38, 1919, pp. 148-150. The accompanying photographs were reproduced through the courtesy of Mr. James.

The old way of turning these slide dampers always took at least six men working in pairs, each pair working at alternate periods, often only a few minutes each, and usually taking about one and one-half hours to do the job. Quite frequently some of the men were overcome with the gas, necessitating artificial resuscitation to relieve their condition.

The strongest argument in favor of this gas mask is that the men will not do this work now without this mask.

Fifty feet is probably the greatest length of hose through which a man can comfortably breathe; beyond this length the resistance becomes so great that a pump should be used to force a continuous stream of air to the face, at a rate of 80 to 100 liters ($3\frac{1}{2}$ cubic feet) per minute.

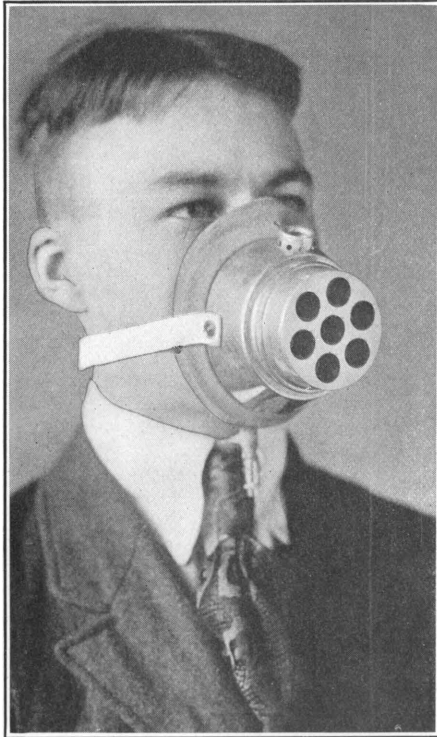
In using an air mask without a pump, a check valve should be placed in the air line within a few feet of the face piece to prevent the exhaled air from going back into the air line. An excellent plan is to attach a special metal coupling containing this check valve to a belt at the waist of the wearer. The flexible hose connection to the mask is attached to one end of this valve coupling and the 50-foot air hose to the other end. The radius of use of air masks and helmets is limited by the length of hose attached, which determines the distance from pure air. In general, the longest practicable length of hose is about 100 feet. Air masks are well adapted for cleaning tanks containing irrespirable vapors and for similar work. Their usefulness is reduced by the fact that the hose is cumbersome and when used with air pump an extra man is required to work the pump. Air helmets are much used in sand blasting and similar very dusty work, where the pure air supply may be obtained from an air-pressure line.

DESCRIPTION AND PROPERTIES OF THE UNITED STATES ARMY TYPE OF GAS MASKS.

CONSTRUCTION.

American soldiers at the time of the signing of the armistice were supplied with a mask known as the R. F. K., which had a face piece of rubberized fabric. This mask is pictured in Plate V, *A*, and the details are given in figure 1. The nonshattering eyepieces had metal frames in order to make their insertion in the fabric gas-tight. Attached to the interior of the mask was a mouthpiece, through which air was breathed, and a nose clip that prevented inhalation through the nose. This type of mask is familiar to most persons. However, as an improved face piece, shown in Plate V, *B*, had been developed and was being produced in quantity shortly before the armistice was signed, and is used also in masks now produced commercially, the R. F. K. will not be considered further.

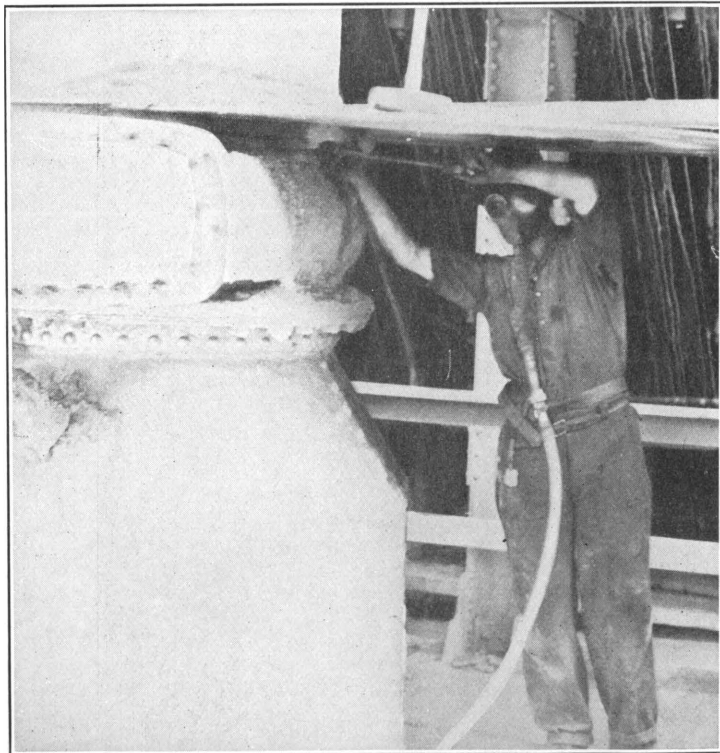
The newer type of face piece or mask is known as the Tissot type and is so designed that the wearer may breathe through his nose in



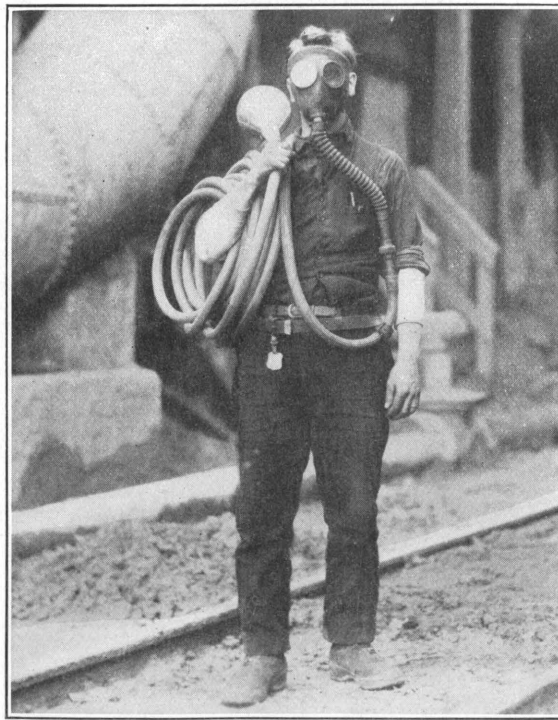
A. "PIG SNOUT" RESPIRATOR CONTAINING A MOISTENED SPONGE.



B. "PIG SNOUT" RESPIRATOR WITH PAPER FILTER FOR DUST AND SMOKE.



A. MAN WEARING A TISSOT MASK, TIGHTENING GAS SLIDE-JOINT.



B. MAN EQUIPPED WITH TISSOT MASK AND AIR HOSE.

normal fashion. The mask is made of a stockinette-covered rubber of sufficient thickness to prevent collapse during the suction from inhalation. Large eyepieces, set close to the eyes, afford a wide angle of vision. Purified air from the canister passes through a rubber tube—corrugated to prevent collapse and to increase flexibility—into the space between the face and the mask. This fresh, relatively dry air as it is drawn into the mask, passes over the eyepieces and prevents fogging by the condensation of the moisture in the exhaled air. Exhaled air passes from the nose downward, and is discharged through a flutter valve, which allows passage in the exit direction only. When this mask is properly adjusted to the face, it is fairly comfortable, and the leakage of unpurified air is negligible.

The canister that contains the absorbent material is carried in a haversack that hangs from the neck, as shown in Plate V, *C*. Figure 4 (p. 33) pictures the standard United States Army canister and the details of its construction. The capacity of this canister is 42 cubic inches of absorbent, which is a mixture of 60 per cent by volume of activated charcoal and 40 per cent by volume of permanganate soda lime, both sized to pass

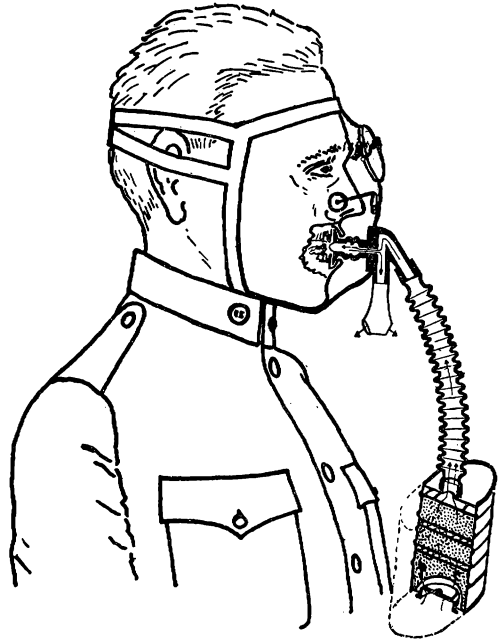


FIGURE 1.—Details of the R. F. K. mask.

through a screen of eight meshes to the inch and be retained on a screen of 14 meshes to the inch. Canisters for industrial use need not be limited to 42 cubic inches of absorbent. In fact, because of its longer life, a canister to hold 100 cubic inches or more would be of advantage for many industrial purposes. For other purposes, where only short life is needed, smaller canisters are desirable. Plate VI shows a small canister with mouthpiece directly attached; it is supported by the teeth, and a nose clip is used. This type was used for emergency purposes by some men working with poison gas during the war. The two filters (fig. 2) of cotton wool wadding in the U. S. Army canister are capable of filtering out the coarser dust and mist particles, but very finely divided particles, such as tobacco smoke, pass through the canisters to some extent. As will be shown

later, the canisters remove the smoke from ordinary wood fires. The rubber disk valve at the bottom allows air to flow through the canister in one direction only. The heavy spring pressing on the stiff wire screen at the top holds the granular absorbent firmly in position. Corrugations on the tinned iron container add stiffness to the can, and tend to prevent the passage of gas along the walls.

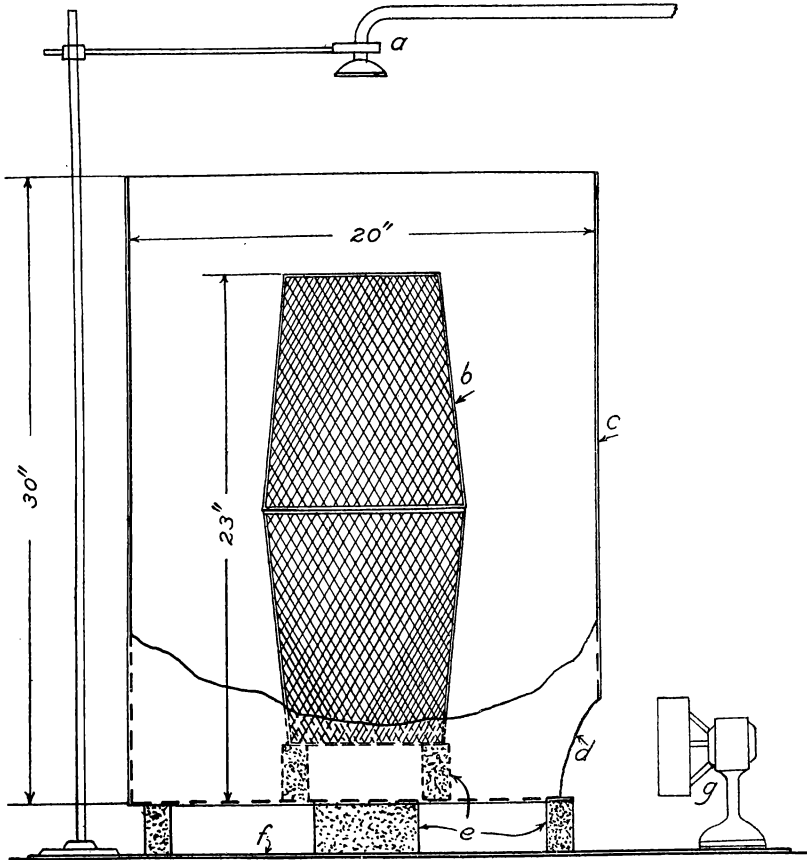
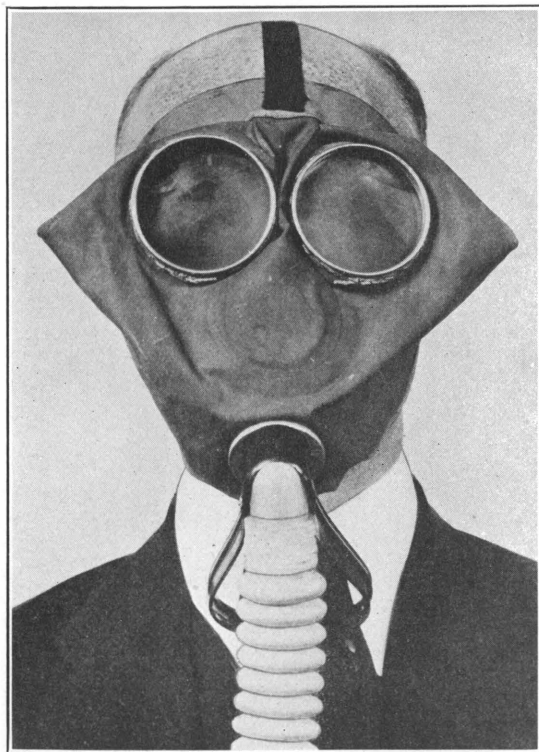


FIGURE 2.—Apparatus used for making smoldering fires: *a*, Sprinkler; *b*, coarse wire basket; *c*, can; *d*, hole in can; *e*, bricks; *f*, asbestos; *g*, fan.

The canister itself is comparatively inexpensive, so that when the absorbent is exhausted it can be replaced by a new one at small cost.

CARE AND INSPECTION OF GAS MASKS.

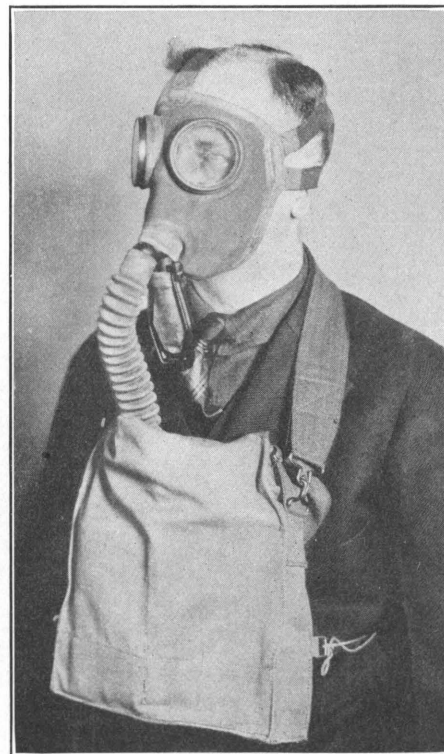
Masks are constructed largely of rubberized fabric. Rubber deteriorates under the action of light and air, and the higher the temperature the more rapid is the deterioration. Fabric deteriorates if allowed to remain moist. Hence, masks should be kept in cool



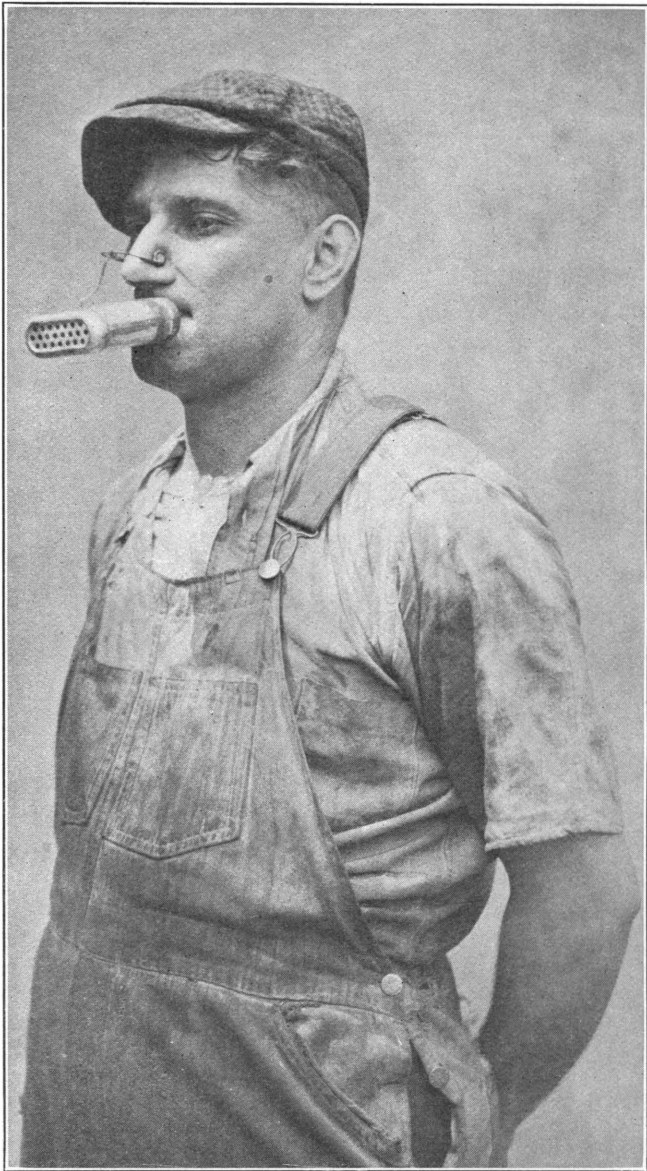
A. R. F. K. MASK USED BY THE U. S. ARMY.



B. AIR MASK SUPPLIED WITH FRESH AIR THROUGH LONG HOSE.



C. TISSOT TYPE OF U. S. ARMY GAS MASK.



SMALL CANISTER WITH MOUTHPIECE DIRECTLY ATTACHED,
SUPPORTED BY THE TEETH.

places where there is no excess moisture, and should be protected from light and air. Manufacturers provide cases or boxes in which to keep them, and the masks will last many times longer in the cases than outside. It is impossible to state the life of masks stored without use, as for instance, ammonia masks kept for emergencies; but it is believed that when properly stored they will retain their usefulness at least two years. After a mask has been used, it should be cleaned and dried before being put away. When masks are used by different persons, it is advisable to clean and disinfect them between times. The Bureau of Mines recommends that the masks, separated from the canister, be immersed and washed in a 2 per cent solution of lysol, and then dried in the open air, with the lysol solution adhering. Masks of the mouthpiece type should always be disinfected at intervals even if worn by only one person. Sharp folds and creases are to be avoided in putting away masks.

The eyepieces should be kept clean, preferably by rubbing the glass with a small piece of pure soap and then cleaning with a soft cloth; blowing the breath upon the glass will supply moisture for the purpose. Soldiers were provided with a small piece of soft cotton flannel for cleaning the glasses. Clean glass has less tendency to fog from moisture and permits better work.

Canisters should be protected, especially from dampness and air on the inside, and should be kept cool. The manufacturers send them out with plug seals covering the bottom valve opening, and with corks closing the hose nipple, unless the latter are attached to a mask. When completely protected from the action of outside air, canisters should last for years; but when free access of outside air is allowed, they may deteriorate rapidly, especially canisters containing soda lime, the absorbent for acid gases. Extra canisters should be kept on hand to replace those worn out by use. The purpose of a canister is marked on it by the manufacturer. Before using a canister one should always read the inscription to see that the canister is suited for the gas in which it is to be worn.

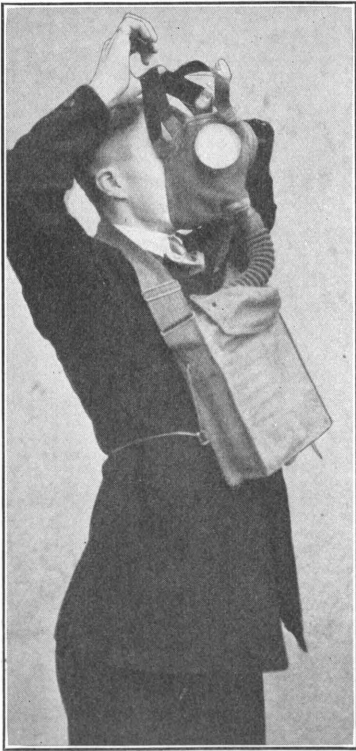
The life of a canister in various uses can not be foretold, because it depends on the concentration of the gas encountered and the volume of gas passed through. When a man works vigorously, as in walking $3\frac{1}{2}$ miles in an hour, he breathes about 32 liters of air a minute. During intense exertion he may breathe 60 or 80 liters a minute or much more. When he is at rest, he breathes only 7 or 8 liters per minute. Canisters in continuous use under a wide variety of circumstances in industries have shown lives varying from a few hours to many weeks. Likewise, it is impossible to tell the residual life of a canister after use without testing it against gas, which spoils it for further use. Resistance to the flow of air may indicate the probable life. At a flow of 85 liters per minute, the resistance of

fresh canisters is about $3\frac{1}{2}$ inches of water column or less. If the resistance increases to more than 4 inches, the canister has probably failed. But this test has not much practical importance, because of the special, rather complicated apparatus necessary and because the resistance does not change markedly in every canister. When a canister has been wet with water on the inside, it should not be used a second time. When an assembled mask is stored after use, the bottom opening of the canister should be closed with the plug stopper.

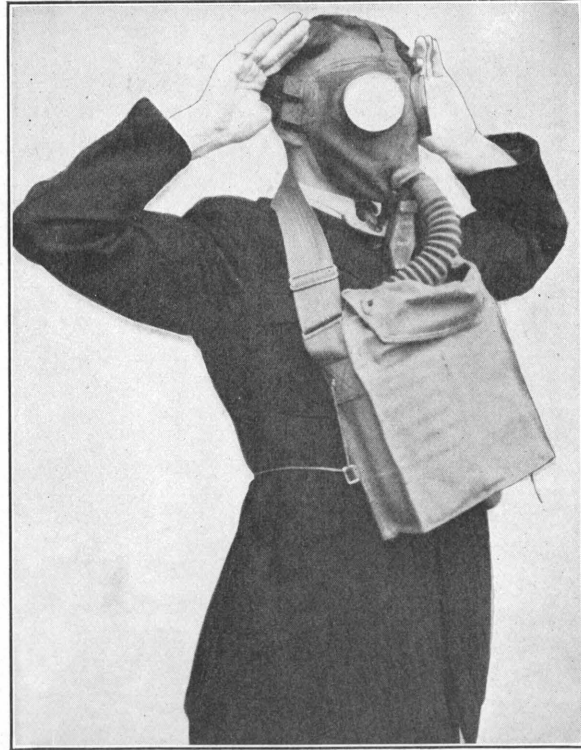
Masks and canisters assembled and kept ready for use should be inspected and tested for leaks at periods of not more than two weeks. A man who is to wear a mask should also test it for fit and leaks before he enters a dangerous place. To do this, the plug that closes the bottom opening is removed, the mask is put on, and adjustment made on the head bands until the mask fits closely but comfortably. Resistance to breathing should cause but little effort, nor should it be noticeably inconvenient. Then the bottom opening is closed with the palm of the hand and suction exerted with the lungs until the face piece collapses. If there are no leaks, the mask and canister will hold the vacuum for 15 seconds without change. If the mask is tight, the wearer should enter the gas cautiously to see that the canister is active. Most gases and smokes may be perceived by their odor or by their irritating the nose or throat. When a canister is in use, failure at the end of its life is gradual, so that time is given for the wearer to escape. When evidences of failure are noticed, the wearer should immediately go to fresh air and replace the canister with a fresh one.

HOW TO PUT ON A GAS MASK.

The haversack or harness that supports a gas mask on a wearer is made adjustable to allow the canister to hang a comfortable distance from the face. After the adjustment is once made for a person it need not be changed. This arrangement of the haversack was called the "alert" position by soldiers, and they were trained to be able to remove a mask from the haversack and properly adjust it to the face in six seconds after command. Most uninformed persons in putting on a mask seem inclined first to put on the mask elastics like a hat and then adjust the face piece. This method is awkward, slow, and unsatisfactory. The rapid method taught to soldiers is this: Grasp the mask before the face with both hands, the thumbs pointing upward under the elastics, as shown in Plate VII, *A*, push the chin well into its position in the mask, then pull the elastics over the head as far as possible, as shown in Plate VII, *B*. After a little practice one is able to adjust in a single movement a Tissot type mask so that it is properly placed, gas-tight, comfortable, and the elastics are smooth.



A. ADJUSTING GAS MASK.



B. ADJUSTING MASK WITH ONE MOVEMENT.

ABSORBENTS FOR GASES.

The Bureau of Mines and the Chemical Warfare Service of the Army experimented with many absorbents for poisonous or toxic gases in general and with special absorbents for individual gases or classes of gases that might be used in warfare. The tests thus included most of the gases commonly met in the industries.

The more useful absorbents are briefly described below:

CHARCOAL.

Charcoal, properly made, may be considered the one universal absorbent for gases, as it absorbs to some degree every gas, both toxic and nontoxic. Its capacity and activity against any gas varies with the material from which it is made, but more especially, and over very wide limits, with the process of manufacture. However, charcoal has such a small capacity for absorbing certain gases met, both in warfare and in the industries, that it is of no practical value as an absorbent for them. Among these gases are carbon monoxide and ammonia. The properties of charcoal, as made by different processes and from different materials, have been described by Lamb, Wilson, and Chaney,²⁸ and by Chaney.²⁹ It is sufficient to state here that the best charcoal, per unit of volume, is made from the dense shells of nuts, such as cocoanut, peach stones, and the like. Distillation is done in ordinary coal-gas retorts at temperatures of about 1,000° C. After distillation ends, the material is "activated" by passing steam or air through it at lower temperatures. Activation removes hydrocarbons from the cellular carbon surfaces, thus greatly increasing the activity and capacity of the charcoal. Charcoal made by ordinary processes of distillation is worthless as an absorbent in gas masks. Charcoal may be impregnated with other materials to increase its capacity for certain gases or to cause chemical decomposition of some gases.

The special function of charcoal in the Army canister is to absorb organic vapors. Among the organic vapors that may be met in industrial operations are: Acetone, alcohols, aniline, benzene, carbon bisulphide, carbon tetrachloride, chloroform, ether, formaldehyde, gasoline and petroleum distillates, toluene, and others.

SODA-LIME.

The properties and capacities of soda-limes made by different formulas are described in detail in the paper by Lamb, Wilson, and

²⁸ Lamb, A. B., Wilson, R. E., and Chaney, N. K., Gas-mask absorbents: *Jour. Ind. Eng. Chem.*, vol. 11, 1919, pp. 420-438.

²⁹ Chaney, N. K., The activation of carbon: *Trans. Am. Electro-Chem. Soc.*, vol. 36, 1920, pp. 91-101

Chaney³⁰ previously cited. The standard Army soda-lime was made by mixing in the proportions indicated the ingredients named below:

Composition of ingredients.	Per cent.
Hydrated lime.....	45
Portland cement.....	14
Infusorial earth.....	6
Sodium hydroxide.....	1
Water.....	Approx. 33

The mixture was dried in slabs about $1\frac{1}{2}$ inches thick, crushed, and screened. The part that passed a screen of 8 meshes to the inch and remained on a screen of 14 meshes to the inch was used. Material this size was sprayed with a solution of sodium permanganate, after which the moisture content was about 13 per cent and the sodium permanganate content about 3 per cent. For certain industries, such as require absorption of carbon dioxide, the amount of sodium hydroxide could be increased to advantage; also the permanganate might be omitted and the formula otherwise varied.

The especial function of soda-lime is to absorb acid gases. Some of the acid gases met in the industries are carbon dioxide, chlorine, formic acid, hydrogen chloride, hydrogen cyanide, hydrogen sulphide, nitrogen peroxide, phosgene, and sulphur dioxide.

MIXED CHARCOAL AND SODA-LIME.

The properties of the mixed charcoal and soda-lime, as used in the Army canisters, is the same for most gases as for each constituent when unmixed. But, for some gases, the mixture works to advantage. Thus phosgene is absorbed by both soda-lime and charcoal, but in the presence of moisture, which is always present, charcoal acts in a way to decompose phosgene and change it to carbon dioxide and hydrogen chloride gases. The capacity of charcoal for these gases is low and they are given off readily. However, the capacity of soda-lime for the liberated gases is higher than its capacity for phosgene. Thus the resultant capacity of the mixture for phosgene is higher than that due to each constituent acting separately. A similar action occurs with chlorine.

AMMONIA ABSORBENTS.

Perrott, Yablick, and Fieldner³¹ investigated various materials for absorbing ammonia and found that the salt hydrates of certain heavy metals, such as copper, cobalt and nickel, and silica gel were very effective. The best material was copper sulphate or blue vitriol impregnated on granular pumice stone. This absorbent has a high

³⁰ Work cited, pp. 420-438.

³¹ Perrott, G. St. J., Yablick, Max, and Fieldner, A. C., A new absorbent for ammonia respirators; *Jour. Ind. and Eng. Chem.*, vol. 11, 1919, p. 1013.

capacity for ammonia and will effectively remove the gas from air breathed in concentrations of the gas higher than the skin will bear. Thus it is man's skin, rather than the gas mask worn, that limits his capacity to withstand ammonia gas in air. Although copper sulphate is a most satisfactory absorbent for ammonia, it is useless against other gases.

SILICA GEL.

Silica gel³² is a hornlike material, made by mixing together sodium silicate, also called water glass, and muriatic acid. It combines some of the useful properties of charcoal with that of an ammonia absorbent. For certain organic vapors it has an absorption that compares favorably with high-grade charcoal. Its capacity and activity for ammonia are not equal to those of copper sulphate and pumice stone but are sufficient to make it a satisfactory absorbent for ammonia. This combination of the properties of both charcoal and kupramite (copper sulphate and pumice stone) in one material may make silica gel a very useful absorbent for some industrial purposes.

ABSORBENT FOR CARBON MONOXIDE.

Because of the widespread occurrence of carbon monoxide and its deadly nature, an adequate absorbent for it would be a great boon to fire fighters and to workers generally. The Bureau of Mines and the Chemical Warfare Service³³ have made progress in producing absorbents for removing carbon monoxide, and it is expected that and these will soon be available for industrial use.

GASES AND ATMOSPHERES AGAINST WHICH THE GAS MASK DOES NOT PROTECT.

Absorbents for all gases for which absorbents are known have been described in the foregoing paragraph. Table 1 lists those gases and atmospheres against which no absorbent is known for protecting the wearer of a gas mask.

In addition to noting the limitations of all gas masks, the reader should remember that canisters are now being produced commercially containing absorbents that may have a high capacity for a single gas or class of gases and not absorb others. For this reason, the purpose and capacity of the canister should be exactly understood by the wearer of a gas mask before he intrusts himself to it in a dangerous atmosphere.

³² Patrick, W. A., Silica gel, U. S. Patent 1,297,724, Mar. 18, 1919.

³³ Lamb, A. B., Bray, W. C., Frazer, J. C. W. The removal of carbon monoxide from air; Jour. Ind., and Eng. Chem., March, 1919, vol. 12, pp. 213-221.

TABLE 1.—*Gases and atmospheres in which gas masks are inadequate.*

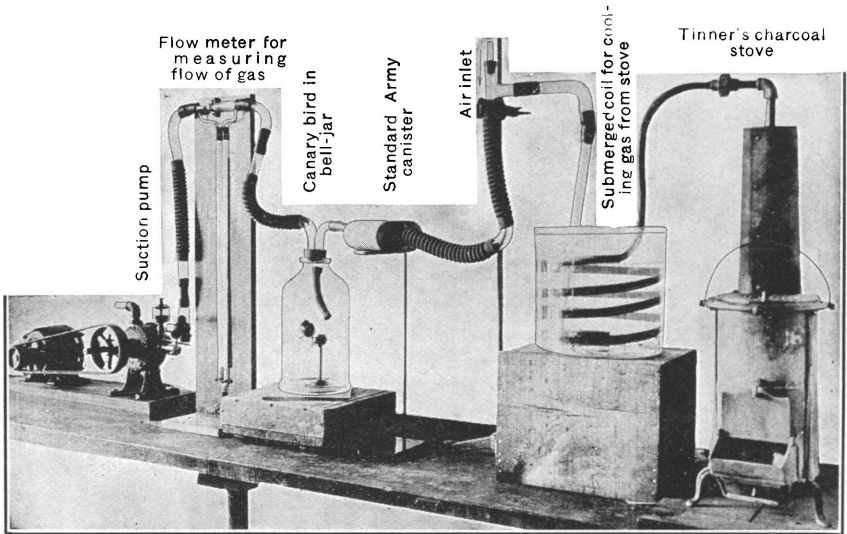
Gas or atmosphere.	Where found.	Remarks.
Methane.....	May be found wherever natural gas is produced or used; also in coal mines.	No adequate absorbent is known. The gas is harmless in itself but may cause suffocation when present in air in sufficient quantity to reduce the oxygen content below 13 per cent.
Atmospheres deficient in oxygen.	Flues, apparatus in industrial plants, mines and closed rooms in buildings after fires and explosions.	The wearer of a gas mask must have an adequate supply of oxygen in the atmosphere around him, regardless of the content of poisonous gas. For entering an atmosphere deficient in oxygen, either self-contained breathing apparatus or a helmet supplied with air from a pump through hose should be used.
Atmospheres containing higher concentrations of toxic gases.	Chemical and metallurgical apparatus; rooms where large quantities of gas are evolved without adequate ventilation.	The gas mask is essentially an apparatus for removing from air toxic gases in comparatively low concentrations, such as those on battlefields. In general, unless special information as to the activity and capacity of a mask is available, it should not be used in toxic gases having a concentration more than 1 or 2 per cent.
Carbon monoxide.....	Products of incomplete combustion of coal, wood, and most combustible matter; producer gas, blast-furnace gas and products of many chemical and metallurgical operations; coal gas, water gas, after-damp in mines after fires and explosions.	No adequate absorbent is available at present; the Army mask canister is useless against this gas. Being odorless and tasteless, carbon monoxide may give no warning effects, and it is the most dangerous of all gases commonly met in civil life.

EXPERIMENTS WITH INCOMPLETELY BURNING FIRES.

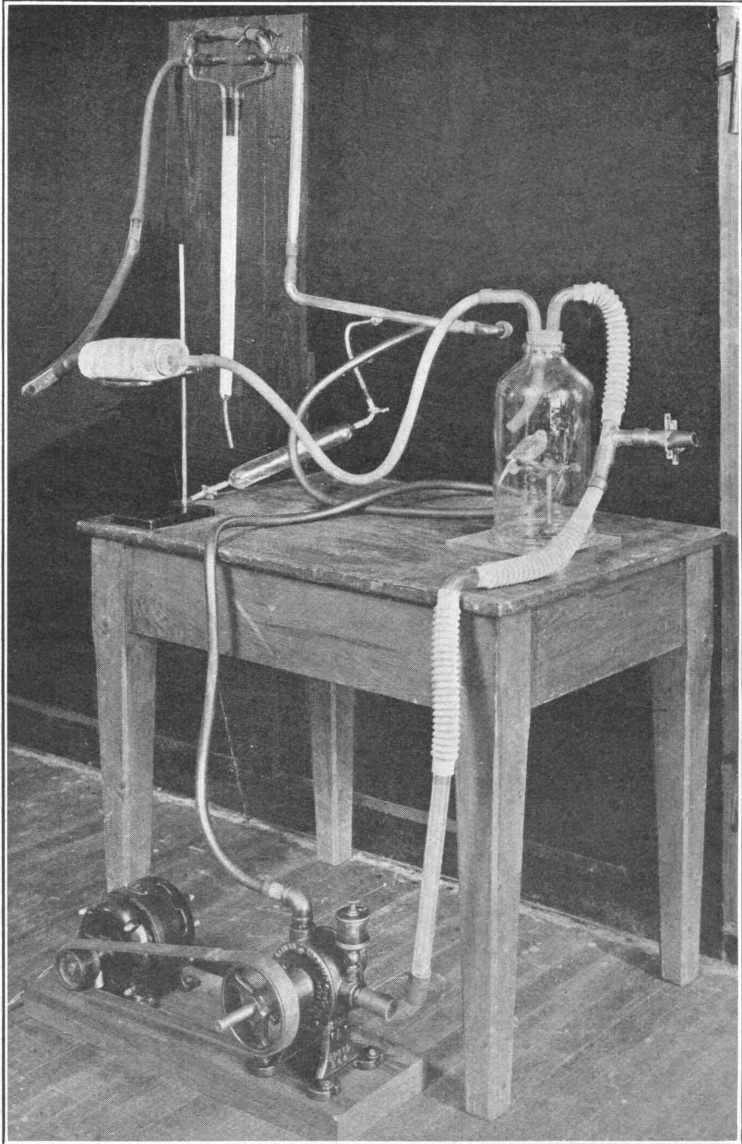
In order to demonstrate the ineffectiveness of the Army canister in protecting against the products of incomplete combustion, two kinds of experiments were arranged. In the first experiment, a small, portable charcoal stove, such as is used by tinner for heating soldering irons, supplied the gases. Such charcoal fires produce no smoke, and the gases produced are invisible. In the second experiment, in a gas-tight unventilated chamber, built for experimental purposes, smoldering fires of excelsior, cotton waste, and like material produced gases and a thick dense smoke.

EXPERIMENTS WITH CHARCOAL FIRES.

Plate VIII shows the apparatus used for the experiments with a charcoal fire. Products of combustion were obtained from a point within the fire bed of a tinner's stove. From the stove the gaseous products of combustion were drawn through a copper coil submerged in water for cooling. Air was then added, and the mixture was drawn through an Army gas-mask canister. From the canister the gases passed through a bell jar containing a perch on which sat a canary bird. Thence they passed through a flow meter, and finally were discharged from a suction pump. The glass parts of the line enabled an observer to see that the gas underwent no visible change. Carbon dioxide is the only gas other than carbon monoxide produced by the



APPARATUS USED TO DEMONSTRATE THE INADEQUACY OF THE ARMY CANISTER FOR PROTECTION AGAINST CARBON MONOXIDE.



GAS CHAMBER USED FOR EXPERIMENTAL PURPOSES AT THE PITTSBURGH EXPERIMENT STATION OF THE BUREAU OF MINES.

combustion of charcoal. This gas is absorbed by the Army canister, and its presence during the experiment described was indicated by the warming of the canister. The carbon monoxide overcame the canary, which fell from its perch in less than a minute.

EXPERIMENTS WITH FIRES IN A CLOSED ROOM.

In figure 3 are shown the details of the room or gas chamber used at the Pittsburgh experiment station of the Bureau of Mines. Plate IX is a picture of the chamber. The floor, walls, and ceiling are constructed entirely of sheet metal. The windows are of glass. The wooden doors, such as are made for large refrigerators, are lined on the inside with sheet metal, have edges bordered with rubber and handles made to exert a clamping effect and fasten the doors tightly against their jams. All metal joints are soldered. The glass windows are cemented in the metal sash with a putty containing linseed oil and red lead, so the joints between glass and metal are air-tight. Special valves are set in the roof for connecting the room with a flue leading to an exhaust fan. Each valve consists of a sheet-iron bell suspended in a tube of slightly larger diameter, which has at the bottom, inside, an annular space containing mercury. When the bell is seated in the annular space, the mercury seal makes the valve gas-tight. A chain attached to the bell runs over pulleys to a point where it may be reached by one on the outside of the chamber. Raising the bell into a closed space above a T in the pipe permits the gases in the chamber to be exhausted.

Experiments have shown that the room is nearly gas-tight. During 24 hours the interchange of gas between the inside and outside of the closed chamber amounts to less than 10 per cent of the chamber volume.

Smoldering fires were built inside this chamber in the apparatus shown in figure 2 (p. 24). It consisted of an ash can with a large hole cut in one side near the bottom and set on bricks. Air could be blown through the can by means of an electric fan set before the hole. The combustible material was put into a holder made of two wire wastebaskets, and set inside the ash can. A spray nozzle held above the fire box was connected by hose to a faucet outside. Whenever a blaze burst out it was damped by a spray of water.

It was necessary to keep the fire burning slowly to prevent a rapid liberation of heat, which would cause the walls to expand and endanger the glass windows. A water-sealed inlet and outlet for air prevented excessive pressure from expansion of air in heating. Slow fires were desired, however, to simulate the actual fires that occur in closed rooms, cellars, and other confined places where the oxygen supply may be insufficient to support rapid and complete

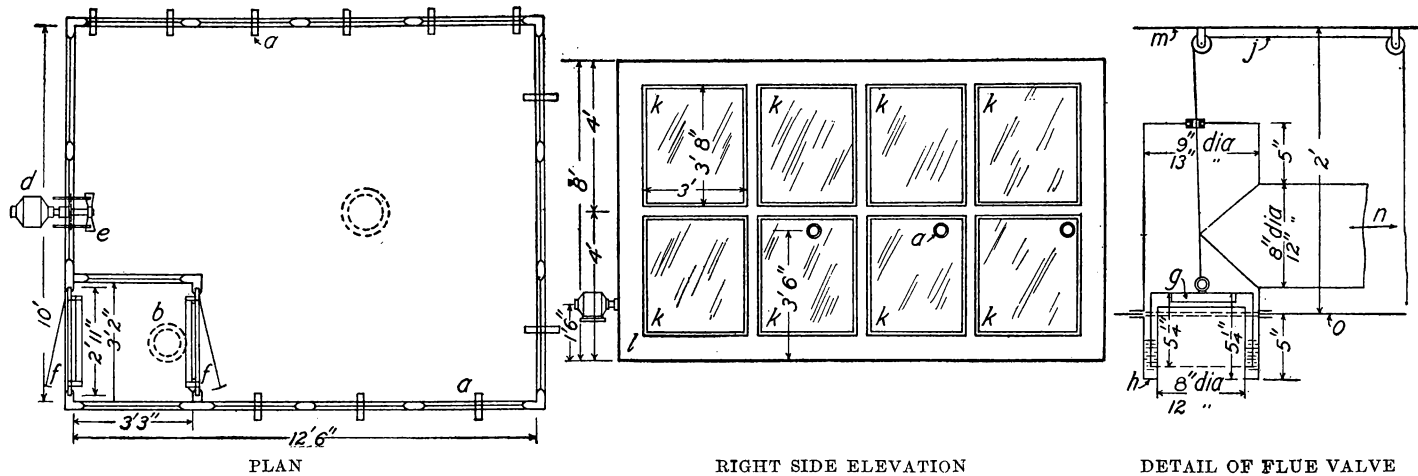


FIGURE 3.—Detail of gas chamber used at the Pittsburgh experiment station of the Bureau of Mines for experimental purposes. *a*, Standard W. I. 2-inch pipe, threaded both ends, set with two nuts and rubber gasket; *b*, 8-inch flange in roof for exhaust flue; *c*, 12-inch flange in roof for exhaust flue; *d*, motor; *e*, fan; *f*, refrigerator doors; *g*, 25-pound weight to submerge bell side in mercury well; *h*, annular mercury well; *i*, round-throated ferrule, $\frac{3}{8}$ -inch hole; *j*, $\frac{3}{8}$ -inch galvanized-metal sash cord; *k*, plate glass 36 by 44 inches; *l*, No. 16-gage sheet steel; *m*, ceiling; *n*, to hood; *o*, roof of gas house.

NOTE.—No. 24-gage steel roof; No. 16-gage steel floor. All sheet-metal joints soldered; back center panel has glass at top and bottom.

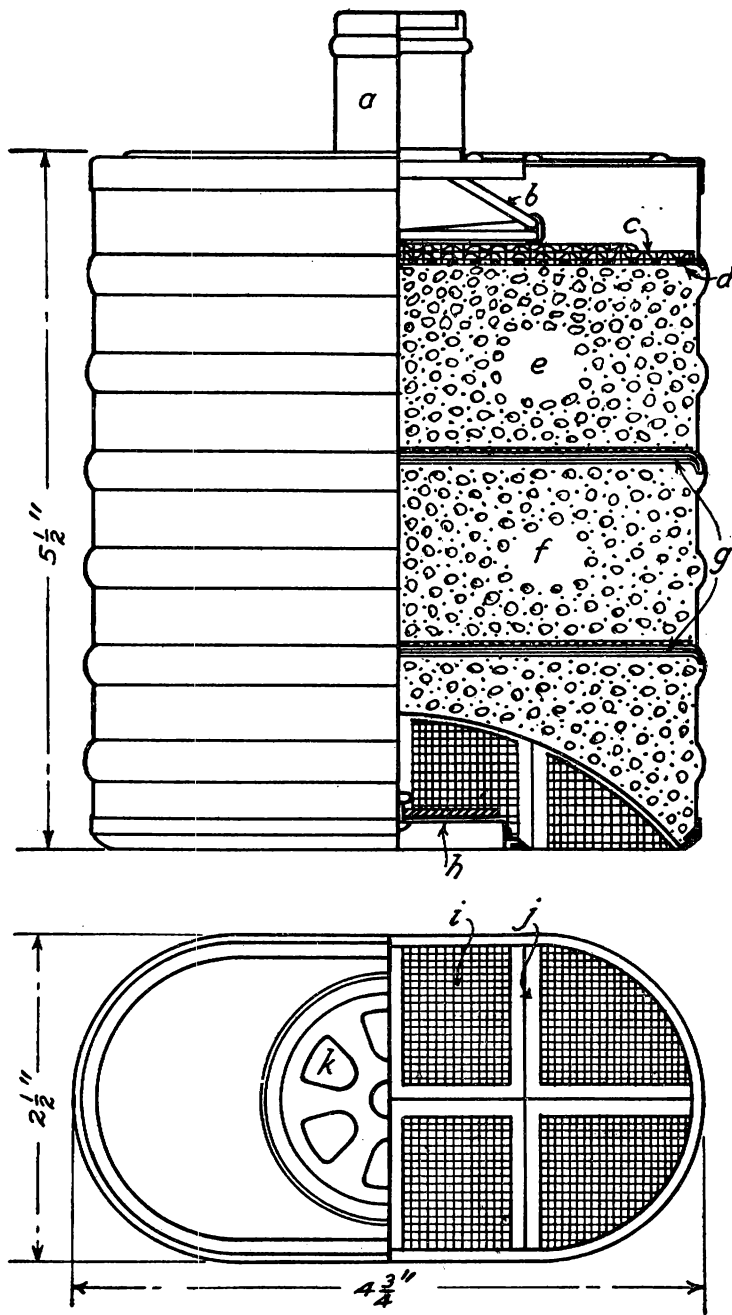


FIGURE 4.—Army gas-mask canister, capacity 42 cubic inches of absorbent: *a*, Hose nipple; *b*, strong spring; *c*, stiff wire; *d*, toweling; *e*, mixed charcoal and soda lime absorbent; *f*, mixed charcoal and soda lime absorbent; *g*, cotton wool fillers between wire screens; *h*, rubber disk check-valve; *i*, wire-screen dome; *j*, sheet-metal stiffener for dome; *k*, air inlet.

CARBON MONOXIDE, CARBON DIOXIDE, AND METHANE, PER CENT.

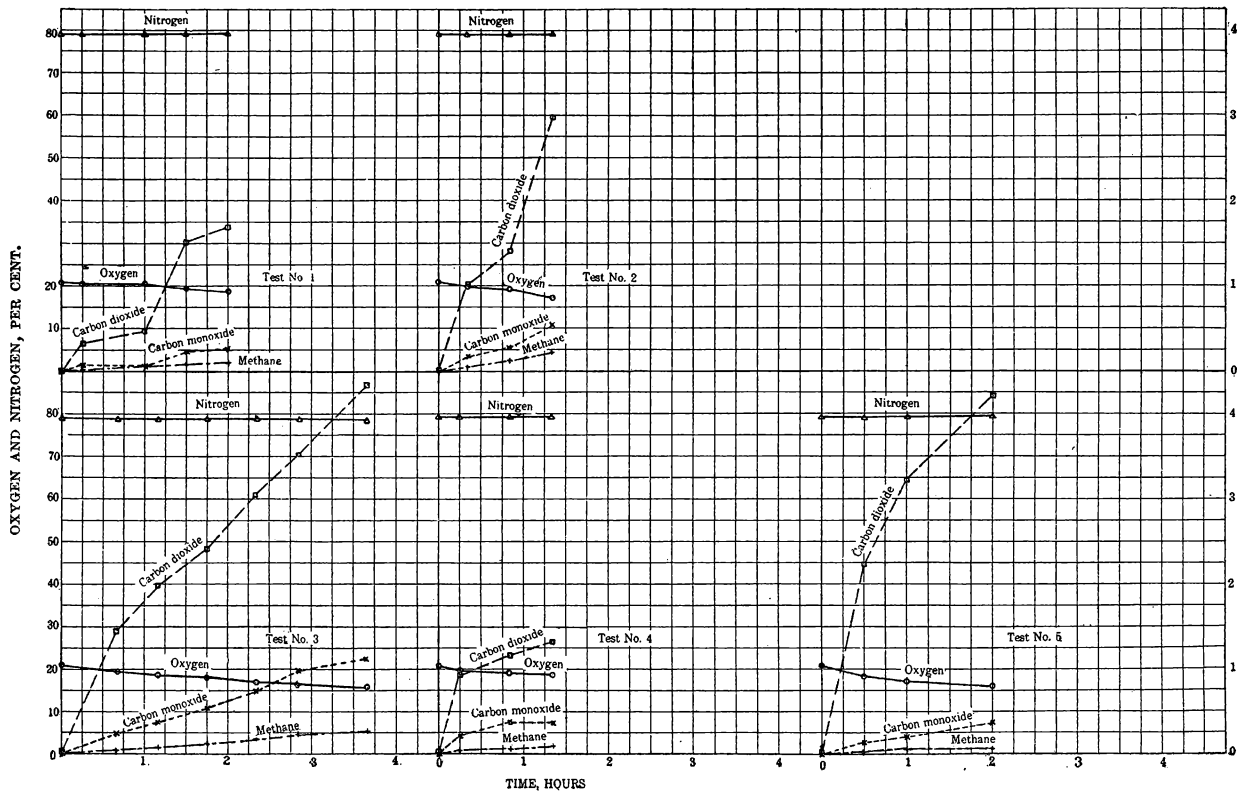


FIGURE 5.—Curves showing relation between change of composition of gases in the experimental chamber, with time, during experimental fires.

combustion and where there is greatest danger from carbon monoxide. Several fires with different combustibles were built in the apparatus.

In order to test the protection from smoke afforded by Army gas masks in the different atmospheres, masks were worn into the chamber long enough at a time for the wearer to obtain the information but not long enough to be overcome by the carbon monoxide. In one test the effect was determined by subjecting a canary bird to the air from the chamber, which was first drawn through a canister. Comparative tests were also made with different kinds of respirators and gas masks.

RESULTS OF TESTS WITH FIRES IN A CLOSED ROOM.

The results of the tests with smoldering fires in the closed chamber are given in tabular form in Table 2, which follows. Figure 5 shows graphically the relation between change of composition of gas in the chamber with time for some of the experiments. Table 3 gives the results of tests on the different masks and respirators against smoke.

DISCUSSION OF RESULTS OF TESTS WITH FIRES.

Table 2 shows that smoldering fires form carbon monoxide in dangerous quantities. The proportion that may be present in any confined atmosphere where a fire exists depends upon duration of the fire, the volume of air present, and the rate of burning of the carbonaceous matter. Ventilation reduces the amount of poisonous gas by displacing some of the vitiated air with an equal volume of fresh air. Hence ventilation should be established in the space where the wearer of a gas mask has to go in order to reduce the danger of carbon monoxide poisoning.

The irritating, suffocating smokes and gases produced by the fires were completely removed by the Army gas mask, but the wearer had no indication from the air he breathed that carbon monoxide was present. Although the mask was worn in the smoke for periods of three minutes or less, not long enough for a man to be overcome, the experiments with the canary birds show conclusively that the danger existed.

Closely confined spaces, like the one in the experimental chamber, are found in only a few places, as in mines and in cellars and vaults of buildings. Fires in such places are especially dangerous. In rooms of buildings above ground, there is usually enough ventilation to prevent accumulation of products of combustion in such concentration as may be encountered below ground. Also, the fire fighter may open doors and windows to insure an exit for the products of combustion.

TABLE 2.—Results of tests with smoldering fires in closed room.

Experiment No.	Materials used for fire.	Total weight of materials.	Time after starting fire.	Analysis of gas, per cent.					Man entered room at time after start.	Length of time man was in room.	Remarks.
				CO ₂ , carbon dioxide.	O ₂ , oxygen.	CO, carbon monoxide.	CH ₄ , methane.	N ₂ , nitrogen.			
1	Excelsior, cotton cloth, paper.	Pounds. 3	H. m.						H. m.	Mins.	{ Smoke very dense. Hand could not be seen when 18 inches before face. No noticeable smoke penetrated Tissot type Army gas mask with type H standard Army canister. At end of test mask was tried by man outside of smoke room breathing air from room through canister for one minute. Mask gave full protection from the smoke and irritating fumes.
			0 00	0.03	20.93	0.00	0.00	79.04	} 0 17	4	
			0 15	.35	20.53	.08	.03	79.01			
			1 00	.47	20.34	.07	.07	79.07			
			1 30	1.53	19.11	.24	.09	79.03			
2 00	1.68	18.81	.27	.11	79.13						
2do.....	5	0 00	.03	20.93	.00	.00	79.04	} 1 20	1	{ Smoke very dense. Objects more than 15 inches distant could not be seen through smoke. Army mask—Tissot type with standard canister—allowed no smoke to penetrate it, and the air breathed was seemingly normal.
			0 20	1.04	19.81	.18	.06	78.91			
			0 50	1.41	19.35	.28	.13	78.89			
3do.....	6	1 20	2.96	17.37	.57	.21	78.89	} 3 40	1	{ Smoke not very dense. Light could be distinguished through width of chamber. Gas mask apparently supplied very pure air to wearer though he would have been overcome had he remained a few minutes longer. The canary bird in bell jar, as shown in Plate VIII, was overcome by the air drawn from the chamber and through a canister, at this time, in less than one minute.
			0 00	.03	20.93	.00	.00	79.04			
			0 40	1.45	19.61	.24	.05	78.65			
			1 10	1.97	18.64	.37	.08	78.90			
			1 45	2.40	17.92	.57	.12	78.91			
4	Wood, cotton, waste paper, rubber, excelsior, sulphur.	4	2 20	3.06	17.10	.75	.18	78.89	} 1 05	2	{ Sulphur dioxide is included with carbon dioxide in the analysis. Separate determination showed 0.05 per cent SO ₂ ; 0.05 per cent SO ₂ is unbearable to breathe. Gas mask apparently gave perfect protection. Besides the times specified a man entered the chamber six times during the test for 15-second periods. He had headache at night.
			2 50	3.55	16.43	.95	.22	78.85			
			3 40	4.34	15.77	1.13	.26	78.50			
			0 00	.03	20.93	.00	.00	79.04			
			0 15	.92	19.73	.22	.04	79.09			
5	Charcoal.....	5	0 50	1.16	19.13	.36	.06	79.14	} 2 00	1	{ Charcoal burned in tinner's portable stove. Man wearing gas mask received no indication of impurities in the air he breathed.
			1 00	3.22	17.19	.21	.06	79.32			
			2 00	4.20	16.02	.36	.05	79.37			
6	Excelsior.....	3	2 15	.53	20.34	.14	.04	78.95	} 2 15	2	{ Smoke very dense and tinged yellow, very irritating to the eyes. The Army mask gave perfect protection against it.

TABLE 3.—Results of tests with different masks and respirators in smoke.

Materials used for fire.	Total weight of material.	Type of canister on gas mask.	Type of face piece on gas mask.	Type of respirator.	Time apparatus was worn in smoke.	Protection against smoke.	Remarks.	
Excoelsior, paper, cotton waste.	Pounds. 2½	Standard Army or H type.	Tissot, nose-breathing.	.....	Minutes. 3	Good.....	Analysis of the gas in the chamber showed its constituents were: Per cent. Carbon dioxide..... 0.75 Oxygen..... 19.73 Unsaturated hydrocarbons..... .40 Carbon monoxide..... .19 Hydrogen..... .05 Nitrogen..... 78.88 Smoke not very dense; objects could be distinguished 4 feet through it.
				.....	3	...do.....	
		Army J type, contains two-thirds the absorbent of the H type; otherwise the same. Commercial canister with charcoal and soda-lime filler but no filter pads. Same as above with one filter pad.	Tissot.....	None.....	A noticeable but not discomfoting amount of smoke came through.
					.....	2	Fair.....
					Rubber body with moist sponge filter.	.....	None.....
					Cloth and leather with silk gauze and dry sponge filter. Rubber body with paper filter.	.....	...do..... ...do.....

Table 3 shows that the respirators of the "pig snout" type offered no noticeable protection against smoke, whether the filtering medium was a moist sponge, paper, or a combination of fine silk gauze and dry sponge. The commercial canister with only one filter pad gave sufficient protection against smoke to be worn with full comfort. The odor of smoke that penetrated it was quite mild. The Army canisters, which contained two filter pads, gave complete protection against the smoke, and no odor of smoke could be detected. Although no smoke penetrated the Army masks in these tests, it has been found at times that a very small amount of smoke will pass through the Army masks. In those cases, the smoke particles have been unusually small. However, the amount of smoke that has penetrated has not been sufficient to cause much discomfort.

The experiments show especially that the Army gas mask may be used only to remove the suffocating and irritating smokes and gases of fires from the air breathed and that no reliance can be put upon it for protection from carbon monoxide.

The length of time a fireman may safely remain in the smoky atmosphere will depend upon the amount of carbon monoxide present, and this the fireman can not possibly foretell. In the fire at the Pittsburgh Paper Stock Co., the firemen wearing masks worked for a total time of two to three hours without ill effects. On the other hand, firemen wearing masks have been overcome at Rochester, N. Y., and elsewhere, before they returned to fresh air. The building at Pittsburgh was well ventilated, but the fire at Rochester was in a basement, where ventilation was poor.

A man wearing a mask and breathing heavily at hard work in the atmosphere developed in experiment No. 3, Table 2, would probably be overcome in less than two minutes. Hence no definite limit of time that a man protected by a gas mask of the Army type may safely remain in a smoke-filled space can be set, but this conclusion may be made: When a fire fighter finds it necessary to enter a smoke-filled space inside a building, he may use the mask to protect himself from the smoke, but should accomplish his purpose and leave the dangerous region without delay.

EXPERIMENTS WITH CARBON TETRACHLORIDE FIRE-EXTINGUISHER LIQUIDS.

Chemists and many persons interested in fire fighting know that carbon tetrachloride, although a comparatively stable liquid, tends to decompose when heated to a high temperature. The decomposition yields chlorine and other irrespirable gases.

Because of the death of two men working in the Navy Department and the overcoming of an employee of the Bureau of Mines as a

result of fighting fires with carbon tetrachloride extinguishers, the matter was investigated. The results showed that phosgene, hydrogen chloride, and in some cases chlorine, as well as the vapors of carbon tetrachloride itself, were evolved. The mixture of these gases and vapors with the air in the chamber of 1,000 cubic feet capacity formed an atmosphere that would quickly kill a man unprotected against it.

Commercial carbon tetrachloride and two well-known brands of carbon tetrachloride fire-extinguishing liquids were used in experiments. Qualitative tests for carbon bisulphide and chloroform gave the following results:

Results of qualitative tests for carbon bisulphide and chloroform.

Kind of liquid.	Carbon bisulphide.	Chloroform.
Commercial carbon tetrachloride	Present	Absent.
Extinguisher liquid No. 1	do	Present.
Extinguisher liquid No. 2	do	Do.

Analytical distillation of the liquids gave the results shown in Table 4.

TABLE 4.—*Results of distillation of carbon tetrachloride fire-extinguisher liquids.*

[200 cc. distilled in a 6-inch Hempel flask.]

Amount distilled (per cent.)	Commercial carbon tetrachloride.— Barometer, 739 mm.		Liquid No. 1.— Barometer, 730 mm.		Liquid No. 2.— Barometer, 743 mm.	
	Temp., °C.	Sp. gr.	Temp., °C.	Sp. gr. at 15°C.	Temp., °C.	Sp. gr. at 15°C.
First drop.....	67		54		54	
1.....	71		68		69	
2.....	72		69		70	
10.....	74.3	1.599	71	1.567	71.5	1.564
20.....	74.8	1.596	71.5	1.579	72	1.580
30.....	75	1.600	72	1.583	73	1.588
40.....	75.1	1.600	72.5	1.588	73	1.588
50.....	75.3	1.603	73	1.591	73.5	1.593
60.....	75.3	1.603	73	1.591	74	1.595
70.....	75.4	1.603	73.7	1.596	74.5	1.598
80.....	75.5	1.604	74	1.598	75	1.601
90.....	75.5	1.606	74.3	1.601	75.5	1.602
95.....	75.5	1.606	74.5	1.603	76	1.603
Dry point.....	75.5		74.5		76	
Distilled, per cent.....	97.1		97.5		95	
Residue, per cent.....	1.3		1.6		4.5	.897

REMARKS.—First distillate of commercial carbon tetrachloride gave odor of carbon bisulphide. First distillate of liquid No. 1 smelled of chloroform. First distillate of liquid No. 2 smelled of carbon bisulphide. Residue smelled of kerosene and was inflammable.

From the results of Table 4 it appears that one of the commercial extinguisher liquids was carbon tetrachloride, with an admixture of chloroform to prevent freezing; the other was a mixture of carbon

tetrachloride, chloroform, and a high-boiling petroleum distillate, the last added for the same purpose.

In order to determine the behavior of both commercial carbon tetrachloride and the other liquids as regards decomposition into gases when the liquids are put on a fire, experiments were made with small fires of excelsior and other inflammable material in the 1,000 cubic foot chamber. Other experiments in which the extinguisher fluids were poured upon red-hot iron were made in the same chamber. The air was stirred with an electric fan to insure a uniform concentration of gas throughout the chamber.

For investigating decomposition products obtained by pouring carbon tetrachloride on red-hot iron, a 6-inch channel iron was heated to bright red heat over a length of 2 feet; then it was quickly placed near the floor of the chamber, and the contents of a 1-quart fire extinguisher were steadily sprayed or poured upon it by a man wearing a gas mask or one-half hour breathing apparatus. After the extinguisher was emptied, the fan was started, and samples of the gas were taken as soon as its concentration was uniform. These samples were analyzed for various products of decomposition, including carbon tetrachloride (CCl_4), muriatic acid gas (HCl), phosgene (COCl_2), and chlorine (Cl_2) in parts per million (p. p. m.); and carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and nitrogen (N_2), in per cents.

Similar experiments were made with burning excelsior, rags, and other waste material. The results of these experiments are given in Table 5.

Table 5 shows that in all the experiments the atmosphere created by using the fire extinguisher was exceedingly dangerous. A rather surprising result of this investigation was the fact that phosgene, which is extremely poisonous, was liberated in every experiment in toxic quantities.

Experiment No. 1, in which 800 c. c. of carbon tetrachloride was poured on a red-hot 4-inch I beam, showed 168 parts per million of phosgene in the atmosphere of the chamber. This concentration is fatal. Chlorine was not found as a decomposition product in most of the experiments. Experiments Nos. 2 and 6 show some chlorine, but not enough to be considered very dangerous.

Small quantities of carbon monoxide were given off in most of the experiments, both with liquid No. 1 and liquid No. 2. Hydrogen chloride or muriatic acid gas was present in sufficient concentration to be irritating, but would hardly be dangerous. Carbon tetrachloride vapor was present in concentrations ranging from 0.2 to 0.6 per cent, or 2,000 to 6,000 parts per million. This concentration is not considered sufficient to produce anaesthesia in a short time. However, if the chamber volume were much smaller there would undoubtedly

TABLE 5.—Results of experiments with heated carbon tetrachloride fire-extinguisher liquids in the closed chamber.

Ex-periment No.	Liquid used.	Vol-ume of liquid used, c. c.	Source of heat.	Esti-mated temp., °C.	Results of analyses.								Color of smoke.	Remarks.
					CCl ₄ , p. p. m.	HCl, p. p. m.	COCl ₂ , p. p. m.	Cl ₂ , p. p. m.	CO, per cent.	CO ₂ , per cent.	O ₂ , per cent.	N ₂ , per cent.		
1	Commercial, CCl ₄ .	800	4-inch I beam.....	825	4,350	144	168	0	0.00	0.03	20.51	79.46	Yellow, like chlorine..	Odor of CCl ₄ and HCl noticed. Phosgene could be detected by odor.
2	Do.....	1,000	6-inch channel.....	600	5,850	.....	80	23	.00	.4	20.3	79.3	.....do.....	
3	Do.....	1,000	Excelsior fire.....	.....	5,130	110	60	0	.41	3.49	16.59	{ 79.39 CH ₄ .12	} Red-brown, nearly black.	Could detect HCl and COCl ₂ by odor. Could detect HCl and COCl ₂ by odor. Do.
4	No. 1.....	1,000do.....	4,970	82	15	0	.17	1.22	19.70	{ 78.68 CH ₄ .17			.....do.....
5	No. 2.....	300	.....do.....	.....	2,000	65	19	0	.22	.81	19.87	{ 79.06 H ₂ .04	.....do.....	
6	No. 1.....	400	6-inch channel.....	825	2,607	60	30	10	.16	.31	20.68	{ 78.84 H ₂ .01	} Yellow, like chlorine..	
7	No. 2.....	1,000	6-inch channel, plus 4-inch I beam.	950	2,078	236	42	0	.22	.36	20.52	78.90	Black.....	Liquid burned on iron with a flickering flame.

be a high enough concentration of carbon tetrachloride vapor to cause anaesthesia by itself, and men would become instantly unconscious, and furthermore the phosgene present would produce effects in the lungs and respiratory system that would prove fatal.

When commercial carbon tetrachloride is poured on red-hot iron, it produces a yellowish smoke that looks much as though chlorine were one of the decomposition products. This is not the case, however, and no chlorine was found, either by chemical test or by odor, except in experiments 2 and 6.

The predominating odor was carbon tetrachloride itself, phosgene, and hydrochloric acid. The yellowish color of the smoke was found to be due to iron chloride formed by the action of carbon tetrachloride on the hot iron. This iron chloride vaporizes, then reacts with the moisture in the air, hydrolyzes, and forms hydrochloric acid and iron oxide. Liquid No. 1 gives the same sort of smoke as does commercial carbon tetrachloride, whereas liquid No. 2 gives a black smoke, its color seemingly due to particles of carbon formed by decomposition of the kerosene or other petroleum oil that is put in this extinguisher to lower the freezing point.

It was of course impossible for a man to take even one breath of the atmosphere created in the gas chamber while spraying the extinguisher on hot iron or burning excelsior.

DISCUSSION OF RESULTS OF TESTS WITH LIQUIDS CONTAINING CARBON TETRACHLORIDE.

All three liquids decomposed in the same way when put on a fire. Whether the source of heat was a wood fire or red-hot iron made no material difference, except that with the fires the percentage of carbon monoxide and perhaps of certain other gases was largely increased, owing to products of decomposition from the combustible itself.

As a result of these experiments, the Bureau of Mines believes that carbon tetrachloride extinguishers should not be used on fires in confined spaces by persons who are not protected against the fumes produced in this way, or who are unable to hold their breath and get away at once from the immediate vicinity of the fire after applying the extinguisher. The Army gas mask will provide adequate protection from all the gases, except carbon monoxide, which was not found in sufficient concentration to be dangerous in the short time required to use an extinguisher. The results of the tests should not discourage the use of carbon tetrachloride fire extinguishers, which are very effective in extinguishing incipient fires, because in nearly every fire the ventilation, or the large amount of air usually present, prevents the formation of very dangerous concentrations of poisonous gas. Also the operator is nearly always able to escape easily and quickly from the vicinity of the gas as soon as he notices it. The purpose of

the tests made by the bureau was to show the danger of using such extinguishers in small, unventilated places where rapid escape is impossible.

ATMOSPHERES IN BURNING MINES.

Although no analyses of vitiated air from burning buildings are available, so far as is known, the Bureau of Mines has made many analyses of gases in burning mines. Some representative analyses are given in Table 6.

These figures show conclusively the presence of carbon monoxide in deadly amounts and prove that the ordinary Army gas mask can not protect the wearer from poisonous gases in a burning mine. *The Army type of gas mask is not to be used in burning mines.*

As a result of the experience of its engineers and of the collection of such data as are given in Table 6, the Bureau of Mines recommends the use of self-contained oxygen-breathing apparatus by men doing rescue work in mines. If such apparatus are not available, it is preferable to enter the mine without breathing apparatus rather than to trust to other types of breathing appliances. The Army gas mask would give the wearer in the mine a false sense of security by removing distasteful fumes from the air breathed and allowing the carbon monoxide to pass through unnoticed. The smoke and gases from fires in mines serve to warn the workers of the presence of dangerous gas.

The Bureau of Mines has published considerable information on mine fires and the use of oxygen-breathing apparatus. Among its publications are Bulletins 44 and 62; Technical Papers 11, 13, 24, 59, 62, 82, 103, 134, and 150; Miners' Circular 10; and a handbook on rescue and recovery work in mines. The titles of these publications are given in the list on page 67.

UTILITY OF ARMY GAS MASKS IN FIGHTING FIRES.

Whether or not firemen should adopt the Army gas mask for general use has been much discussed. Theoretically it would seem that the half-hour oxygen-breathing apparatus, which keeps out all gases and supplies oxygen, would be much safer than the gas mask for fire fighting. But practical experience shows that firemen, as a rule, do not favor oxygen-breathing apparatus. To them it seems cumbersome and uncertain in action. The combination of oxygen cylinder, breathing bag, regenerator canister, valve and pressure gage appears too complicated for the rough and ready work of fire fighting. Although such apparatus has been on the market for a number of years, it is seldom put into practical use, even when on hand, at fires. Firemen prefer to take their chances unencumbered, or at most simply to tie a wet handkerchief or towel over the nose and mouth to keep out some of the smoke.

TABLE 6.—Analyses of gases from mine fires.

Mine.	City or town.	State.	Date of fire.	Laboratory No.	Character of mine.	Analyses, per cent.					Remarks.
						CO ₂ .	O ₂ .	CO.	CH ₄ .	N ₂ .	
Mountainview.....	Butte.....	Mont...	Aug. 20, 1913	4062	Copper..	1.90	16.62	0.29	0.02	81.13	
				4063	do.....	3.29	14.49	.40	.09	81.72	
Tramway.....	do.....	do.....	Mar. 8, 1917	8651	do.....	2.57	17.50	.22	.21	79.47	
				8652	do.....	3.10	16.89	.23	.30	79.44	
Leonard.....	do.....	do.....	Mar. 9, 1917	8673	do.....	5.40	14.43	1.17	.95	77.93	SO ₂ , 0.12 per cent.
High Ore Modoc.....	do.....	do.....	July 6, 1917	9163	do.....	3.20	13.35	.28	.....	83.13	SO ₂ , 0.04 per cent.
West Colusa.....	do.....	do.....	Oct. 22, 1917	9290	do.....	10.02	7.28	.91	.31	81.48	
				9291	do.....	6.98	11.11	.57	.28	81.06	
Pennsylvania.....	do.....	do.....	Feb. 21, 1916	7154	do.....	1.45	18.80	.20	Trace.	79.45	H ₂ , 0.10 per cent.
				7156	do.....	4.82	14.58	.68	.44	79.09	H ₂ , 0.39 per cent. Four men without breathing apparatus were overcome in this atmosphere.
East Colusa.....	do.....	do.....	Feb. 18, 1919	10320	do.....	10.05	1.72	.26	.07	87.88	H ₂ , 0.02 per cent.
				10313	do.....	10.07	1.67	.35	.04	87.84	H ₂ , 0.03 per cent.
				10314	do.....	10.91	1.92	.28	.04	87.82	Do.
Idria.....	Luria.....	Calif....	Dec. 31, 1918	10227	Quick-silver.	.59	20.23	.10	.06	79.02	
Conglomerate No. 5....	Calumet.....	Mich....	Jan. 28, 1916	7063	Copper..	5.19	14.69	.69	.27	78.84	H ₂ , 0.32 per cent.
				7064	do.....	4.09	15.84	.65	.18	79.03	H ₂ , 0.21 per cent.
Consolidated Virginia and Ophir.	Virginia City	Nev.....	July, —, 1914	5225	Gold....	2.60	16.38	.18	.16	80.68	
Mizpah.....	Tonopah.....	do.....	July 16, 1914	5226	do.....	2.62	16.30	.25	.10	80.70	
				5318	do.....	5.56	13.80	.71	.10	79.65	H ₂ , 0.18 per cent. Artificial fire, built for training purposes.
Weber.....	Fairview.....	do.....	Sept. 3, 1914	5421	do.....	9.32	10.14	1.88	.83	76.97	H ₂ , 0.72 per cent; C ₂ H ₄ , 0.14 per cent.
				5422	do.....	9.22	10.25	2.02	.72	76.31	H ₂ , 1.28 per cent; C ₂ H ₄ , 0.20 per cent. Fire in timbered drift (abandoned), was kindled for rescue-training purposes.
Yellow Jacket.....	Gold Hill....	do.....	June 1, 1916	7657	do.....	11.51	4.09	.53	.....	83.78	H ₂ , 0.09 per cent. (This fire caused the death of four men.)
				7658	do.....	.27	16.28	.40	.07	82.47	H ₂ , 0.07 per cent. (This fire caused the death of four men.)
Government.....	Carthage....	N. Mex.	Mar. 6, 1918	9598	Coal....	6.67	2.34	.52	.66	89.81	One man lost his life in this fire, while exploring with breathing apparatus; he removed mouthpiece and talked against commands of party leader. Analysis of blood showed death from carbon monoxide.
Owl Creek.....	Gebo.....	Wyo....	Mar. 8, 1918	9593	do.....	4.54	5.44	.31	.34	89.37	
Valley Camp.....	Valley Camp	Pa.....	Jan. 19, 1917	3369	do.....	8.30	10.91	.44	1.67	78.68	
			Feb. 26, 1913	3370	do.....	3.00	15.61	.33	.84	80.17	Canary bird overcome in this gas. One man without breathing apparatus was rendered unconscious, but was rescued and revived.
				3370	do.....	6.37	10.73	.84	1.49	80.57	

Therefore the utility of the gas mask must be considered from the practical point of view rather than the theoretical. A review of the many reports of tests in experimental fires by city fire departments shows: (1) That firemen are favorably impressed with the simplicity of the gas mask and will wear it; (2) that in the great majority of these tests it protected the eyes and throat from irritating smoke and was a great improvement on sponge respirators and wet cloths; (3) that the mask did not encumber the wearer or retard his effectiveness in fire fighting; (4) that no special training was required in learning how to use the mask; (5) that in comparison with the oxygen-breathing apparatus very little attention is required to keep the gas masks in good condition.

These experiments by fire departments corroborate the experiments of the Chemical Warfare Service and of the Bureau of Mines in proving conclusively that the Army gas mask, when fitted with a canister containing cotton filter pads, activated charcoal, and soda lime, effectively filters out irritating smoke particles, and, in addition, protects against most chemical fumes in the concentrations likely to be met in fires.

However, in using the Army mask the following serious limitations must be kept in mind: (1) It furnishes no oxygen; hence it should not be worn into a place where a safety lamp or a fireman's oil-burning lantern will not burn; (2) it should not be used where there is reason to suspect carbon monoxide, as in smoldering fires in basements and other confined, unventilated spaces, and especially in confined places where broken illuminating gas pipes add carbon monoxide to the air; (3) it offers very poor protection against ammonia; (4) finally, the Army mask may break down in unusually high concentrations of poisonous gases. It was originally designed for outdoor use, where the poisonous gases are considerably diluted with air. Caution must be used, therefore, in going into rooms where the concentration of the accumulated gas may be great enough to pass through the mask.

RECOMMENDED GAS MASK FOR FIRE FIGHTERS.

Perhaps the most serious limitation of the Army mask for fire fighting is its inability to protect against ammonia and carbon monoxide. Although special ammonia canisters are now available commercially, and carbon monoxide canisters soon will be available, the fire fighter does not know in advance what gas or combination of gases he may find. Many buildings contain ammonia refrigerating plants, and all cities outside the natural gas belt are piped for artificial gas containing carbon monoxide. The fireman, therefore, must have, in a single mask, protection against all these gases, either by attaching several canisters to the same face piece or by increasing

the size of the fireman's canister to about three times the volume of the present Army canister. This larger canister should contain special absorbents for ammonia and carbon monoxide, when the latter is developed, in addition to the present filling of charcoal, soda lime, and filter pads. With such a canister, a fireman could safely enter any atmosphere in which a safety lamp would burn.

SPECIFICATIONS FOR FIRE-FIGHTERS' GAS MASK.

In order to promote the production of an adequate combination gas mask for fire fighters, the Bureau of Mines will cooperate with city fire departments in obtaining more accurate information as to the actual gases present in connection with fires, and with manufacturers of gas masks in testing and approving suitable gas masks when submitted to the bureau in accordance with schedule 14.³⁴

Fire departments desiring to cooperate in obtaining information on the presence of carbon monoxide in gases from fires should communicate with the Pittsburgh experiment station of the Bureau of Mines. They will be furnished vacuum bottles, with full instructions for taking samples and forwarding them to the bureau's laboratory for analysis.

Gas masks submitted by manufacturers for approval will be tested to determine whether they pass the following requirements:

REQUIREMENTS FOR BUREAU OF MINES APPROVAL.³⁵

I. COLOR AND MARKINGS.

Distinctive color and marking to indicate the purpose of each canister or absorbent container are required for the purpose of safeguarding the wearers. The colors required are indicated in the following table:

TABLE 7.—*Colors to indicate purpose of masks.*

Mask type letter.	Chemical properties of gases absorbed.	Distinctive color required.
A	Acid	White.
B	Organic vapor	Black.
C	Ammonia	Green.
D	Other special individual gases	Color to be assigned.
E	Dusts, smokes, mists	White or black stripes.
E	Acid and organic vapors	Yellow.
A.B. Combinations of those above.	Combinations of those above	Combinations of those above. When a dust filter is combined with a gas respirator it is to be indicated by black or white stripes.

The canisters or containers for the absorbent material shall be either painted completely in these colors or the color shall be made a distinctive part of the canister design. On the canister shall be indicated, in bold letters, this statement:

FOR USE ONLY IN (Name gas or gases.)

³⁴ Procedure for establishing a list of permissible gas masks; fees, character of tests, and conditions under which gas masks will be tested. Sched. 14, Bureau of Mines, 1919.

³⁵ Procedure for establishing a list of permissible gas masks; fees, character of tests, and conditions under which gas masks will be tested. Sched. 14, Bureau of Mines, 1919. Supplement to Sched. 14, Bureau of Mines, 1920.

The manufacturer will state the gas or gases, or classes of gases, in which the gas mask is to be used. For this purpose, it is permissible to attach a metal plate bearing the proper inscription in raised or other distinct letters, or to stamp the statement into the metal of the can with a male and female die. The statement may be printed or stenciled with paint, or paper labels may be used. The latter must be attached with a heat-proof cement and varnished to prevent loosening by moisture.

If a dust respirator is combined with gas absorbents, the fact should be indicated, as, for example:

FOR USE ONLY IN AND IN DUSTS. (Name gas or gases.)

The knapsack or case in which the gas mask is kept must also have the same statement indicated conspicuously in bold letters. The distinctive color or colors may be that of the letters themselves or that of the background, or part of the design, in such fashion that the distinctive colors are prominent.

Metal plates or painted or printed stencils may be used on the knapsacks, but paper labels will not be permissible here.

For chemical smokes or fumes, the canister or container for the absorbent material shall be of a color to indicate the purpose of absorbent material contained, and shall be striped with a strongly contrasting color, either black or white, to indicate the filters. The stripes may be so placed as to indicate the number and position of the filters. On the canister or container shall be indicated, in bold letters of contrasting color, this statement:

FOR USE ONLY IN —————. (Name gas or gases and chemical fume, according to the purpose of the manufacturer.)

The knapsack or case in which the gas mask is kept must also have the same statement indicated on front and back, in bold letters on a striped background of the proper colors, to indicate the purpose of the absorbent and the filter.

2. MATERIALS.

The gas mask and equipment must be constructed of materials in all its parts suitable for the purpose they must serve. This applies to the fabric, rubber, metal, chemical, and other parts.

3. DESIGN AND CONSTRUCTION.

The excellence of design and mechanical construction, as well as the workmanship, will be considered. This will be done with regard to safety to the wearer, freedom of his movements and his vision, the fit of the face and head pieces, and the comfort which is afforded under all conditions of use. There will also be considered the ease with which canister or other parts of necessarily short life may be replaced by fresh parts, and the tightness of the whole apparatus, with a view to insuring the wearer against leaks of unpurified air, both before and after such changes are made.

4. FACE-PIECE TEST.

Two men wearing the gas masks will enter a room containing 1 per cent of sulphur dioxide; if necessary, a canister for acid gases will be attached to the mask for this test. Thirty minutes will be spent in work designed to provide observations on the freedom of movement permitted, freedom from leaks, and the comfort allowed to the wearer. The time will be divided as follows:

10 minutes: Walking, turning head, dipping chin.

5 minutes: Calisthenic movements, such as swinging arms, turning body, bending body at hips.

10 minutes: Sitting at rest, then walking and easy movements.

5 minutes: Pumping air into gas cylinder of about 1 cubic foot capacity, with a tire pump, to a pressure of 25 pounds.

To meet approval, it will be necessary that no sulphur dioxide come through the mask during the test and that no undue discomfort be experienced because of the fit or other mechanical features of the gas mask.

5. RESISTANCE TO FLOW OF AIR.

Before and after the chemical tests described under paragraphs Nos. 6 and 7, the pressure drop of air passing through the canisters at a rate of 85 liters per minute will be determined in inches of water-column height. At no time must the resistance exceed 4 inches of water.

The resistance to flow of air of the complete mask and canister to inspiration and to expiration, will be determined on a mechanical apparatus, the rate being 85 liters per minute continuous flow; the resistance must not exceed 6 inches of water pressure.

6. CANISTER TESTS.

Type A—Acid gases.—Nine canisters or parts containing the absorbent, separated from the face piece and harness, will be tested on a chemical testing apparatus, under these conditions:

(1) Number of canisters, three.

Gas used for testing, chlorine.

Concentration of chlorine in air, 5,000 parts per million.

Humidity, 50 per cent relative humidity.

Temperature, room temperature (approximately 25° C.).

Rate of flow of gas, 32 liters per minute, continuous flow.

(2) Number of canisters, three.

Gas used for testing, hydrogen cyanide.

Concentration of hydrogen cyanide in air, 5,000 parts per million.

Humidity, 50 per cent relative humidity.

Temperature, room temperature (approximately 25° C.).

Rate of flow of gas, 32 liters per minute, continuous flow.

(3) Number of canisters, three.

Gas used in testing, sulphur dioxide.

Concentration of sulphur dioxide in air, 5,000 parts per million.

Humidity, 50 per cent relative humidity.

Temperature, room temperature (approximately 25° C.).

Rate of flow of gas, 32 liters per minute, continuous flow.

Tested in this way, the life or service time must be at least 20 minutes for each canister. The end of the life will be at the time at which a test shows 5 parts per million of chlorine, hydrogen cyanide, or sulphur dioxide in the air coming from the canisters.

Type B—Organic vapors.—Three canisters or parts containing absorbent, separated from the face pieces and harness, will be tested on a chemical apparatus, under these conditions:

Vapor used for testing, carbon tetrachloride.

Concentration of carbon tetrachloride in air, 5,000 parts per million.

Humidity, 50 per cent relative humidity.

Temperature, room temperature (approximately 25° C.).

Rate of flow of gas, 32 liters per minute, continuous flow.

Tested in this way, the life or service time of each canister must be at least 20 minutes. The end of the life will be the time at which the air, after passing through the canister, imparts a green color to a small gas flame containing some of the air admixed with the gas and impinging on a clean copper wire.

Type C—Ammonia.—Three canisters containing the absorbent, separated from the face pieces and harness, will be tested on a chemical testing apparatus, under these conditions:

Concentration of ammonia in air, 20,000 parts per million, or 2 per cent by volume.

Humidity, 50 per cent relative humidity.

Temperature, room temperature (approximately 25° C.).

Rate of flow of gas, 32 liters per minute, continuous flow.

Tested in this way, the life or service time must be at least 20 minutes. The end of the life will be the time at which the air, after passing through the canister, contains 100 parts per million, or 0.01 per cent by volume, of ammonia.

Type D—Other special individual gases.—Similar tests will be performed on other special gases, and will be arranged as the need arises.

Type E—Smoke, dust, and mist filters—Class I.—Three filters, separated from the face piece and harness, will be tested on a smoke-testing apparatus, under these conditions:

Fume used, tobacco smoke.

Rate of flow of gas, 85 liters per minute.

Length of test, five minutes.

Tested in this way, the filters must retain at least 95 per cent of the passing tobacco smoke at the end of the five-minute period.

Class II.—Six filters, separated from the face piece and harness, will be tested on a smoke-testing apparatus and by man tests as follows:

(a) *Tobacco-smoke test.*

Number of canisters, two.

Rate of flow of gas, 85 liters per minute.

Length of test, five minutes.

Tested in this way, the filters must retain at least 50 per cent of the passing tobacco smoke at the end of the five-minute period.

(b) *Cotton-smoke man test.*

Number of canisters tested, two.

Nature of test: Two men will wear the masks into a room of about 1,000 cubic feet capacity filled with the smoke from the smudge burning of 1 pound of cotton waste. If the masks are not made with attached canisters for the absorption of gases, such canisters shall have been attached to the filters. The men will remain 10 minutes in the room if the canisters fulfill the following requirement: No discomforting irritation of the respiratory system or eyes to be experienced by either man; this requirement is necessary for approval.

(c) *Tin tetrachloride man test.*

Number of canisters, two.

Nature of test: Two men stationed outside of a chamber of about 1,000 cubic feet capacity, in which is an atmosphere containing 500 parts per million as by volume of tin tetrachloride fumes, will breathe the atmosphere from the chamber through the canisters or filters. If necessary, a canister for absorbing acid gases will be attached to the filters. The men will continue the test for 20 minutes if the filters fulfill the following requirement: No discomforting irritation to be experienced by either man; this requirement is necessary for approval.

The applicant will state the class for which he desires tests.

Other types.—Combinations for different types of gases, as above: Canisters may be tested according to two or more methods, under (A), (B), (C), (D), and (E) above, to secure approval for different gases classed under the different types.

To meet the approval of the Bureau of Mines, it will be necessary that the life for gases in each class or type be equal to the separate requirements.

7. CHEMICAL STABILITY.

To determine the chemical stability under extreme conditions of dryness and moisture, two canisters will be subjected to each of the following tests for which approval is desired:

(a) Air free from carbon dioxide, at room temperature and 25 per cent relative humidity, will be passed through each canister, at a rate of 64 liters per minute, for a period totaling six hours. The canisters will then be tested, as described under paragraph 4, against gases as follows:

Approval for acid gas, chlorine.

Approval for organic vapor, carbon tetrachloride.

Approval for ammonia, ammonia.

Approval for special gas, special gas to be arranged.

Approval for dust and mists, no test.

Approval for combinations, any two or more of above.

To meet approval, the lives must not fall below 10 minutes in any test.

(b) Air free of carbon dioxide, at room temperature and 85 per cent relative humidity, will be passed through each of two canisters at a rate of 64 liters per minute, for a period totaling six hours, and the canisters will then be tested as described in (a) above.

To meet approval, the lives must not fall below 10 minutes in any test.

8. HIGH RATES OF BREATHING AND MAXIMUM CONCENTRATION.

To insure protection at high rates of breathing in gas of high concentration, a stream of air containing 1 per cent of gas and flowing at a rate of 64 liters per minute will be passed continuously through a canister. The other conditions of the tests will be these:

Humidity, 50 per cent relative humidity.

Temperature, room temperature (approximately 25° C.).

Gas used in testing:

Approval for acid gas, phosgene.

Approval for organic vapors, carbon tetrachloride.

Approval for special gas, ammonia, or other special gas.

Approval for dusts and mists, no test.

Approval for combinations, any two or more of the above.

Concentration, 10,000 parts per million, or 1 per cent by volume, for any gas.

Number of canisters, two, tested against any gas.

To meet the approval of the Bureau of Mines, the life of the canisters under any of the above tests against gas must be at least five minutes.

APPROVAL FOR HIGHER CONCENTRATIONS.

The Bureau of Mines requires that a gas mask pass the tests outlined above in order to secure approval for use in concentrations of 1 per cent of gas, which is the minimum for which the bureau will grant approvals. To secure the approval for higher concentrations, the canister must pass tests similar in every way, except that the concentration is increased in test 8 above in steps of 1 per cent, as far as practicable, and those tests are made on each gas for which approval in higher concentrations than 1 per cent is desired. Approval will be granted for use of the gas mask in the maximum concentration for which it successfully passes the test.

SUMMARY AND CONCLUSIONS.

1. City firemen have been overcome while wearing Army gas masks for fighting fires. This paper gives information on the use and limitations of gas masks and breathing apparatus in general.

2. The chemistry of combustion and of the various gases found in fires and commonly met in industrial plants are described.

3. The effects of poisonous gases when breathed and the methods of treatment for gas poisoning are discussed.

4. Self contained oxygen breathing apparatus gives protection against all gases and atmospheres to fire fighters in mines and buildings.

5. Because of their weight, time required for adjustment, and care necessary to keep them in working condition, self-contained oxygen breathing apparatus have not been considered entirely satisfactory, especially by city firemen.

6. The Army gas mask often fills the need of a smoke and chemical fume filter, but will not protect against carbon monoxide, atmospheres deficient in oxygen, or atmospheres containing ammonia gas.

7. The Army gas mask gives excellent protection against smoke and the irritating and distasteful products of combustion.

8. Special absorbents have been developed for removing ammonia gas from air breathed, which protect the wearer in concentrations as high as the skin will bear.

9. Poisonous carbon monoxide is given off from smoldering fires in poorly ventilated places, such as cellars, vaults, and small closed rooms. The use of ordinary gas masks in such places is dangerous. Also, where the same gas may come from broken illuminating gas pipes, their use is dangerous for the same reason and because of the possibility of insufficient oxygen.

10. There is little danger from carbon monoxide from open, freely burning fires.

11. Gas masks of the Army type *should not be used in mines* after fires and explosions. Self-contained oxygen breathing apparatus should be used.

12. Carbon tetrachloride fire-extinguisher liquids when used on fires in confined spaces produce small quantities of the poisonous gases, phosgene, chlorine (in some cases), and hydrogen chloride, as well as the vapors of carbon tetrachloride itself. These gases are dangerous. The Army type gas mask is recommended for protection against them.

13. The Bureau of Mines will cooperate with fire departments in determining the nature of gases found in fires and with manufacturers in approving suitable gas masks for fire fighting.

14. Enough progress has been made by chemists working under the direction of the Bureau of Mines and subsequently in the Chemical Warfare Service, in the development of an absorbent for carbon monoxide to raise the hope that a combination canister for a fireman's mask, which will protect against smoke, ammonia, carbon monoxide, and practically all chemical fumes, will soon be commercially available. When this is accomplished, a fireman can be protected in any atmosphere where a safety lamp will burn.

TABLE 8.—Conversion table for gases: Parts per million versus milligrams per liter.

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

M. W.	1 Mg./L.- p. p. m.	1 p. p. m.- Mg./L.	Molec- ular weight.	1Mg./L.- p. p. m.	1 p. p. m.- Mg./L.	Molec- ular weight.	1Mg./L.- p. p. m.	1 p. p. m.- Mg./L.	Molec- ular weight.	1Mg./L.- p. p. m.	1 p. p. m.- Mg./L.	Molec- ular weight.	1 Mg./L.- p. p. m.	1 p. p. m.- Mg./L.	Molec- ular weight.	1Mg./L.- p. p. m.	1 p. p. m.- Mg./L.
1.....	24, 450	0.000409	51	479	0.002086	101	242. 1	0.00413	151	161. 9	0.00618	201	121. 6	0.00822	251	97. 4	0.01027
2.....	12, 230	.0000818	52	470	.002127	102	239. 7	.00417	152	160. 9	.00622	202	121. 0	.00826	252	97. 0	.01031
3.....	8, 150	.0001227	53	461	.002168	103	237. 4	.00421	153	159. 8	.00626	203	120. 4	.00830	253	96. 6	.01035
4.....	6, 113	.0001636	54	453	.002209	104	235. 1	.00425	154	158. 8	.00630	204	119. 9	.00834	254	96. 3	.01039
5.....	4, 890	.0002045	55	445	.002250	105	232. 9	.00429	155	157. 7	.00634	205	119. 3	.00838	255	95. 9	.01043
6.....	4, 075	.0002454	56	437	.002290	106	230. 7	.00434	156	156. 7	.00638	206	118. 7	.00843	256	95. 5	.01047
7.....	3, 493	.0002863	57	429	.002331	107	228. 5	.00438	157	155. 7	.00642	207	118. 1	.00847	257	95. 1	.01051
8.....	3, 056	.000327	58	422	.002372	108	226. 4	.00442	158	154. 7	.00646	208	117. 5	.00851	258	94. 8	.01055
9.....	2, 717	.000368	59	414	.002413	109	224. 3	.00446	159	153. 7	.00650	209	117. 0	.00855	259	94. 4	.01059
10.....	2, 445	.000409	60	408	.002454	110	222. 3	.00450	160	152. 8	.00654	210	116. 4	.00859	260	94. 0	.01063
11.....	2, 223	.000450	61	401	.002495	111	220. 3	.00454	161	151. 9	.00658	211	115. 9	.00863	261	93. 7	.01067
12.....	2, 038	.000491	62	394	.00254	112	218. 3	.00458	162	150. 9	.00663	212	115. 3	.00867	262	93. 3	.01072
13.....	1, 881	.000532	63	388	.00258	113	216. 4	.00462	163	150. 0	.00667	213	114. 8	.00871	263	93. 0	.01076
14.....	1, 746	.000573	64	382	.00262	114	214. 5	.00466	164	149. 1	.00671	214	114. 3	.00875	264	92. 6	.01080
15.....	1, 630	.000614	65	376	.00266	115	212. 6	.00470	165	148. 2	.00675	215	113. 7	.00879	265	92. 3	.01084
16.....	1, 528	.000654	66	370	.00270	116	210. 8	.00474	166	147. 3	.00679	216	113. 2	.00883	266	91. 9	.01088
17.....	1, 438	.000695	67	365	.00274	117	209. 0	.00479	167	146. 4	.00683	217	112. 7	.00888	267	91. 6	.01092
18.....	1, 358	.000736	68	360	.00278	118	207. 2	.00483	168	145. 5	.00687	218	112. 2	.00892	268	91. 2	.01096
19.....	1, 287	.000777	69	354	.00282	119	205. 5	.00487	169	144. 7	.00691	219	111. 6	.00896	269	90. 9	.01100
20.....	1, 223	.000818	70	349	.00286	120	203. 8	.00491	170	143. 8	.00695	220	111. 1	.00900	270	90. 6	.01104
21.....	1, 164	.000859	71	344	.00290	121	202. 1	.00495	171	143. 0	.00699	221	110. 6	.00904	271	90. 2	.01108
22.....	1, 111	.000900	72	340	.00294	122	200. 4	.00499	172	142. 2	.00703	222	110. 1	.00908	272	89. 9	.01112
23.....	1, 063	.000941	73	335	.00299	123	198. 8	.00503	173	141. 3	.00708	223	109. 6	.00912	273	89. 6	.01117
24.....	1, 019	.000982	74	330	.00303	124	197. 2	.00507	174	140. 5	.00712	224	109. 2	.00916	274	89. 2	.01121
25.....	978	.001022	75	326	.00307	125	195. 6	.00511	175	139. 7	.00716	225	108. 7	.00920	275	88. 9	.01125
26.....	940	.001063	76	322	.00311	126	194. 0	.00515	176	138. 9	.00720	226	108. 2	.00924	276	88. 6	.01129
27.....	906	.001104	77	318	.00315	127	192. 5	.00519	177	138. 1	.00724	227	107. 7	.00928	277	88. 3	.01133
28.....	873	.001145	78	313	.00319	128	191. 0	.00524	178	137. 4	.00728	228	107. 2	.00933	278	87. 9	.01137
29.....	843	.001186	79	309	.00323	129	189. 5	.00528	179	136. 6	.00732	229	106. 8	.00937	279	87. 6	.01141
30.....	815	.001227	80	306	.00327	130	188. 1	.00532	180	135. 8	.00736	230	106. 3	.00941	280	87. 3	.01145
31.....	789	.001268	81	302	.00331	131	186. 6	.00536	181	135. 1	.00740	231	105. 8	.00945	281	87. 0	.01149
32.....	764	.001309	82	298	.00335	132	185. 2	.00540	182	134. 3	.00744	232	105. 4	.00949	282	86. 7	.01153
33.....	741	.001350	83	295	.00339	133	183. 8	.00544	183	133. 6	.00748	233	104. 9	.00953	283	86. 4	.01157
34.....	719	.001391	84	291	.00344	134	182. 5	.00548	184	132. 9	.00753	234	104. 5	.00957	284	86. 1	.01162
35.....	699	.001432	85	288	.00348	135	181. 1	.00552	185	132. 2	.00757	235	104. 0	.00961	285	85. 8	.01166
36.....	679	.001472	86	284	.00352	136	179. 8	.00556	186	131. 5	.00761	236	103. 6	.00965	286	85. 5	.01170
37.....	661	.001513	87	281	.00356	137	178. 5	.00560	187	130. 7	.00765	237	103. 2	.00969	287	85. 2	.01174
38.....	643	.001554	88	278	.00360	138	177. 2	.00564	188	130. 1	.00769	238	102. 7	.00973	288	84. 9	.01178
39.....	627	.001595	89	275	.00364	139	175. 9	.00569	189	129. 4	.00773	239	102. 3	.00978	289	84. 6	.01182

40.....	611	.001636	90	272	.00368	140	174.6	.00573	190	128.7	.00777	240	101.9	.00982	290	84.3	.01186
41.....	596	.001677	91	269	.00372	141	173.4	.00577	191	128.0	.00781	241	101.5	.00986	291	84.0	.01190
42.....	582	.001718	92	266	.00376	142	172.2	.00581	192	127.3	.00785	242	101.0	.00990	292	83.7	.01194
43.....	569	.001759	93	263	.00380	143	171.0	.00585	193	126.7	.00789	243	100.6	.00994	293	83.4	.01198
44.....	556	.001800	94	260	.00384	144	169.8	.00589	194	126.0	.00793	244	100.2	.00998	294	83.2	.01202
45.....	543	.001840	95	257	.00389	145	168.6	.00593	195	125.4	.00798	245	99.8	.01002	295	82.9	.01207
46.....	532	.001881	96	255	.00393	146	167.5	.00597	196	124.7	.00802	246	99.4	.01006	296	82.6	.01211
47.....	520	.001922	97	252	.00397	147	166.3	.00601	197	124.1	.00806	247	99.0	.01010	297	82.3	.01215
48.....	509	.001963	98	249.5	.00401	148	165.2	.00605	198	123.5	.00810	248	98.6	.01014	298	82.0	.01219
49.....	499	.002004	99	247.0	.00405	149	164.1	.00609	199	122.9	.00814	249	98.2	.01018	299	81.8	.01223
50.....	489	.002045	100	244.5	.00409	150	163.0	.00613	200	122.3	.00818	250	97.8	.01022	300	81.5	.01227

FACTORS FOR CONVERSION OF SOME UNITS.

1. Mg. per L. times 28.32=Mg. per cu. foot.
2. Mg. per L. times 1,000=Mg. per cu. meter.

3. Mg. per cu. foot times 35.314=Mg. per cu. meter.
4. Mg. per cu. meter times 0.02832=Mg. per cu. foot.

APPENDIX.

CONVERSION TABLE FOR GASES—PARTS PER MILLION VERSUS MILLIGRAMS PER LITER.

The concentrations of very dilute gaseous impurities in air are conveniently expressed in parts by volume of the gas in question, considered as a perfect gas, per million parts of air-gas mixture. The symbol for parts per million is p. p. m. For toxicological and chemical purposes the weight of the gaseous impurity per unit volume of the mixture is frequently desired; milligrams of the gas in question per liter of mixture, considered as a perfect gas and measured at the average room conditions of 25° C. and 760 mm. of mercury barometric pressure, is customarily used to express this. Mg./L. is used as the symbol. The conversion table that follows has been compiled to aid in converting the expressions of gases in parts per million to milligrams per liter and vice versa. It will prove helpful to chemists and toxicologists.

The compilation has been based on the following reasoning:

On a physical-chemical basis a weight in grams of any pure gas or vapor numerically equal to its molecular weight has been assumed to produce 24.45 liters of a perfect gas when measured at 25° C. and 760 mm. of mercury barometric pressure.

Then, if x is the molecular weight of the gas, x grams will occupy a volume of 24.45 liters at the stated conditions, which will be considered constant hereafter.

(1) x grams = $1,000x$ milligrams.

(2) And $1,000x$ milligrams \simeq 24.45 liters of the gas.

(3) 1 milligram $\simeq \frac{24.45 \text{ liters}}{1,000x} \simeq \frac{24.45}{x}$ cubic centimeters.

(4) 1 milligram in 1 liter of total gaseous mixture $\simeq \frac{24.45}{x}$ c. c. in 1,000 c. c. total.

(5) And, $\frac{24.45}{x}$ c. c. in 1,000 c. c. $:: \frac{1,000 \times 24.45}{x}$ in 1,000,000 c. c. total.

(6) Therefore, 1 milligram per liter $\simeq \frac{1,000 \times 24.45}{x}$ c. c. in 1,000,000 c. c. total.

(7) Simplifying, 1 mg. per liter = $\frac{24,450}{x}$ c. c. per 1,000,000 c. c.

(8) Or 1 Mg./L. = $\frac{24,450}{x}$ p. p. m.

Transformation of equation (8) gives—

(9) 1 p. p. m. = $\frac{x}{24,450}$ Mg./L.

The values in the conversion table have been calculated from equations (8) and (9) for molecular weights from 1 to 300. The accuracy throughout is 1 part in 250 parts.

Examples will show how the tables are used:

Given a concentration of chlorine of 5 Mg./L., what is the concentration by volume?

Chlorine has a molecular weight of 70.92, or 71 in round numbers. The conversion table shows that for a molecular weight of 71—

(10) 1 Mg./L. = 344 p. p. m.

(11) Therefore, 5 Mg./L. of chlorine = $5 \times 344 = 1,720$ p. p. m.

Given a concentration of ammonia in air of 2 per cent by volume, what is the weight per liter at 25° C. and 760 mm. of mercury barometric pressure?

Ammonia has a molecular weight of 17. Then, from the table after molecular weight 17—

(12) 1 p. p. m. = 0.000695 Mg./L.

(13) 2 per cent by volume = 20,000 p. p. m.

(14) 20,000 p. p. m. of ammonia = $20,000 \times 0.000695 = 13.9$ Mg./L.

POISONOUS DOSES OF INDUSTRIAL GASES AND VAPORS IN AIR.

The following table of poisonous doses of industrial gases and vapors when mixed with air summarizes partly the results of many investigators who have studied the effect of polluted air on man and animals. It has been difficult to arrange the data into a homogeneous table, because the standards of measurement and methods of investigation have not been uniform. In order to arrive at the arrangement given here, the authors have taken some liberties in transposing and interpreting many of the data. For this reason reference to original sources, which are cited in all cases, should be made for exact statements.

PUBLICATIONS ON BREATHING APPARATUS AND GASES FROM FIRES.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

- BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.
- BULLETIN 105. Black damp in mines, by G. A. Burrell, I. W. Robertson, and G. G. Oberfell. 1916. 92 pp.
- TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.
- TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.
- TECHNICAL PAPER 59. Fires in Lake Superior iron mines, by Edwin Higgins. 1913. 34 pp., 2 pls.
- TECHNICAL PAPER 62. Relative effects of carbon monoxide on small animals, by G. A. Burrell, F. M. Seibert, and I. W. Robertson. 1914. 23 pp.
- TECHNICAL PAPER 82. Oxygen mine rescue apparatus and physiological effects on users, by Yandell Henderson and J. W. Paul. 1917. 102 pp., 5 pls., 6 figs.
- TECHNICAL PAPER 103. Organizing and conducting safety work in mines, by H. M. Wilson and J. R. Fleming. 1917. 54 pp., 35 figs.
- TECHNICAL PAPER 122. Effects of oxygen deficiency on small animals and on men, by G. A. Burrell and G. G. Oberfell. 1915. 12 pp.
- TECHNICAL PAPER 134. Explosibility of gases from mine fires, by G. A. Burrell and G. G. Oberfell. 1916. 31 pp., 1 fig.
- TECHNICAL PAPER 150. Limits of complete inflammability of mixtures of mine gases and of industrial gases with air, by G. A. Burrell and A. W. Gauger. 1917. 13 pp., 2 figs.
- TECHNICAL PAPER 185. Use of the interferometer in gas analysis, by F. M. Seibert and W. C. Harpster. 1918. 18 pp., 1 pl., 5 figs.
- TECHNICAL PAPER 238. Carbon dioxide and oxygen detectors, by A. C. Fieldner and others. 1920. 23 pp., 3 pls., 12 figs.
- MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 14. Gases found in coal mines, by G. A. Burrell and F. M. Seibert. 1913. 23 pp.

RESCUE AND RECOVERY OPERATIONS IN MINES AFTER FIRES AND EXPLOSIONS, by J. W. Paul and H. M. Wolfkin. 1916. 109 pp.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPER-
INTENDENT OF DOCUMENTS.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the Experimental Mine, by G. S. Rice. 1912. 75 pp., 7 pls., 4 figs. 15 cents.

BULLETIN 62. National mine-rescue and first-aid conference, Pittsburgh, Pa., September 23-26, 1912, by H. M. Wilson. 1913. 74 pp. 10 cents.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs. 5 cents.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp., 1 fig. 5 cents.

TECHNICAL PAPER 77. Report of the committee on resuscitation from mine gases, by W. B. Cannon, G. W. Crile, Joseph Erlanger, Yandell Henderson, and S. J. Meltzer. 1914. 36 pp., 4 figs. 5 cents.

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