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Sept 1927

# Gases and Vapors

## Health Practices Pamphlet No. 9

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*This pamphlet is a compilation of experience. It must not be confused with Federal, State or insurance requirements, or with National Safety Codes.*

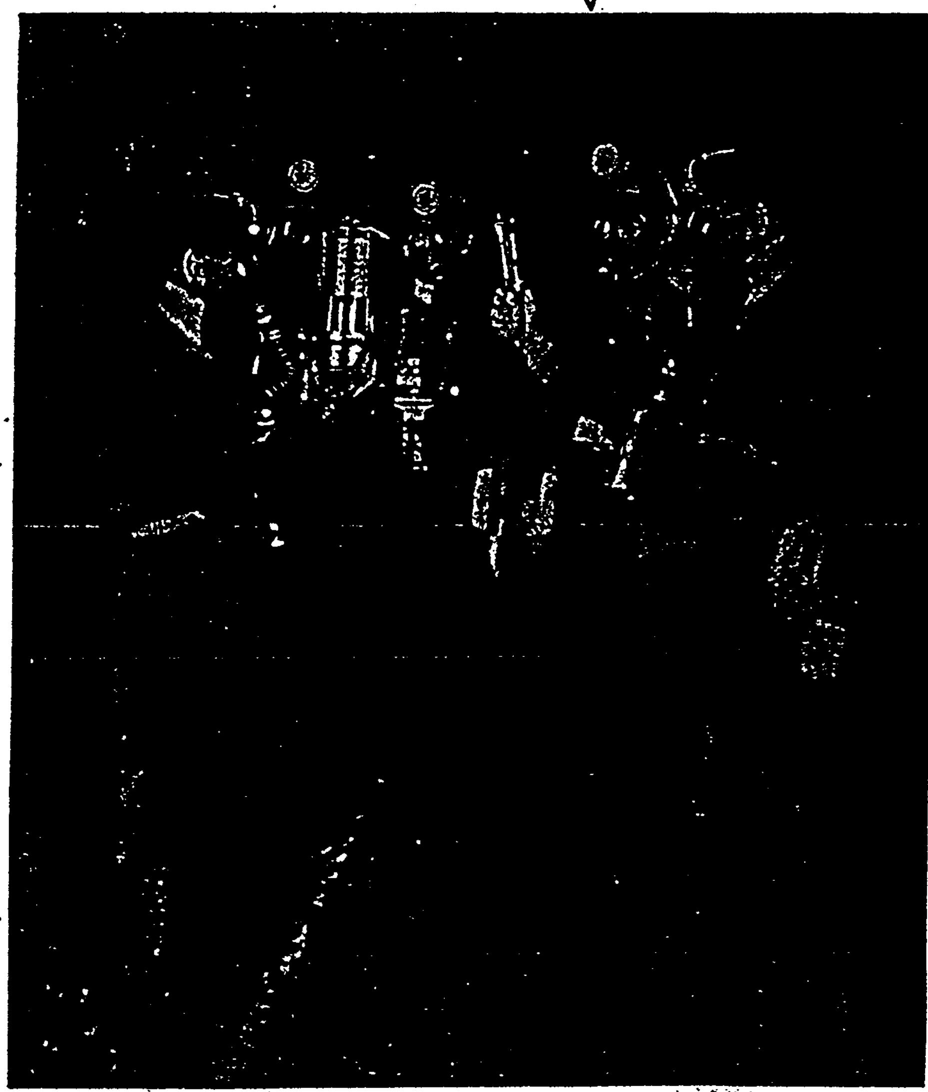
The average workman is generally oblivious to the gaseous substances which he takes into his body with the air he breathes. Even many educated and thoughtful people are usually uninformed on such matters. Yet the importance of the gas hazards of modern industry has been greatly emphasized within recent years.

This pamphlet will deal with (1) the physiology of breathing; (2) relation of the circulation to breathing; (3) the mechanism of the absorption of volatile substances; (4) a classification of noxious gases and vapors; and (5) prevention and treatment of poisoning.

### Physiology of Breathing

The volume of air breathed varies greatly according to every change of bodily activity, such as sitting, lying down, walking, working or running. Under each of these conditions, the person breathes a precise amount, which is determined by the need for oxygen. The greater the activity, the more air needed. The quantity of air exchange is termed respiration. The amount of air breathed is an important factor in the amount of gas or vapor absorbed.

Much emphasis has been placed upon the rate of breathing, but this is a misconception, as the volume of air breathed is the important consideration. The latter constitutes the only effective measurement of respiration.



Courtesy U. S. Bureau of Mines.

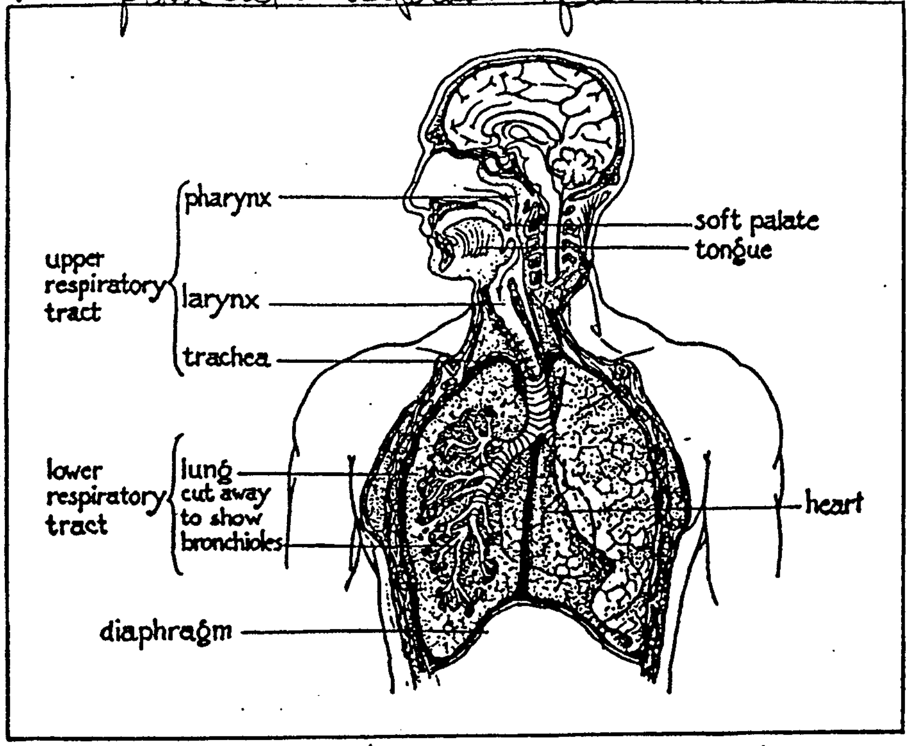
*Gas-mask crew testing mine air for oxygen and for carbon monoxide.*

### The Structure of the Lungs

It is not possible to give a complete description of the lungs in this pamphlet. Only the essentials can be presented and reference should be made to textbooks on anatomy if further information is desired.

The lungs are composed of a great number of very small sacs or air cells, termed alveoli. These cells are the terminal elements of small air tubes which are called bronchioles. The bronchioles are branches of larger tubes, the bronchi, which in turn unite to form still larger tubes, which unite and open into the trachea, or windpipe. The primary purpose of respiration is the exchange of oxygen, which is needed to sustain life, and carbon dioxide, which is formed during the body processes. The small terminal cells are provided with very thin walls of elastic substance almost completely filled with a network of very small (capillary) blood vessels, and covered by a very thin membrane. The gaseous exchange takes place between the blood

Make from cut — Reproduced from Henderson & Haggard p 22.




Courtesy of Henderson and Haggard.

*Diagram of the human breathing apparatus.*

in these vessels and the air in the alveolar sacs.

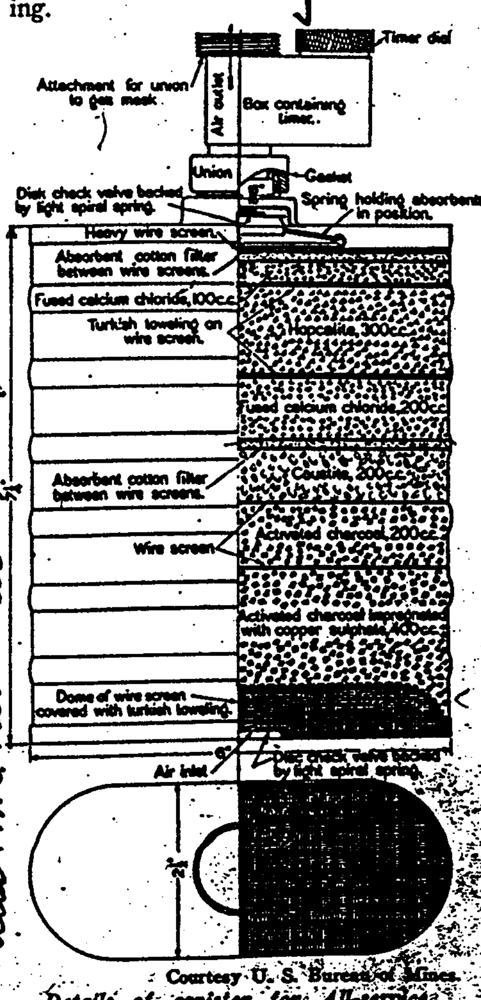
## Mechanism of Breathing

During breathing the air is drawn into and discharged from the lungs by a series of rhythmic contractions and relaxations of the respiratory muscles of the chest walls and floor. During this process oxygen is absorbed by the blood, through the walls of the alveoli and carbon dioxide is likewise removed from the blood.

The nerves and centers of respiration are of the same type as those of all other voluntary muscles of the body. The involuntary element in breathing, however, is relatively greater than for other muscular action. The rhythm and alternating action of respiration are both almost wholly involuntary.

Oxygen is in reality the fundamental controlling factor in the adjustment of breathing. All healthy persons are adjusted to their external environment and breathe volumes of air which have a distinct relation to the activity of the body and other factors. For instance, a sudden and acute fall in the oxygen content of the air will cause a considerable increase in the rate and depth of breathing.

In the ordinary variations of respiration throughout the day, however, oxygen because of its practically constant pressure at lower altitudes, takes little part in the regulation of breathing.




Courtesy U. S. Bureau of Mines.

*Details of canister for All-service gas mask.*

## Carbon Dioxide and Respiratory Regulation

The nerve centers of the brain which control the respiratory muscles, are extremely sensitive to slight variations in the concentration or partial pressure of carbon dioxide in the blood which circulates through them. The result of this sensitive arrangement is to cause a proportional increase or decrease in the volume of breathing as a response to a very small increase or decrease of carbon dioxide production in the body.

This adjustment is maintained even under wide variations in the bodily activity, expenditure of energy, exchange of gases with the atmosphere, and volume of breathing.

The relationship relative to the distinction between oxygen and carbon dioxide as respiratory stimulants can be made clearer by consideration of three simple experiments:

1. A normal man at rest is given a high concentration of oxygen to breathe instead of air. If we check up on the rate and volume of his breathing and on the amount of oxygen consumed, we find practically no effect. The man feels no difference between the high concentration of oxygen and ordinary air which normally contains only 21 per cent of oxygen. It is evident that the oxidation in the tissues and the oxygen consumption of the body have been controlled automatically by conditions which are quite different from those determining the intensity with which a fire burns.
2. With the same apparatus and method, when air with a small percentage of carbon dioxide is used, the volume of breathing increases almost immediately. This is noted particularly in the depth of breathing, there being no increase of the rate. If the expired air is now analyzed, it is found that the body is getting rid of practically the same amount of carbon dioxide as before, or slightly more on account of the muscular exertion involved in the greater volume of breathing.
3. In the third experiment the subject voluntarily forces himself to breathe more deeply, but at about the same rate, for a period of half a minute, using ordinary air. The lungs are thus over-ventilated. But owing to the nature of the combination of oxygen in the blood, no considerably greater amount of oxygen is absorbed. The carbon dioxide content of the blood, however, is temporarily decreased. When the man ceases his voluntary effort of breathing very deeply, he observes that there is a lack of desire to breathe and, in some extreme cases, a complete cessation of respiration, according to the amount of decrease of carbon dioxide within the blood.

Haldane and Priestly have shown that the carbon dioxide content of the alveolar air exhibits an extraordinary constancy under widely varying conditions of exertion and over periods of years.

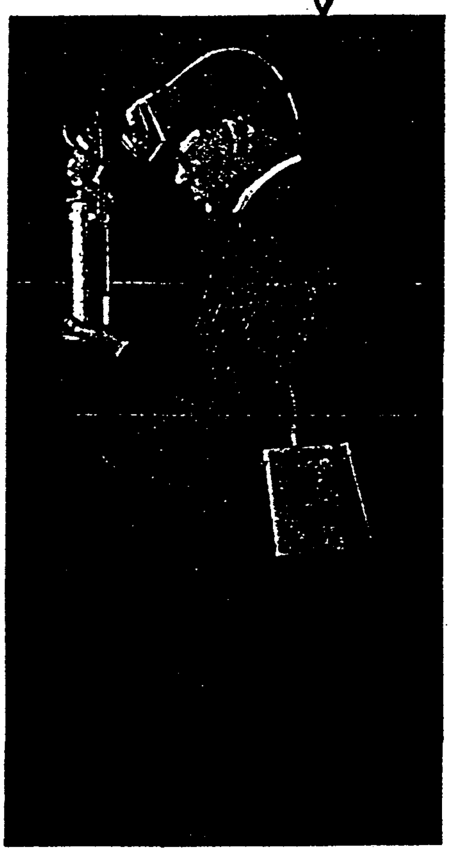
The fundamental conceptions then of the modern theories of the immediate control of respiration are:

1. The regulation of the breathing to the volume necessary to maintain a practically uniform partial pressure of carbon dioxide in the alveolar spaces of the lungs.
2. The action of carbon dioxide in the arterial blood upon the respiratory center of the brain, which will affect this regulation.

### Respiratory Functions of the Blood

A special function of the red coloring matter of the blood (hemoglobin) is to combine with oxygen and carry it in the blood stream from the lungs to the tissues, giving it off where it is needed. The blood also takes back the carbon dioxide from the tissues to the lungs, through which it is excreted.

It has been recognized that hemoglobin also plays a part however, in the transportation of carbon dioxide. It is a common mistake to think of hemoglobin as exclusively exchanging

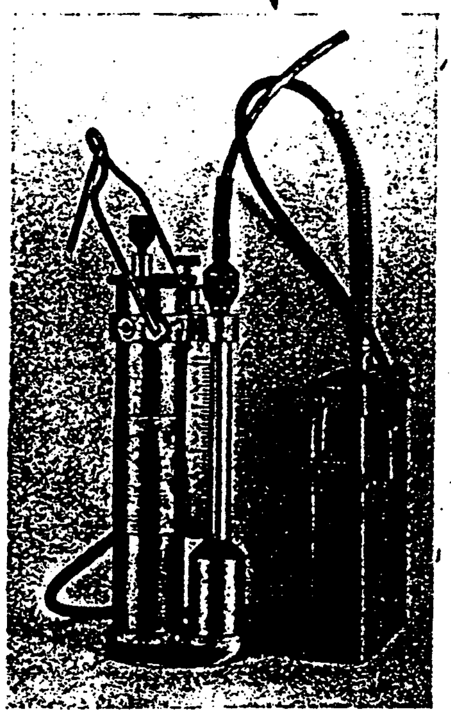


Courtesy U. S. Bureau of Mines.
*Man wearing Burrell methane indicator*

oxygen for carbon dioxide in the tissues and vice versa in the lungs. The blood may transport maximum quantities of both gases at one time.

Although the mechanisms of the transportation in each case are distinct, they nevertheless exert a considerable reciprocal influence upon each other. Carbon dioxide does not itself combine directly with hemoglobin. It is transported and held in the blood in the form of sodium bicarbonate, and to a less extent, other alkaline bicarbonates, usually in solution in the fluid of the blood.

The blood is, therefore, enabled to transport large volumes of oxygen



Courtesy U. S. Bureau of Mines.
*Burrell gas indicator*

and carbon dioxide regardless of slight alterations of their partial pressures, and also with a correspondingly slight alteration of the balance of acid and alkaline elements, within the blood stream.

Hemoglobin then may be said to perform three functions:

1. Combines with oxygen and gives it up equally as readily.
2. Provides an alkali exchange with the plasma (blood fluid) allowing the formation of alkaline bicarbonate for the purpose of transporting carbon dioxide. (The major portion of carbon dioxide however is carried by the plasma.)
3. Takes up and gives off alkali very readily. The acid-alkali balance of the blood is thereby maintained within a narrow limit of variation.

Courtesy U. S. Bureau of Mines.
*Miner wearing type N gas mask and observing flame safety lamp*

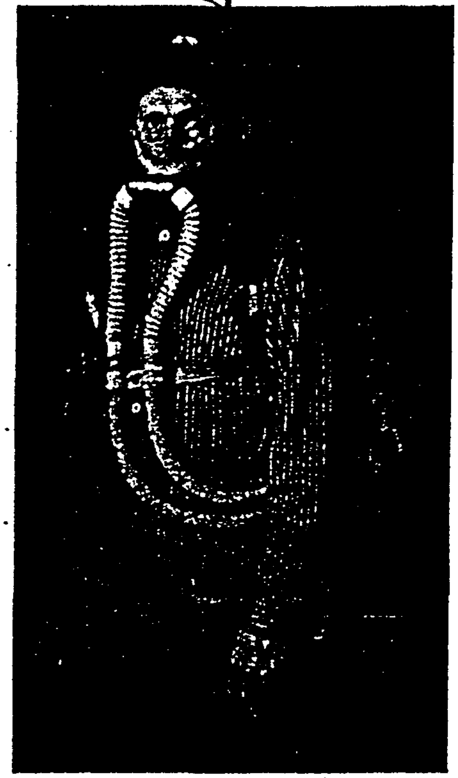
## Absorption of Volatile Substances

Except for irritants and simple asphyxiants, noxious gases and vapors exert their action only after absorption into the blood. The character and intensity of the action are determined largely by the concentration in the blood and the duration of stay, not merely by the poisonous action of the substance.

The physiological action of volatile substances is largely dependent upon the peculiarities of their absorption, elimination, distribution, and destruction. For example, one of the alcohols is more toxic than an equal amount of another, but the difference in the rate at which the concentrations in the blood decrease may render the latter a more dangerous poison than the former.

There are two classes of gases which exert their action after absorption into the blood; namely, *reactive* and *non-reactive.*

*Reactive* substances are changed within the body and eliminated in forms other than those in which they were absorbed. The poisonous action may, therefore, be exerted either by the substance in its original form or by the products of its decomposition. Ethyl alcohol is an example of reactive vapor which exerts its action before destruction has taken place; am-



Courtesy U. S. Bureau of Mines.
*McCaa 2-hour breathing apparatus. Front view.*

line and methyl alcohol are examples of vapors which exert their main actions through the products arising from their decomposition within the body.

*Non-reactive* substances are not changed to any appreciable extent within the body and are, therefore, eliminated in the same form in which they have been absorbed. The simple or uncombined aliphatic hydrocarbons (the so-called "open-chain" series, such as methane, ethylene and acetylene) are examples of non-reactive gases and vapors.

## Principles of Absorption

The absorption of non-reactive gases and vapors depends upon the following factors:

1. Solubility. The total amount of any non-reactive gas or vapor that the body will take up is dependent upon solubility and consequently its concentration within the body.
2. The rate of absorption is directly proportional to the concentration of gas or vapors in the air breathed.
3. The rate of lung ventilation is another factor influencing the rate of absorption. Respiration is very important in determining both the rates of absorption and elimination in the case of readily soluble gases and vapors, but it is comparatively unimportant in respect to relatively insoluble gases.
4. The rate of circulation of the blood has considerable effect upon the rate of absorption and elimination of gases of relatively low solubility. If the rate of circulation is doubled, so that twice as much blood is flowing through the lungs each minute, even with the respiration unchanged, the rate of absorption and elimination would be nearly doubled.

Am. N.S. News - Oct. 1923 - p. 33

*Non-reactive gases* and vapors are eliminated mostly through the lungs. The urine and other excretions carry away only relatively small amounts. The concentration of a gas dissolved in the urine corresponds to that in the blood passing through the kidneys at the moment the urine is secreted. The elimination through the lungs follows definite principles similar to those of absorption.

In general, the process concerned in the absorption of *reactive gases* is the same as for non-reactive gases. There is, however, this difference: the reaction and consequent destruction of the gas prevents the attainment of equilibrium, which usually occurs in breathing non-reactive gases.

The elimination of reactive substances is also influenced by their alteration within the body, the amount of substance eliminated being less than the amount absorbed.

## Classification

Henderson and Haggard in their recent book on "Noxious Gases" have classified gases and vapors as follows:

Courtesy U. S. Bureau of Mines.
*Adjusting type N gas mask*

Courtesy U. S. Bureau of Mines.
*McCaa 2-hour breathing apparatus. Back view.*

1. **Asphyxiants.** These do no direct injury to the respiratory tract, but produce their injurious effects by causing a condition of oxygen deficiency in the body tissues.
2. **Irritants.** These injure certain tissues of the respiratory tract, thereby inducing inflammation of the respiratory passages, and at times the lungs themselves.
3. **Volatile Drugs and Druglike Substances.** This is the anesthetic group and these substances have a druglike action after they have been absorbed through the lungs.
4. **Inorganic and Organometallic Substances.** This group has a wide diversity of action. Some are essentially tissue poisons. The action of these compounds is observed only after absorption into the blood stream.

With these general headings in mind, it is now convenient to consider the sub-groups, naming the actual substances involved.

### Group 1—Asphyxiants

**SUB-GROUP (a) Simple Asphyxiants:** Nitrogen, Hydrogen, Helium, Methane, Ethane, Propane, Nitrous Oxide, Ethylene, Acetylene.

**SUB-GROUP (b) Chemical Asphyxiants:**

Carbon Monoxide.

Cyanogen Compounds, the most important of which are: Cyanogen, Hydrocyanic acid, Acetonitrile, also used S.P. 64-p 8 Field Dict 64

Propionitrile, Methyl isonitrile, Ethyl isonitrile, Benzonitrile, Cyanogen chloride.

### Group 2—Irritants

SUB-GROUP (a) Including gases which act primarily upon the upper respiratory tract:

Ammonia Gas, Hydrochloric Acid Gas, Sulphuric Acid Gas, Hydrofluoric Acid Gas, Formaldehyde.

SUB-GROUP (b) Including those gases which act upon the upper respiratory tract and also spread their action to the deeper structures:

Sulphur Dioxide, Chlorine, Bromine, Iodine, Acrolein, Hydrogen Sulphide. (Dimethyl sulphate).

SUB-GROUP (c) Including those gases which act primarily upon the lungs and only to a much less extent upon the upper respiratory tract:

Nitrogen dioxide, Ozone, Phosgene, Phosphorous trichloride and pentachloride, Arsenic trichloride.

SUB-GROUP (d) Those gases which are not altered or destroyed by contact with the tissues of the respiratory tract. These are essentially the Hydrocarbons and consist mainly of the Fatty Hydrocarbons, their alcohols, ethers and halogen substitution products. These will be mentioned in detail in the next main group.

### Group 3

**Volatile Drugs and Druglike Substances. Anesthetics.**

SUB-GROUP (a) Anesthetic Gases without usual serious after-effects. (However, poisoning may occur.)

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Also S.P. 64-p 4-Sig. 4

*The All-service gas mask, showing timer on the top of the canister and a carbon monoxide detector.*

1. Hydrocarbons—Paraffin Series: Gasoline, Naptha, Benzine.
2. Hydrocarbons—Olefine Series: Ethylene, Propylene, Butylene, Amylene, Hexylene, Heptylene.
3. Hydrocarbons—Acetylene Series: Acetylene, Allylene, Crotonylene.
4. Ethers: Methyl ether, Ethyl ether, Propyl ether.
5. Aldehydes: Formaldehyde, Acetaldehyde, Propaldehyde, Butaldehyde, Acraldehyde.
6. Ketones: Dimethyl ketone (acetone), Methyl-ethyl ketone, Diethyl ketone.

also used S.P. 64 p 7 Field Dict 64

Courtesy Youngstown Sheet & Tube Co.

*The Draeger two-hour self contained oxygen breathing apparatus.*

7. Ethereal Salts of Organic Acids: Methyl formate, Methyl acetate, Methyl butanate, Ethyl formate, Ethyl acetate, Ethyl butanate, Propyl acetate, Butyl acetate, Amyl acetate.

SUB-GROUP (b) **Halogen Derivatives of the Hydrocarbons. Anesthetics injuring chiefly the visceral organs**

1. Halogen Compounds of Methyl: Methyl chloride, Methyl bromide, Methyl iodide, Methylene dichloride, Trichloromethane, Tetrachloromethane.
2. Halogen Compounds of Ethyl and Higher Hydrocarbons: Ethyl chloride, Ethyl bromide, Ethyl iodide, Dichloroethylene, Ethylene dichloride, Trichloroethylene, Trichloroethane, Perchloroethylene, Tetrachloroethane, Pentachloroethane.

Also: N.S. News. Aut. 1933-p. 37

Courtesy U. S. Bureau of Mines.

*Hose mask with Tissot face piece. A helmet can be used instead of a face piece, but the latter is now preferred by most persons.*

SUB-GROUP (c) **Hydrocarbons, Aromatic Series, injuring chiefly the blood-forming system.**

1. Light Oil or Crude Naphtha, the principal constituents being benzene, xylene, toluene, pyridine and thiophene.
2. Middle Oil, consisting mainly of naphthalene and phenol.
3. Heavy Oil, consisting of phenol, cresol and anthracene.
4. Anthracene Oil, consisting of anthracene, phenanthrene and various solid hydrocarbons, that is in the cooled state.
5. Pitch, which remains in the still. (Light, middle, heavy and anthracene oils and pitch are not sufficiently volatile under ordinary conditions to cause poisoning from the inhalation of vapors.)

SUB-GROUP (d) **Hydrocarbons injuring chiefly the nervous system.**

1. Alcohols: Methyl, Ethyl, Propyl, Butyl, Amyl.
2. Carbon Disulphide.
3. Thiophene.

also used S.P. 64-84 Filed with 64

Courtesy U. S. Bureau of Mines.
*The Gibbs two-hour self contained oxygen breathing apparatus.*

SUB-GROUP (c) Organic Nitrogen Compounds, acting upon the blood and circulation.

1. Substances which have predominating action of a "nitrite effect." In general, these are the alkyl nitrites and the alkyl nitro substitution products and are represented by ethyl nitrite and amyl nitrite.
2. Substances whose predominating action is the conversion of oxyhemoglobin to methemoglobin. This class is represented by the amide compounds and the aromatic nitro substitution products, such as:
   - Nitrobenzene
   - Aniline
   - Toluidine
   - Methyl aniline
   - Dimethylaniline

## Group 4—Inorganic and Organometallic Gases

SUB-GROUP (a) Protoplasmic Poisons.
Mercury and Phosphorus.

SUB-GROUP (b) Organometallic Compounds. These are represented by:
Diethyl arsine, Cacodyl, Cacodyl oxide, Diethyl mercury, Tetraethyl lead, Nickel carbonyl.

SUB-GROUP (c) Inorganic Hydric Compounds:
Hydrogen arsenide, Hydrogen phosphyde (Phosphene), Hydrogen sulphide.

## Effects of Exposure

In the prevention of poisoning by gases and vapors, it is essential that the physiological effects induced by various concentrations and by various durations of exposure be known.

Tabulations showing these responses, as worked out by various investigators, and used by Henderson and Haggard, have been listed in the appendix. The order is the same as that used in the classification.

## Prevention of Poisoning

In addition to knowing the physiological effects induced by various concentrations and different durations of exposure, it is also necessary that:

1. This knowledge be applied in such a way that toxic concentrations of gases are prevented in the air breathed by workmen; and
2. If the occurrence of such concentrations cannot be avoided, those who are exposed should be equipped with protective apparatus.

The prevention of a poisonous, unhealthful condition of the air resolves itself into the engineering problem of controlling the degree of contamination. Following steps are necessary:

1. Standards of ventilation should first be determined experimentally.
2. These standards should then be defined in practical terms.
3. Adequate machinery to effect such standards should then be developed.

The research work in preparation for the construction of the vehicular tunnel under the Hudson River is an example of this kind of problem. In this work the first step was to determine the allowable concentration of carbon monoxide which would be breathed during the time of passage through the tunnel; the second step was the development of methods and means of ventilation to maintain this concentration.

In industry it is generally possible to prevent the escape of gases and vapors by one of two methods:

1. Passing the air through activated charcoal which readily condenses a large number of substances. Valuable material thus adsorbed may be recovered by displacement with steam, and the adsorptive power of the charcoal is thus regenerated.
2. Mixing of a relative small amount of chlorine gas with the contaminated air. Small amounts of chlorine in the presence of water vapor destroy a large number of noxious gases. The same apparatus can be used as that applied in chlorinating city water supplies.

The above methods may be carried out only after collecting the contaminated air and leading it out through a large duct.

## Protective Apparatus

Three types of apparatus are available for protection against the inhalation of noxious gases; (1) gas masks, (2) hose masks, and (3) self-contained breathing apparatus. These three forms differ from each other in principle, each having its own advantages and disadvantages in relation to the other types. Each has its own special use (see Safe Practices Pamphlet No. 64.).

## Other Measures

Usually it is necessary to formulate a set of regulations which will apply to the particular kind of gas or vapor with which employees are working in any given plant (see Health Practices Pamphlet No. 7 on Carbon Monoxide).

## Treatment

The methods of treatment for acute poisoning are:

1. Rescue.
2. Artificial respiration.
3. First Aid.
4. Inhalational treatment.

The first step is to remove the man from the contaminated atmosphere, taking him into fresh air, preferably.

also used S.P. 64 p. 7 Filed with 64

Courtesy U. S. Bur[illegible]
*The Paul two-hour self-con[illegible] oxygen breathing appara[illegible]*

into warm uncontaminated air. The rescuer should provide himself properly with suitable gas mask or hose mask, together with a belt and safety line, the line to be held by someone outside the contaminated area.

As soon as rescue has taken place, if breathing has ceased, artificial respiration should be started at once by the Schafer Prone Pressure Method. (See National Safety Council leaflet on Artificial Respiration.)

Chilling occurs quite commonly after any form of gassing. As it greatly increases the liability to pneumonia, the victim should be well-wrapped in blankets, and massage of the legs and arms should be given.

Inhalation of 7% carbon dioxide and 93% oxygen greatly hastens the elimination of volatile substances from the body. This method has come into general use for the treatment of carbon monoxide poisoning. (See Health Practices Pamphlet No. 7.) It has also been extensively used to hasten the elimination of anaesthetics after surgical operations.

Inhalation treatment has also been applied to poisoning by other volatile substances, for example alcoholic drunkenness, and has been found to be an effective aid during artificial respiration.

The mixture of oxygen and carbon dioxide is usually given for a period of twenty to thirty minutes, immediately after the victim has been removed from the poisonous atmosphere. Inhalation may be given in conjunction with artificial respiration.

Next to artificial respiration, the inhalation method is the most useful measure in resuscitation. Experience has shown that there are no ill effects, for the stimulation is of a mild character.

Carbon dioxide and oxygen may be administered by any of the approved inhalators now purchasable upon the market.

## Summary

An understanding of the fundamentals of the physiology of breathing and the circulation is essential in dealing scientifically with the problems caused by the inhalation of poisonous gases and vapors.

The prevention of poisoning can be accomplished through the use of adequate exhaust ventilation systems and proper protective apparatus.

Rescue, artificial respiration, first aid, and inhalational treatment have all been standardized for industrial use.

### Bibliographic Note

The subject matter of this pamphlet was largely derived from a monograph, "Noxious Gases," by Henderson and Haggard, published by the Chemical Catalogue Co., Inc., New York City.

### ACKNOWLEDGMENT

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# APPENDIX

(*Note: The material given here is not exhaustive and complete, but represents the available scientific data. It has been taken from the tables used by Henderson and Haggard in their book "Noxious Gases."*)

## Physiological Response to Various Concentrations of Carbon Monoxide

| | Parts of Carbon Monoxide per Million Parts of Air |
|---|---|
| Concentration allowable for an exposure of several hours | 100 |
| Concentration which can be inhaled for 1 hour without appreciable effect | 400 to 500 |
| Concentration causing a just appreciable effect after 1 hour exposure | 600 to 700 |
| Concentration causing unpleasant but not dangerous symptoms after 1 hour exposure | 1000 to 1200 |
| Dangerous concentration for exposure of 1 hour | 1500 to 2000 |
| Concentrations which are fatal in exposures of less than 1 hour | 4000 and above |

(Henderson, Haggard, Prince, Teague, and Wunderlich, J. Ind. Hygiene, 1921, III, pp. 79, 137.)

## Physiological Response to Various Concentrations of Hydrocyanic Acid Gas

| | Parts of Hydrogen Cyanide per Million Parts of Air |
|---|---|
| Slight symptoms after several hours' exposure | 20 to 40 |
| Maximum amount that can be inhaled for 1 hour without serious disturbance | 50 to 60 |
| Dangerous in 30 minutes to 1 hour | 120 to 150 |
| Rapidly fatal | 3,000 |

(Kobert R., Kompend, der prak. Toxicol, Stuttgart, 1912.)

## Physiological Response to Various Concentrations of Ammonia

| | Parts of Ammonia per Million Parts of Air |
|---|---|
| Least detectable odor (1) | 53 |
| Least amount causing immediate irritation to the eye (1) | 698 |
| Least amount causing immediate irritation to the throat (1) | 408 |
| Least amount causing coughing (1) | 1,720 |
| Maximum concentration allowable for prolonged exposure (2 and 3) | 100 |
| Maximum concentration allowable for short exposure (½ to 1 hour) (2 and 3) | 300 to 500 |
| Dangerous for even short exposure (½ hour) (3) | 2,500 to 4,500 |
| Rapidly fatal for short exposure | 5,000 to 10,000 |

(1—U. S. Dept. of Interior, Bureau of Mines, Tech. paper 248, 1921 table facing page 66.)
(2—Ronzani, E., Arch. f. Hyg., 1909, 70, p. 217.)
(3—Lehmann, K., Arch. f. Hyg., 1886, 5, p. 1.)

## Physiological Response to Various Concentrations of Hydrochloric Acid Gas

| | Parts of Hydrogen Chloride per Million Parts of Air |
|---|---|
| Maximum concentration allowable for prolonged exposure (3a) | 10 |
| Maximum concentration allowable for short exposure (½ to 1 hour) (3a) | 50 |
| Dangerous for even short exposure (3a, 4 and 5) | 1,000 to 2,000 |

(3a—Lehmann, K., Arch. f. Hyg., 1886, 5, p. 1.)
(4—Kohn-Abrest, Annales des Falsifications, 1915, 8, p. 215.)
(5—Leymann, Concordia, 1906, 18, p. 120.)

## Physiological Response to Various Concentrations of Hydrofluoric Acid Gas

| | Parts of Hydrogen Fluoride per Million Parts of Air |
|---|---|
| Maximum concentration allowable for prolonged exposure (2) | 3 |
| Maximum concentration allowable for short exposure (½ to 1 hour) (2) | 10 |
| Dangerous for even short exposure (2) | 50 to [illegible] |

(2—Ronzani, E., Arch. f. Hyg., 1909, 70, p. 217.)

### Physiological Response to Various Concentrations of Sulphur Dioxide

| | Parts of Sulphur Dioxide per Million Parts of Air |
|---|---|
| Least detectable odor (8 and 9) | 3 to 5 |
| Least amount causing immediate irritation to the eyes (9) | 20 |
| Least amount causing immediate irritation to the throat (9) | 8 to 12 |
| Least amount causing coughing | 20 |
| Maximum concentration allowable for prolonged exposure (9) | 10 |
| Maximum concentration allowable for short exposure (½ to 1 hour) (9 and 10) | 50 to 100 |
| Dangerous for even short exposure (10) | 400 to 500 |

( 8—U. S. Dept. of Interior, Bureau of Mines, Bulletin 98, 1915.)
( 9—Fieldner, A. and Katz, S., Eng. and Mining Jour., 1919, 107, p. 693.)
(10—Lehmann, Arch. f. Hyg., 18, 180.)

### Physiological Response to Various Concentrations of Chlorine

| | Parts of Chlorine per Million Parts of Air |
|---|---|
| Least detectable odor (1) | 3.5 |
| Least amount causing immediate irritation to the throat (1) | 15.1 |
| Least amount causing coughing (1) | 30.2 |
| Maximum concentration allowable for prolonged exposure (1) | 1.0 |
| Maximum concentration allowable for short exposure (½ to 1 hour) (11) | 4.0 |
| Dangerous for even short exposure (11) | 40 to 60 |
| Rapidly fatal for short exposure (11) | 1,000 |

( 1—U. S. Department of the Interior, Bureau of Mines, Technical Paper 248, 1921.)
(11—Kobert, R., Kompendium der Prak, Toxicol., Stuttgart, 1912.)

### Physiological Response to Various Concentrations of Nitrous Fumes

| | Parts of Nitrogen Dioxide per Million Parts of Air |
|---|---|
| Least amount causing immediate irritation to the throat (14) | 62 |
| Least amount causing coughing (14) | 101 |
| Maximum concentration allowable for prolonged exposure (14) | 39 |
| Dangerous for even short exposure (14) | 117 to 154 |
| Rapidly fatal for short exposure (14) | 240 to 775 |

(14—Lehmann, K. and Hasegawa, Arch. f. Hygiene, 1913, LXXVII, 323.)

### Physiological Response to Various Concentrations of Phosgene

| | Parts of Phosgene per Million Parts of Air |
|---|---|
| Least detectable odor (1) | 5.6 |
| Least amount required to cause immediate irritation to the eyes (1) | 4.0 |
| Least amount required to cause immediate irritation to the throat (1) | 3.1 |
| Least amount required to cause coughing (1) | 4.8 |
| Maximum concentration allowable for prolonged exposure (1) | 1.0 |
| Dangerous for even short exposure (1) | 25.0 |
| Rapidly fatal | Over 25.0 |

(1—U. S. Department of Interior, Bureau of Mines, Technical Paper 248, 1921.)

### Physiological Response to Various Concentrations of Halogen Compounds of Methyl

| | Parts per Million Parts of Air | |
|---|---|---|
| | Chloroform | Carbon Tetrachloride |
| Slight symptoms after several hours of exposure (4) | 200 | 1,600 |
| Maximum concentration that can be inhaled for 1 hour without serious disturbance (4) | 5,000 to 6,000 | 4,000 to 6,000 |
| Dangerous after 30 minutes to 1 hour of exposure (4) | 14,000 | 24,000 to 32,000 |
| Rapidly fatal for short exposure (2 and 5) | 25,000 | 48,000 to 63,000 |

(4—Kobert, R., Kompend, d. prak. Toxikologie, Stuttgart, 1912, 45.)
(5—Lehmann, K. B., Arch. f. Hygiene, 1911, LXXIV, 1.)
(2—Herrmann, G., Inaugural Dissertation, Wurzburg, C. Fuchs, 1911.)

### Physiological Response to Various Concentrations of Phosphorus Trichloride

| | Parts of Phosphorus Trichloride per Million Parts of Air |
|---|---|
| Maximum concentration allowable for prolonged exposure (11) | 0.7 |
| Maximum concentration allowable for short exposure (11) | 2 to 4 |
| Dangerous for even short exposure (11) | 50 to 90 |
| Rapidly fatal for short exposure | 6,520 |

(11—Kobert, R., Kompendium d. prakt. Toxicol., Stuttgart, 1912.)

### Physiological Response to Various Concentrations of Gasoline Vapor

| | Parts of Gasoline Vapor per Million Parts of Air |
|---|---|
| Least detectable odor | 300 |
| Concentration dangerous for even short exposure | 11,000 to 22,000 |
| Rapidly fatal for short exposure | 24,300 |

(1—U. S. Department of Interior, Bureau of Mines, Technical Paper 272, 1921.)

### Table of Comparative Toxicity of Chlorine Derivatives of the Aliphatic Hydrocarbons

Relative lethal concentrations by volume in air, if lethal toxicity of $CCl_4$ = 1.

| | | | | |
|---|---|---|---|---|
| Methyl chloride | $CH_3Cl$ | | 0.6 | (Approximation) |
| Trichloromethane (chloroform) | $CHCl_3$ | (1) | 2.2 | " |
| Tetrachloromethane (carbon tetrachloride) | $CCl_4$ | (1) | 1.0 | " |
| Dichloro ethylene | $C_2H_2Cl_2$ | (2) | 1.7 | " |
| Trichloro ethylene | $C_2HCl_3$ | (2) | 1.7 | " |
| Perchloro ethylene | $C_2Cl_4$ | (2) | 1.6 | " |
| Tetrachloro ethane | $C_2H_2Cl_4$ | (2) | 9.1 | " |
| Pentachloro ethane | $C_2HCl_5$ | (2) | 6.2 | " |

(Note: The concentration of the last five hydrocarbons have been shown experimentally to be lethal in exposures of 30 minutes or more.)

(1—Waller, A. D., Jour. Amer. Med. Assn., 1919, LIII, 9.)

(2—Herrmann, G., Inaugural Dissertation; Wurzburg, C. Fuchs, 1911.)

### Physiological Response to Various Concentrations of Halogen Compounds of Ethyl and Higher Hydrocarbons

| | Parts per Million Parts of Air | | | |
|---|---|---|---|---|
| | Trichloroethylene | Perchloroethane | Tetrachloroethane | Pentachloroethane |
| Rapidly fatal for short exposure | 37,000 | 30,900 | 7,300 | 9,600 |

(2—Herrmann, G., Inaugural Dissertation, Wurzburg, C. Fuchs, 1911.)

(5—Lehmann, K. B., Arch. f. Hygiene, 1911, LXXIV, 1.)

### Physiological Response to Various Concentrations of Coal Tar Distillation Products*

| | Parts per Million Parts of Air Benzene, Toluene and Xylene |
|---|---|
| Slight symptoms after several hours of exposure (7) | 1,570 to 3,130 |
| Maximum concentration that can be inhaled for 1 hour without serious disturbance (7) | 3,130 to 4,700 |
| Rapidly fatal for even short exposure (7) | 19,000 |

*The concentrations given here are for acute effects: exposure of several hours a day to concentrations lower than those mentioned leads in a short time to chronic poisoning.

(7—U. S. Department of Interior, Bureau of Mines, Technical Paper 272, 1921.)

### Physiological Response to Various Concentrations of Carbon Disulphide*

| | Parts of Carbon Disulphide per Million Parts of Air |
|---|---|
| Slight symptoms after several hours of exposure (7) | 322 to 386 |
| Maximum concentration that can be inhaled for 1 hour without serious disturbance (7) | 483 to 807 |
| Dangerous after 30 minutes to 1 hour of exposure (7) | 1,160 |

*The concentrations given here are for acute effects; exposure of several hours a day to concentrations lower than those mentioned leads in a short time to chronic poisoning.

(7—U. S. Department of Interior, Bureau of Mines, Technical Paper 272, 1921.)

### Physiological Response to Various Concentrations of Aromatic Nitro-Substitution Products and Amido Compounds

| | Parts per Million of Air | | |
|---|---|---|---|
| | Nitrobenzene | Aniline | Toluidine |
| Slight symptoms after several hours exposure | 0.2 to 0.4 | 7.0 to 26.0 | 6.0 to 23.0 |
| Maximum amount that can be inhaled for one hour without serious disturbance | 1.0 | 105.0 to 160.9 | 91.0 to 140.0 |

### Physiological Response to Various Concentrations of Arsine

| | Parts of Arsine per Million Parts of Air |
|---|---|
| Slight symptoms after several hours of exposure (8) | 30 |
| Dangerous for exposure of one hour (9) | 50 |
| Fatal to man in exposure of 30 minutes (9) | 250 |

(8—Dubitsky. Quoted from Koelsch. I. Zentralbl. f. Gewerbehyg., 1920, VIII, 121.)

(9—Kokn Abrest, E., Annales des Falsifications, 1915, VIII, p. 215.)

### Physiological Response to Various Concentrations of Hydrogen Phosphide

| | Parts of Hydrogen Phosphide per Million Parts of Air |
|---|---|
| Maximum amount that can be inhaled for 1 hour without serious result (11) | 100 to 200 |
| Dangerous in 30 minutes to 1 hour (11) | 400 to 600 |
| Rapidly fatal (12) | 2,000 |

(11—Kobert, R., Kompend. d. prak. Toxikologie, Stuttgart, 1912, 45.)

(12—Rambousek, Industrial Poisoning, London, 1913, 191.)

### Physiological Response to Various Concentrations of Hydrogen Sulphide

| | Parts of Hydrogen Sulphide per Million Parts of Air |
|---|---|
| Slight symptoms after several hours (11) | 100 to 150 |
| Maximum amount that can be inhaled for 1 hour without serious disturbance (11) | 200 to 300 |
| Dangerous in 30 minutes to 1 hour (11) | 500 to 700 |
| Rapidly fatal (11 and 15) | 1,000 to 3,000 |

(11—Kobert, R., Kompend. d. prak., Toxikol., Stuttgart, 1912.)

(15—Sayres, R. R., U. S. Bureau of Mines, Report on Hydrogen Sulphide as an Industrial Poison, Investigations Serial Number 2491, June, 1923.)