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INDUSTRIAL ACCIDENTS AND HYGIENE SERIES

CARBON-MONOXIDE POISONING

By ALICE HAMILTON, M. A., M. D.

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CARBON-MONOXIDE POISONING.

INTRODUCTION.

Carbon monoxide (CO) is the most widespread and one of the most important poisons connected with human life and industry. Poisoning from this gas has greatly increased in all civilized countries, especially during recent years. At the First International Congress of Labor, called in accordance with the provisions of the labor convention in the Peace Treaty, and held in the fall of 1919 in Washington, D. C., the delegates were instructed to call the attention of their respective Governments to the continued increase of industrial carbon-monoxide poisoning and to request that investigations be made in each country with a view to its prevention. This increase has been brought about by the extended use of gas as a source of heat and power and the increasing use of motor cars and engines, the exhaust gases of which are more or less rich in carbon monoxide. These new factors have more than offset the improvements in blast-furnace procedure and in the prevention of mine explosions, for, although the last two sources of carbon-monoxide poisoning now yield fewer disastrous cases than they did in former years, the number of industrial accidents from carbon monoxide continues to grow from year to year.

The present inquiry was undertaken for the purpose of ascertaining the extent and seriousness of industrial carbon-monoxide poisoning in the United States, for, strangely enough, very little is known about it. It is known that the gas is responsible for many thousands of deaths each year. According to McNally, chemist to the office of the coroner of Cook County, Ill., carbon-monoxide poisoning as a cause of death held the fourth place in the death records of that county in 1916, but the greater number of these cases are not industrial; they are the result of inhaling illuminating gas, either accidentally or with suicidal intent. It is not known how many deaths from carbon monoxide are caused by industry in the United States, nor how many cases of severe so-called "gassing" occur without a fatal termination. In foreign countries, as will be seen later, carbon-monoxide gassing from which the victim recovers is often followed by severe, and sometimes lasting, injury to organs or to the nervous system. Whether in this country this occurs after gassing in steel mills, smelters, coal mines, gas works, garages, and so on, is a question that can not be answered, except with regard to the last. American medical literature contains a considerable number of instances of men

who were overcome in closed garages by the exhaust gases from motor-car engines, and who, after recovering consciousness, displayed symptoms of distinct mental impairment, the symptoms lasting sometimes for many months. It seems reasonable to suppose that if gassing in garages has this effect—an effect also noted sometimes after accidental or suicidal illuminating-gas poisoning—it must also follow other forms of industrial carbon-monoxide poisoning, but there is nothing in American medical literature which furnishes a positive answer to this question. It may be that there is something in the mode of poisoning in garages, or in the character of the exhaust gases, which are known to contain other toxic compounds besides carbon monoxide, which will account for these serious aftereffects, and that these factors are not present in other forms of industrial carbon-monoxide poisoning; or it may be that the prominence of the victims of exhaust-gas poisoning and the more thorough medical examination accorded them have resulted in knowledge concerning the remote effects of the accident, which in the case of laboring men might fail to be discovered, or, if discovered, fail to be reported. This is another question to which so far no positive answer can be given.

It is true of all well-known industrial poisons that however striking and distressing are the acute effects, they are neither so numerous nor so permanently crippling as are the injuries caused by long exposure to small repeated doses of the poison. An acute attack of lead colic is agonizing, but the man may recover from it completely, while the results of repeated minute doses of lead, such as a printer may absorb throughout 20 or 30 years of work, may result in a general hardening of all the blood vessels, with a consequent slow starvation of the organs through an insufficient blood supply. The same thing is true of benzol poisoning. Acute poisoning may bring a man close to death's door, but if he escapes he usually recovers completely. On the other hand, slow benzol poisoning attacks the tissues on which he must depend for the formation of blood and brings about a degree of anemia that may be fatal. Reasoning from such industrial poisons as these, whose effects are well known, it is a natural supposition that the same thing would be true concerning carbon monoxide—that workers exposed over months and years to air contaminated with small quantities of this gas would suffer from symptoms less striking than those of acute gassing but really more serious. Concerning this also, the evidence, even in foreign literature, is inadequate and unsatisfactory, while in the United States there is absolutely none. Yet hundreds of thousands of men and women work in air which contains small quantities of carbon monoxide, enough, often, to cause headache and dulling of the intellect. Such conditions are found in printing shops, in pressing rooms of clothing factories, in bakeries and laundries, in soldering, and in new buildings where salamanders are used to dry out the walls.

Therefore, in planning a survey of carbon-monoxide poisoning in the United States, the following problems were considered to be the ones especially calling for study and solution:

First. The actual extent of acute carbon-monoxide poisoning in American industry, and its distribution throughout the different branches of industry.

Second. Does such acute poisoning cause lasting damage to the victim after the subsidence of the acute symptoms?

Third. Is there any difference in the character of carbon-monoxide poisoning in the various industries, and, if so, what is the ground for this difference?

Fourth. Is there any evidence of chronic industrial carbon-monoxide poisoning, and if so, what is its character and in what industries does it occur?

It has been possible to make only a preliminary survey of the extent and seriousness of industrial carbon-monoxide poisoning in the United States. The results presented have been gathered from the following industries: The manufacture of steel; the manufacture of coke by-products; the smelting of zinc; the production of sublimed zinc oxide; the smelting of lead; coal mining; metal mining; the manufacture of illuminating gas; the laying of gas pipes and the reading of gas meters; the testing of motor cars, repair work, and ordinary garage work; and linotype work in printing shops which use a gas jet under the lead pot. The last two industries were selected as probable sources of chronic carbon-monoxide poisoning.

In order to have a clear idea of the nature of carbon-monoxide poisoning, it is necessary to go to foreign sources in part for information, although, whenever possible, American authorities have been used. A great deal of valuable material is furnished by the United States Bureau of Mines, and, under the auspices of this bureau and of the Public Health Service, experiments are at present being carried on by experts to solve some of the outstanding problems with regard to carbon-monoxide gas. In the following section of this report a brief review is given of the essential facts, so far as they are known, concerning the mode of action of carbon monoxide, as gathered from German, French, British, and American literature.

DESCRIPTION OF ACUTE POISONING AS GIVEN IN AMERICAN AND FOREIGN LITERATURE.

According to Haldane,[1] a man at rest can breathe an atmosphere of one part of carbon monoxide per thousand parts of air two hours and a half before the blood becomes saturated with it to the extent of 50 per cent; but in a man at active work a like atmosphere will cause unsteady gait and other symptoms in one hour, an atmosphere of two parts per thousand will cause unsteady gait and increasing powerlessness in half an hour, and with three parts per thousand this condition comes on in 20 minutes. When the amount of carbon monoxide in the air is not more than one part in a thousand, the symptoms come on slowly if the man is at rest, but the blood may progressively take up carbon monoxide till fully 50 per cent of the hemoglobin has been saturated with it. At that point the man is suffering from the effects so that he is confused, his intellect dulled, and there is muscular weakness. If he remains at rest he may escape serious damage, but even at this concentration of gas, if he makes great exertions to escape from such atmosphere, he may lose consciousness. It has often happened

[1] Haldane, John S. Quoted in Occupations, by Thomas Oliver. Cambridge, 1916, p. 89.

that members of a rescuing party have suffered more severely than the men they came to save, because they were working hard while the latter were sitting still. With two parts of carbon monoxide to a thousand parts of air, utter powerlessness and unconsciousness come on, and three parts mean death unless rescue is fairly prompt.

The onset of symptoms may be as sudden as a stroke of lightning, but usually, even in exposure to a high percentage of the gas, the man has some warning, such as pressure and throbbing in the head, "caving in" of the knees, blurred sight, roaring in the ears, pain in the stomach, a sweetish taste in the mouth, or nausea. Some men can tell that an attack of gassing is threatened by the effect on the throat—a feeling of dryness and constriction. Glaister,[2] of England, says that coal miners have told him of feeling weakness in the legs, which warned them that they ought to leave the mine, but the gas had so dulled their minds that they kept on working mechanically till they fainted. Apfelbach,[3] of Chicago, observed some 300 cases of industrial gas poisoning and found that in about one-third of the cases there were no warning symptoms at all. It is easy to see the reason for this in the steel industry. Blast-furnace gas contains about 30 per cent of carbon monoxide, which is a much higher percentage than would be encountered in any but an unusual mine accident, and the effect on the man breathing it would be almost instantaneous.

The cases caused by blast-furnace gas and producer or power gas usually come on with rapidity. The same thing is true in some cases of mine accidents, when death has apparently occurred almost instantaneously, for the men are found sitting in natural positions, perhaps with their lunch in their hands, or with their picks as if they had just paused in their work. The most detailed descriptions of gradual gassing come from coal mines. The classical one is that given by Sir Clement LeNeve Foster, who was severely gassed while engaged in rescue work in the great Snaefell mine disaster. He writes: "I suddenly felt decidedly queer, took out my little brandy flask, but already my fingers seemed incapable of opening it. Everything seemed to be in a whirl; there seemed to be a dense white fog. We all sat without trying to escape. The foot of the ladder was quite near, but none of us made an effort to reach it." When he found himself being overcome, he took out his notebook and wrote a farewell letter to his wife and children. In this letter he would repeat certain words, even whole sentences, again and again. He remarks: "I had absorbed enough of the poison to paralyze me to a certain extent, but at the same time my reason had not left me. The general sensation was like a bad dream, and yet I was able to reason properly and write intelligently, though in a disjointed fashion."

When he was rescued and brought to the surface he had a feeling of exhilaration and was in full possession of his senses, for he asked the physician to take a sample of his blood. An hour afterwards he wired to his wife as follows: "Am perfectly right; do not believe any report to the contrary. I repeat I am perfectly right. Clement."

[2] Glaister, John, and Logan, David Dale. Gas Poisoning in Mining and Other Industries. New York, 1914.
[3] Apfelbach, George. In Diseases of Occupation, by Kober and Hanson. Philadelphia, 1916, pp. 43–74.

A few hours later he felt very sick, and afterwards became unconscious and had an epileptiform seizure.

According to many authorities, in carbon-monoxide coma, the lips should be rosy red and there should be an appearance of perfect health, but in industrial cases this seems to be rarely true. It is much more common to find pallor, with red blotches on the skin, and blue lips. These red spots are areas of distended blood vessels, but there may be also actual hemorrhages into the skin. The pulse is slow, strong, and full; then, if the case becomes more serious the pulse changes and is rapid and weak. A disturbance of the blood vessels is seen in flushing of the skin, followed by cold sweats. Gilman Thompson,[4] of New York, has studied the course of 90 cases of carbon-monoxide poisoning who were taken to hospitals and therefore could be carefully observed. Following are the most important of his findings:

All were unconscious when brought to the hospital. They had been poisoned by gas containing for the most part 5 to 10 per cent of carbon monoxide, but in some instances as high as 20 to 30 per cent. In almost all cases there was fever, sometimes preceded by a subnormal temperature. The fever lasted from one day to a week; the maximum duration in any noncomplicated case was 22 days. In cases which were not fatal the highest temperature, with the exception of one unusual case in which the temperature reached 108°, was 104.8° F.; in fatal cases, 107°.[5] The pulse was rapid and weak, but regular. The respiration was rapid, regardless of the condition in the lungs, and was labored and jerky, usually 30 to 36 per minute, and in one case as high as 80. The symptoms in the digestive tract were not severe nor characteristic, nor was there any characteristic change in the urine. On the other hand, in the 29 cases in which blood counts were made, an increase of white cells was found in all but two. Of these 27 cases, 18 had counts between 18,000 and 44,000 (the normal number is about 7,000), and all of those who died (17) had counts above 18,000. The increase in white cells reached its maximum in 24 hours, but sometimes not for 48 hours, and this condition subsided slowly, lasting sometimes for three weeks. It was always a sign of danger to life.

The nervous symptoms were varied. As the patients recovered consciousness, there was confusion, drowsiness, headache, vertigo, blueness of the lips, hands, and feet, reddened areas over the body, and disturbances of sight. Sometimes mental weakness, loss of memory, dullness, and confusion would last for days; sometimes muscular weakness or muscular spasms would develop; but usually there was prompt recovery. It was shown that even if unconsciousness lasted for four or five days the patient might recover. There were convulsions in 7 per cent of the cases. Pneumonia seldom occurred, and death was due, not to this complication, but to the effect of the poison on the brain.

The later consequences of gassing have been described by British, French, and German writers, and apparently differ somewhat, according to the character of the accident. Thus, Glaister believes that the effect on the heart is not so marked in coal-mine gassing as

[4] Thompson, W. Gilman. Medical Record, 1904, vol. 66, pp. 41–47.

[5] Apfelbach has seen cases with a temperature of 107° F. and even one of 110° F. just before death.

in producer-gas poisoning, where the loss of consciousness may apparently be due to heart failure. Slow, gradual gassing undoubtedly causes much more severe permanent damage than does quick gassing, even though the latter may bring on deep coma and convulsions, and seem for the time being much more serious. It is the victims of slower gassing in coal mines and garages who are most likely to develop pneumonia, weakness of the heart, paralysis, and mental disturbances, not the victims of sudden gassing at blast furnaces.

AFTEREFFECTS.

A man who recovers from a fairly severe gassing has a throbbing headache, a sensation of constriction in his temples, a feeling as if his head would split, he is dizzy, his legs and sometimes his arms, back, and neck feel powerless, and he may even not be able to hold up his head. He is numb, and there are instances in which a man who has been burned while unconscious does not feel the pain of the burn after he regains consciousness. He shivers and can not get warm, he has a feeling of oppression in the chest and palpitation of the heart, and if he attempts to walk home he may bring on a cardiac weakness. Pneumonia is a very important aftereffect, and in countries which grant compensation for occupational diseases, a very puzzling situation frequently develops in connection with pneumonia after gassing. The British believe that carbon monoxide is a more frequent cause of pneumonia in miners than even nitrogen-oxide fumes, although the latter are very irritating to the lungs and would seem to do much more damage. They believe from their experience, not only in England, but in the mines of South Africa, that carbon monoxide lessens the resistance of the lungs, and therefore prepares the way for pneumonia. In the mines of the Rand, this is the great occupational disease. The ore mined there is siliceous, and after some years of work the men's lungs are affected with silicosis. These men are said to be prone to pneumonia after carbon-monoxide poisoning, the condition of their lungs rendering them less resistant to its effects.

Cases of post-gassing pneumonia usually develop one to three days after the accident and may be ushered in by a hemorrhage from the lungs. The characteristics of this form of pneumonia are that it is lobar in type, caused by the pneumococci, the right lung is mostly affected, and the disease develops rapidly. The temperature is not high, but the pulse is disproportionately rapid and thready, the heart dilates, and if death occurs it is early in the course of the disease, on the third or fourth day.

For descriptions of the nervous symptoms and the mental symptoms following carbon-monoxide poisoning it is necessary to turn almost exclusively to foreign literature, especially the English and French, for there is very little in the American, and of the few cases that have been described in the United States the majority are connected with but one source—the exhaust gases of motor-car engines. On the other hand, the English have a wealth of material of this sort, chiefly from their coal mines, and the French also, from a great variety of industries in which coal gas is used as a source of heat and light. Glaister finds nervous and mental disorders so common among coal

miners that he calls them characteristic of colliery accidents in England and he believes that the action of carbon monoxide is most marked on nerve tissue. He finds the same thing to be true of illuminating gas and automobile exhaust gases. He describes many cases of mental impairment, especially loss of memory, loss of initiative, inability to work hard, depression, dullness, premature senility, childishness, and change of disposition.

A striking instance given by him was an accident that occurred about the year 1900 in the Coltness Iron Works. An engineer, 20 years of age, described as being a most intelligent workman, was sent into an exhauster, a space just large enough for one man, to make some repairs about the fans. The air inside was tainted with carbon monoxide. When he came out after finishing his work he complained of feeling a little giddy, but, remembering that he had left his chisel behind, he went back to get it and had no sooner entered the exhauster than he collapsed and sank unconscious to the bottom. There was no way of getting him out except by taking the exhauster to pieces, unscrewing bolts, etc., and by the time this was done he had been about an hour in this confined place, breathing an atmosphere with an unknown percentage of carbon monoxide. The accident happened between 11 and 12 in the forenoon. After a long struggle he recovered consciousness, but was dazed and stupid, talked incoherently, and was very "heady" till 5 or 6 in the evening, when he began to talk quite rationally and could write his name. Except for these first few hours he had little apparently wrong with him for nearly three days, when suddenly his mind became a complete blank. He knew nobody, not even his own mother, and could do nothing on his own initiative. His powers of speech, sight, and hearing were good. If asked to look through a window at a horse he would repeat the word "horse," but if questioned further his answers would be silly and irrelevant. He had to be tended like a baby. This went on for a month or two, then there was a slight improvement, and he is described as being at this stage like a big simple child, who was very easily managed. After a time he was given lessons by the village schoolteacher, beginning like a child with his alphabet, and soon after he started work, but here also he had to begin as an apprentice, as he had forgotten everything, even how to handle his tools. At the end of ten years he was in the best of health, talking rationally and intelligently, and seeming to an ordinary observer quite normal, but those who knew him before his illness said that mentally he was only a shadow of his former self. He had lost all initiative, always had to be told what to do, and if a responsible job was given to him he was sure to get excited. His memory was poor, he was very easily irritated, losing command of himself, and then was hardly responsible for what he did. After an attack of anger or excitement his memory became much worse. He was, however, constantly improving.

Many instances could be given from both English and French literature of mental deterioration following accidental gassing. The most important symptom in these cases seems to be loss of memory. Briand,[6] of France, declares it to be quite common. It is not slow

[6] Briand. Annales d'hygiéne publique et de mèdecine lègal, 1889, vol. 21, p. 357.

and progressive as in alcoholic dementia, but comes on suddenly. Usually it is only as to events following the accident, but sometimes it takes the form known as retrograde amnesia, wiping out the memories of past life. In a case reported by Sanger Brown, of Chicago, the events of the three or four days just preceding the accident were erased along with those of the days just following. Apfelbach, like all American observers, finds this condition very rare in industry, but gives the history of one typical case. This man lay in coma for 12 hours, then he was delirious and had involuntary evacuations and muscular twitchings. After the delirium passed off he was stuporous or confused and apathetic. When Apfelbach saw him four months later he had lost memory for places, could not find his way about the works or find his way home; he could not remember having seen the doctor before. He had lost the memory of all the events of his life except his childhood, and could not recollect the happenings of a day or two previous. His speech was slow and his gait slow and awkward, but his reasoning powers were good.

The most carefully studied instances of this aftereffect of carbon-monoxide poisoning in American literature are those that come from exposure to the exhaust gases in garages, probably because the victims are often educated men, not infrequently physicians, who are able to describe their own mental symptoms clearly and who are attended by well-trained physicians. One such case is described by Dr. C. W. Hitchcock,[7] of Detroit. A chemical engineer of college education was overcome by carbon-monoxide gas in his garage and was found unconscious on the floor more than an hour later, the engine of the car running at the time. He was given medical treatment at once and partly recovered consciousness some four or five hours later. The week following he was very weak and could recognize his friends but would forget that any one of them had been there as soon as he left the room. About five months later when Dr. Hitchcock saw him he was lax in his personal appearance, quite unlike his normal self, and his face had rather a blank expression. He lacked initiative for any work, could drive his car only in quiet, familiar places, was despondent and not so friendly in his attitude to people as before. He had begun to be able to listen to and follow short stories. Five months later he was better but still unable to resume work; his memory was still uncertain, especially for the most recent events. Things happening five or ten minutes back seemed the hardest to recall. He could remember events of the past eight months, but the first two months after his accident were almost a blank. He was still depressed and it would take him a whole afternoon to do what he would ordinarily have done in 10 minutes. He lacked his former ambition and energy and was decidedly wanting in initiative. Fourteen months after the accident his memory was still poor, but he was gaining somewhat in self-confidence.

Much less common than the above form is delirium or mania following gassing. Cases of this sort have been reported in connection with a colliery accident in Scotland and the inhalation of charcoal fumes in France and of coal gas in Germany. Usually the effect is transient, but a case seen by Thomas Oliver[8] was insane

[7] Hitchcock, Charles W. Journal American Medical Association, 1918, vol. 71, p. 257.
[8] Oliver, Thomas. Diseases of Occupation. London, 1908, p. 60.

for two years. Such cases have sometimes been of medico-legal importance, for the victims may during the period of excitement commit a crime, even a murder. According to Dr. Ira Miltimore, at that time with the Illinois Steel Co., at Gary, Ind., it is not at all uncommon to have a man who has been gassed while at work pass through a stage of violent delirium. He described a typical case as follows: The man is overcome by the gas, but does not lose consciousness completely. He is hurried by ambulance to the hospital, reaching there usually about 10 or 15 minutes after the occurrence of the accident. By this time he is often delirious, even maniacal, so that he has to be restrained in bed. This stage, however, lasts only a few hours; then he gradually becomes rational and complains of intense headache. European authorities say that excitement, delirium, or hysterical symptoms are more likely to be seen in women than in men.

Among the nervous aftereffects of severe gassing paralyses of all kinds, but most often of the legs, are found. Such paralysis may come on at the time of the accident or develop some days later. Almost all the motor nerves have been involved in different cases, and besides this form of paralysis there may be injury to the vasomotor nerves or to the optic nerve. Two cases of this kind have been described by W. J. McGurn,[9] of Boston, as cases of multiple sclerosis due to repeated inhalation of carbon monoxide by men working over hot-water heaters with leakage of gas. The first had an acute attack of gassing with a terrible headache, dizziness, vomiting for several hours, bluish lips, and unsteady walk. Four days later he complained of numbness in the legs and difficulty in walking. Two weeks later he had double vision. All this time he continued working at the leaky furnace. His condition grew progressively worse, and at the end of two years he was unable to walk, there was atrophy of the muscles of the back, legs, and arms, there were wide areas of anesthesia, and his sight was failing; and his mind was unimpaired, but he had lost the sense of position of his limbs. He died six years later, emaciated and helpless from muscular contractures. The Wassermann test was negative. The second case, also of a man exposed for some time to gas from a leaky furnace, began in very much the same way, only the symptoms were even severer, for he was delirious, with rapid, labored respiration, wide pupils not reacting to the light, and for several minutes clonic convulsions. There was loss of strength in the right hand, loss of sensation, and diminished vision, especially in the right eye. These acute symptoms cleared up and, though his vision was impaired, he went back to work. He quickly became much worse, lost strength and weight, his gait was spastic, he could not coordinate his muscles, and he had mental depression, loss of memory, and some defect of speech. Finally he could not stand alone or lift a foot from the floor, or feed himself. After 16 months in the country, he recovered the use of his limbs, but typical symptoms of disseminated sclerosis, an intention tremor, a loss of sense of position, and atrophy of muscles developed.

[9] McGurn, Wm. J. Medical Record, 1917, vol. 91, pp. 149–151.

RELAPSING FORM.

The relapsing form of carbon-monoxide poisoning is a term used to indicate those cases which, having apparently recovered from the first effect of the poison, develop, after a period of fair health, serious symptoms that may lead to death or insanity. Several instances of this form are described by McConnell and Spiller,[10] of Philadelphia. One was a man of 69 who had been overcome by carbon monoxide and had dizziness and headache persisting for a long time. A month after his apparent return to health he developed paralysis of the right side, quickly followed by his death. Another was a woman who, after recovery from acute poisoning, developed mental disturbance, aphasia, convulsions, and rigidity of the muscles. She had been overcome by coal gas and had seemed to recover, but then passed into a condition of paralysis with contraction of the muscles, including those of mastication, so that she had to be fed through a nasal tube. She died 40 days after her accident.

Lewin,[11] of Germany, who has had much to do with the medico-legal aspect of industrial poisoning, says that these cases present great difficulty when it comes to deciding questions of compensation. He mentions a man who after severe gassing recovered and at the end of 36 hours was apparently well except for headache, but 20 days later he had a recurrence with increasing paralysis of the limbs, which was complete on the 24th day, and on the 25th he died. Another victim of gas was able to be up and about for 5 or 6 days after his accident, then he was seized with convulsions, followed by lockjaw and death. After lighter poisoning, Lewin has often seen pneumonia come on some 6 to 14 days later; after severer poisoning there may be mild or severe nervous symptoms, sometimes no more than what are usually called "accident neurosis," that is, a sense of weariness and general illness, with pains in the legs, and sometimes much severer symptoms, such as blindness, deafness, paralysis of various kinds, or delirium or dementia. This latter class of cases may also develop pneumonia and bloody urine. The prognosis is always poor in cases that suffer a relapse.

UNUSUAL SYMPTOMS.

There are a few special symptoms of gassing which should be mentioned before leaving this subject. The occurrence of fever has already been spoken of. It usually comes on during the period of unconsciousness and may last till consciousness returns or even longer, while in some cases it appears first several days after the accident. Sometimes the rise of temperature is very high, especially if there are convulsions, and this is always an extremely grave sign. The highest thus far noted was in a case of Apfelbach's, which reached 110° F. just before death.

A rapid loss of weight after gassing with carbon monoxide has been observed frequently and can be produced experimentally in animals, but it seems probable that in these cases there has been an injury to the central nervous system; in fact, such cases usually show paralysis or mental impairment. Diabetes is one of the possible

[10] McConnell, J. W., and Spiller, William G. Journal American Medical Association, 1912, vol. 59, pp. 2123 and 2124.
[11] Lewin, L. Die Kohlenoxydvergiftung. Berlin, 1920.

aftereffects, and so are various forms of skin disease, although carbon monoxide is not at all irritating to the skin. They, too, are probably of nervous origin. There may be excessive perspiration, or dropsy of the skin, or eruptions, blisters, necrosis, and even gangrene.

The digestive system may undergo a great variety of disturbances, such as excessive salivation, bleeding from the gums and throat, gastric and intestinal indigestion, vomiting, and severe abdominal pain. There are no characteristic changes in the urine. In the lungs all sorts of inflammatory conditions may be found. The heart symptoms are among the most constant: Rapid pulse, palpitation, low blood pressure, and often irregularity. A permanent weakening of the heart is one of the most frequent aftereffects of accidental carbon-monoxide poisoning.

The changes in the blood vessels are important from the medico-legal point of view, for if acute carbon-monoxide poisoning has the effect of weakening the walls of the blood vessels, then an apoplectic stroke, which follows (even after a fairly long interval) an accidental gassing, should be regarded as an industrial accident. This view has been repeatedly held in England and occasionally in the United States. For instance, recently in one of the large steel towns in the United States a man was gassed, lost consciousness, was under medical treatment for several days, then went back to work and was apparently well for about a month, when he died from hemorrhage in the brain. The coroner's office held that since the man was only 32 years old and not a syphilitic, the damage to the vessel wall which led to its rupture was to be traced to the effect of the gas. It has been shown repeatedly in animal experiments that coal gas causes relaxation of the blood vessels through a sudden weakening of the muscular fibers. This causes slowing of the circulation and the collection of blood in the smaller vessels, and then degenerative changes, especially fatty, in the walls of the arteries. Hemorrhages into the skin from rupture of vessels on the surface of the body are not at all unusual, causing red blotches on the skin and purple spots on the lips and the mucous lining of the mouth.

Among the more unusual symptoms which have been attributed to carbon-monoxide poisoning are paralysis of some of the muscles of the eyes, leading to the well-known miners' nystagmus. Affections of the optic nerve, leading to partial or total blindness, have occurred after severe gassing, and so have affections of the nerve of hearing.

EFFECT ON CHILD OF GASSING OF MOTHER.

Carbon monoxide can pass from the mother's blood into the blood of the fetus, and, according to Nicloux,[12] the latter may contain an equal quantity of gas. Lewin describes the case of a woman who, toward the end of her pregnancy, attempted suicide with illuminating gas. She was found unconscious in the morning and 11 hours later gave birth to a dead child, which was, however, so rosy that the midwife attempted artificial respiration, unable to believe that it was dead. It was found that one-fifth of the baby's hemoglobin had taken up carbon monoxide. In another case the mother's blood

[12] Nicloux, M. Comptes rendus de la Societe de Biologie, 1901, vol. 53, p. 120.

contained 18 per cent carbon monoxide and the blood of the fetus only 4.07 per cent. It has long been believed, since Roman days in fact, that the smoke from extinguished candles would bring about premature labor, and Lewin believes that there is evidence to show that while slight carbon-monoxide poisoning in the mother may produce no symptoms striking enough to arouse attention, it may be quite enough to kill the child in utero, and that such poisoning is probably fairly common in industries where women are employed and where the air is vitiated with carbon monoxide. He has known of an instance of this sort, a pregnant woman working on a printing press which was driven by a gas motor. Some accident allowed gas to escape, she was seized with symptoms of carbon-monoxide poisoning, and aborted.

INDIVIDUAL SUSCEPTIBILITY.

Every student of carbon-monoxide poisoning is impressed with the great variety of injuries which it may set up. In this respect carbon monoxide differs from every other known poison. Even the symptoms of acute poisoning vary more than is usual, and when it comes to the aftereffects, it seems that any organ or tissue of the body may show injury, and it is impossible to predict what the course of any individual case will be. To begin with, there is a great difference in individual susceptibility, and although it seems plain that drunkards succumb soonest, still that is not nearly enough to account for the varying effects of the gas on different victims who, apparently, have been exposed to the same amount. For instance, in the greatest mine disaster on record, the one in the Courrieres district in France, 1,100 men died from carbon-monoxide poisoning and 13 escaped. It has been said by some that women are less susceptible than men, and that in cases of family poisoning it is more likely to be the woman who escapes with her life than the man, but in such cases the source of the gas is usually some leak from the domestic supply, and it is quite possible that the woman, employed in the house for most of the time, has acquired a partial immunity by breathing small quantities of gas for many days. The Zola case was cited in proof of the theory that women resist gassing better than men. Madame Zola lived while her husband died, but he was found dead on the floor, having gotten up from bed, and it may be that the exertion he had made was the last straw.

According to Glaister, experienced foremen in industrial establishments in England believe that vigorous young men are especially liable to be gassed, and that middle-aged men should always be selected for a piece of work which involves exposure. Glaister agrees with this and considers that the young and the old are both oversusceptible, the former probably because of their deeper inspirations and greater chest capacity.

DESCRIPTION OF CHRONIC POISONING AS GIVEN IN AMERICAN AND FOREIGN LITERATURE.

When chronic carbon-monoxide poisoning is considered the situation is not nearly so clear. The symptoms which may be attributed to long exposure to small quantities of this gas are not character-

istic and might be explained on other grounds, especially as they are usually found in working people, in whose environment and mode of life there are many features besides the exposure to gas which could be held responsible for ill health and for the more or less vague symptoms of which they complain. It is in European countries, especially in France, that we find the theory held most generally as to the injury caused by chronic carbon-monoxide poisoning. In 1869, Moreau,[13] of Tours, proposed to call the mental disorders of carbon-monoxide poisoning "the insanity of cooks" (*folie des cuisiniers*), because so many cooks were subject to it. Ill-ventilated gas stoves, devoid of flues, such as are found in poor dwellings, are looked upon by the French as the probable source of many unrecognized cases of poisoning. Even more frequent in France is the escape of gas from the slow combustion coal stoves so common on the Continent. Landouzy[14] emphasized this at the meeting of the International Congress of Tuberculosis in 1905, and said that the disappearance of anemia and headache in poor people who were sent to the country could be explained by their escape from carbon-monoxide poisoned air to pure air.

Sèe,[15] in 1873, wrote about "The dizziness of cooks," and described a condition which he said was very common among them, consisting in severe headache, sometimes intolerable, dizziness, muscular weakness, sense of weariness, staggering gait, and sometimes nausea and vomiting. Usually the attack began after leaving work and going out into the fresh air, or on waking in the morning, or at the end of the day's work. Some men never experienced it; others seemed to acquire a tolerance which could, however, be upset by an unusually long exposure. These men practically always suffered from digestive disturbances.

From the British it is learned that the most serious symptoms of chronic carbon-monoxide poisoning consist in disturbance of the nervous mechanism of the heart, palpitation, distress over the heart, a feeling of oppression, and irregular pulse, which on very slight exertion becomes rapid. Observations were made on steel workers. Glynn,[16] in 1895, described chronic poisoning in a boy of 16 who was employed in a shop where the air was contaminated with carbon monoxide. He suffered from pain in the calves of the legs, loss of power affecting especially the extensor muscles, tenderness on pressure, and sensations of crawling and pricking. He recovered on removal from work. Glaister believes that women feel the effects of chronic poisoning more than men; that in factories where the air is contaminated with gas the women suffer more from nervous symptoms than do the men.

The changes in the blood which are caused by carbon monoxide have been studied in connection with chronic carbon-monoxide poisoning, with varying results. The effect of saturating some of the red corpuscles with carbon monoxide instead of oxygen is to cause a number of fresh corpuscles to be thrown into the circulation in an effort to

[13] Moreau. Quoted by Glaister and Logan in Gas Poisoning in Mining and Other Industries, p. 276.
[14] Landouzy, L. London Lancet, 1905, Vol. II, p. 1433.
[15] Sèe. Quoted by Glaister and Logan in Gas Poisoning in Mining and Other Industries, p. 312.
[16] Glynn, T. R. British Medical Journal, 1895, vol. 1, p. 759.

keep up a normal supply of oxygen. This means that the red-blood-cell count may be high in a man who is continually exposed to carbon monoxide. Von Jaksch reports a blood count of 6,390,000 per cubic millimeter (the normal number is five to five and one-half million). Glaister examined a stoker in a gas works who was suffering severely from loss of motor power, pain in his abdomen and in the left side of the head, loss of appetite, and weakness. Three counts of the blood showed, respectively 8,200,000, 9,500,000, and 11,200,000 red cells, but the hemoglobin was only 62, 76, and 90 per cent. He was sent to the mountains and gained in weight but was otherwise unimproved, and four months later the count was still between 9,400,000 and 11,000,000, with hemoglobin of 90 per cent. This increase in red corpuscles is found both in experimental animals and in human beings without any symptoms of ill-health at all. Nasmith and Graham [17] succeeded in keeping the blood of guinea pigs 25 per cent saturated with carbon monoxide for days at a time. The animals were lively and continued to gain weight normally and their blood showed a decided increase of red blood corpuscles. An examination of the blood of steel workers was made by Apfelbach and Karasek for the Illinois occupational disease investigation in 1910. Sixty-eight men, all steel workers who had either been recently gassed or subject to frequent gassings, were selected, and the blood examined for hemoglobin and red and white cell counts. They found that there was an increased number of red cells which ran from 5,500,000 to 9,676,000, more than half, or 66 per cent, being over 6,000,000, but no immature red cells were found. The hemoglobin ran from 95 to 125 per cent, more of them being over than under 100 per cent. No abnormality was found in the white corpuscles.

Apfelbach later presented the results of 5 examinations made of people suffering from acute carbon-monoxide poisoning, and 11 of men and women employed in work exposing them to chronic poisoning. The first series of examinations may be briefly summarized as showing that after severe gassing the blood has on the third day and still more on the sixth day an increased number of red corpuscles, from 100,000 to more than 1,000,000 over the normal. The second series of examinations is more interesting and is reproduced here:

RESULTS OF EXAMINATION OF 11 PERSONS EXPOSED TO CHRONIC CARBON-MONOXIDE POISONING.

[From Kober and Hanson, Diseases of Occupation, Philadelphia, 1916, p. 72.]

Sex.	Occupation.	How long employed.	Red-blood-cell count.	Symptoms noted.
		Years.		
Female	Tailor shop	6	5,762,100	Headaches.
Do	Laundry	1	6,432,130	Do.
Male	Can manufacturer	22	7,611,310	Headache, anorexia.
Do	do	10	6,421,140	Neurasthenia.
Do	do	4	5,280,710	Do.
Do	Salamander	3	8,497,600	Headaches, anorexia.
Do	do	5	6,311,000	Nausea.
Do	do	5	6,311,000	Headaches.
Do	do	12	4,376,000	Do.
Do	Tailor	5	6,378,000	Do.
Do	do	6	5,810,000	Do.

[17] Nasmith and Graham. Journal of Physiology. London, 1906–7, vol. 35, p. 32.

Some years later, in 1917, the Illinois Steel Co. undertook an examination of 176 blast-furnace and open-hearth men at the Gary and South Chicago plants. These employees were given physical examination, analysis was made of the urine, and the blood examined for percentage of hemoglobin and for the red-cell and white-cell count. The men had all been employed for several years in work which exposed them continually to small quantities of carbon monoxide and the majority of them had suffered from acute gas poisoning. The records of the examination were furnished by the chief surgeon.

The men who had suffered from acute gas poisoning, in describing their experience, said that usually they noticed first a severe headache, dizziness, ringing in the ears, weakness of the legs, nausea and vomiting, and in some cases loss of consciousness. After regaining consciousness a severe frontal headache would persist for from a few hours to a few days. None of the men were at that time suffering from any nervous disorders nor were the findings from the blood examination or from the urine analysis of any particular significance. The red blood-cell count was as follows:

RED-BLOOD-CELL COUNT OF 176 BLAST-FURNACE AND OPEN-HEARTH MEN.

Red blood cells per cubic millimeter.	Number of men.	Per cent of total.
Under 4,500,000	6	3.4
4,500,000 to 5,000,000	56	31.8
Over 5,000,000 to 5,300,000	67	38.1
Over 5,300,000 to 5,600,000	19	10.8
Over 5,600,000 to 6,000,000	23	13.1
Over 6,000,000	4	2.2
Not examined	1	.6
Total	176	100.0

This shows that only 15 per cent of the men had red-cell counts much above the average and only 2.2 per cent had counts which would be called strikingly high. The white-cell count showed nothing of interest, nor did the urine analysis or blood-pressure estimations. It must be remembered in discussing such results as these that a group of men who have worked for years at blast furnaces and open hearths, many of them working a 12-hour shift regularly, can not be regarded as average men—they are a selected group, they represent the survival of the fittest, for no man of only average physique could endure the strain. If one were really to seek an accurate picture of the effect of such work as this on ordinary men, one would have to examine not only those still employed but those who have been obliged to drop out.

In works on chronic carbon-monoxide poisoning Grawitz[18] is always quoted, and sometimes the quotation is much more emphatic than Grawitz's original statement. What he says is that anemia of profound degree, resembling pernicious anemia in type, may be found as a result of continual breathing of carbon monoxide in coal gas, such as he saw in a woman who did pressing in a tailor shop and in whom this seemed to be the cause. Lewin speaks of pro-

[18] Grawitz, E. Klinische Pathologie des Blutes. Leipzig, 1911, p. 416.

found anemia with a red-blood-cell count as low as 1,500,000 as a result of chronic poisoning. On the other hand, there are some observations of a high red-cell count with low color index; that is, a low percentage of hemoglobin. One of these was reported by Reinhold.[19] The man was employed in a gas factory, working for two years on a 12-hour shift and exposed to a good deal of gas. After nine months he began to suffer from a sense of weariness and weakness, left-sided headache, loss of appetite, alternating with ravenous appetite, and pains in the abdomen. No carbon monoxide was shown by the spectroscope, but a count of the red cells gave 9,500,000, but only 76 per cent hemoglobin, and later on 11,200,000 with 90 per cent hemoglobin. A similar though not so striking a case is reported by Apfelbach, of Chicago. This man was working for certain periods every day over a burning soldering machine, during which time it was possible to inhale carbon-monoxide fumes. His symptoms pointed to profound anemia. Apfelbach ruled out tuberculosis, lead poisoning, and nephritis, and, finding that the man had a red-cell count of about 7,000,000, he made the diagnosis of chronic carbon-monoxide poisoning. The man improved on changing his work.

An interesting finding and one which, if confirmed, would be of decided economic importance, was that made by Karasek and Apfelbach in the course of an investigation of carbon-monoxide poisoning for the Illinois Commission on Occupational Diseases in 1910. They examined 400 workers, half of them employed in the steel works of South Chicago, the other group employed in plants where there was no possibility of carbon-monoxide poisoning. The two groups were of the same nationalities and the character of their work was similar, as were also their home conditions. A comparison was made of the muscular strength of the hand, using the ordinary hand dynamometer, and, as shown below, it appeared that the steel workers exposed to carbon monoxide had decidedly less muscular strength than working men of the same age not so exposed.

	Average strength.
Ages 20 to 40:	
Steel workers	117.13
Car-company workers	146.11
Other trades	134.43
Ages over 40:	
Steel workers	94.3
Car-company workers	127.25
Other trades	113.01

The whole question of chronic carbon-monoxide poisoning is very obscure as to its nature, its prevalence, and its diagnosis. It can not be regarded as caused by an accumulation of carbon monoxide in the body, which reaches a certain degree and then produces symptoms, because that could occur only if a person were breathing carbon-monoxide contaminated air all the time, and this is never true. During the hours when pure air is being taken in, the carbon monoxide is pretty quickly discharged. However, it is possible that, although the gas does not accumulate in the blood, there may be a piling up of the slight injuries produced by its presence until the point is reached when the effect on the health becomes noticeable. This effect may be simply a slow starvation of the tissues, but if

[19] Reinhold. Münchener medizinische Wochenschrift, 1904, vol. 51, p. 739.

such starvation results in impairment of function of an organ, the secondary effects of that may be decidedly harmful. There is a marked variation in the way different individuals are affected by long exposure to small quantities of carbon monoxide. One person will suffer from ill-health, constant headache, neuralgic pains, perhaps albumen in the urine, after a few months' work in a room where others have passed several years with no trouble at all. An interesting report from France by Courmont[20] describes the effect on 35 individuals of working for periods up to three years in a room with leaking gas pipes. It was found that the air had contained from time to time 1 part of carbon monoxide in 1,000 parts of air to 1 in 10,000 parts of air. Twelve of the 35 had albuminuria and three had sugar in the urine, but none had any symptoms of heart weakness or of damage to the blood vessels. They complained of headache in the forehead or temples, less often in the back of the head. Thirty-two out of the 35 had neuralgic pains in the lower part of the back or in the intercostal nerves, and in some cases there were areas of great tenderness on the skin and sensation of crawling or pricking.

There is great difficulty in diagnosing this form of occupational poisoning, because so rarely are the symptoms at all characteristic. Usually there is only complaint of headache, palpitation of the heart, breathlessness, general nervousness, and disturbed sleep. Indigestion (especially for solid food), loss of appetite, and acid eructations two or three hours after meals are very common. There may be sleeplessness at night and drowsiness in the daytime. Often this drowsiness is so great as to lead to the taking of stimulants. The French attribute the alcoholism of male cooks to the effect of gas from the stoves, and say that they suffer from loss of energy and great irritability.

A great number of industrial workers are exposed to small quantities of carbon monoxide in the course of their work, and may suffer from poisoning, although there is almost no positive evidence that this is actually the cause of the ill-health so often complained of in these trades. Those who are most in danger are thought to be the following:

Laundry workers, especially ironers.
Pressers in tailor shops.
Furnace tenders.
Gas workers, especially men making connections and reading meters.
Painters working in rooms in which salamanders are kept burning to dry the walls.
Printers, especially linotypists, and men working at melting kettles heated with gas.
Molders of metal where gas is used for heat.
Men working in canneries on soldering machines.
Miners, especially in mines where blasting is done continuously.
Garage workers, especially repairers.

The results of tests made on garage workers and linotypists to determine the presence of carbon monoxide in their blood are given in the final sections of this report.

[20] Courmont, Jules. Bulletin de l'Academie de Médecine, 1910, vol. 64, pp. 491–503.

OTHER CONSTITUENTS OF INDUSTRIAL GASES.

Although the effect of these industrial gases is always attributed to the carbon monoxide which they contain, it must not be forgotten that there are dangerous substances present besides carbon monoxide. Analysis of coal gas shows the presence not only of large proportions of carbon dioxide, nitrogen, and hydrogen, but such toxic gases as benzol and toluol, sulphureted hydrogen, hydrocyanic acid, and a small quantity of ethylene. The most important constituent next to carbon monoxide is undoubtedly benzol. This is a well-known poison, for it is used largely in industry as a solvent for gums, resins, fats, and rubber. It is obtained in the distillation of coal in the production of coke, as one of the by-products, together with toluol and some xylol. These three compounds all have the same effect on human beings, but toluol is weaker than benzol and xylol distinctly weaker than toluol.

Benzol attacks the central nervous system, causing loss of consciousness, muscular twitching, sometimes convulsions, and death from respiratory failure. If the dose is not so large, there is dizziness, confusion, roaring in the ears, impairment of vision, headache, and nausea. If benzol is inhaled in small quantities for a long period of time, a chronic poisoning is set up which shows itself in very profound anemia, loss of both red and white blood cells, and in hemorrhages into the tissues under the skin and through the mucous membranes, the skin shows purpuric spots like bruises, there is bleeding from the gums and throat and sometimes from the stomach and the intestines. Hemorrhages into such tissues as the brain and spinal cord cause symptoms of paralysis and mental disturbance.

It is quite possible that some of the puzzling features of carbon-monoxide poisoning will be found to belong not to carbon monoxide but to benzol. The chronic anemia of slow gassing and the nervous and mental symptoms which follow both rapid and slow gassing are possibly referable to the benzol present in the gas. Illuminating gas practically always contains benzol and in greater proportion as the proportion of water gas increases. Gases from motor engines contain benzol, especially when the fuel is composed of coal-tar oils as well as petroleum oils. It is possible that this is the explanation of the puzzling fact that paralysis and mental disease seem to occur so much oftener after gassing accidents in garages than after any other form of industrial carbon-monoxide poisoning.

Experimenters have found that if they use coal gas as a substitute for pure carbon monoxide their experiments will not come out the same. An interesting observation was made by Staehelin, who was experimenting on frogs with carbon monoxide. Having no more pure gas he tried to use ordinary illuminating gas instead, but found that he got quite different results—rigidity of the muscles, and convulsions, which had never followed the use of pure carbon monoxide. Then he tested the other constituents of illuminating gas and found that benzol in the same proportion as that found in the gas would set up convulsions and muscular rigidity.

In the early days of motor cars the cases of gassing that occurred from breathing the exhaust gases of engines were attributed to

gasoline fumes and the name "petromortis" was given to accidents of this sort. Later on all these came to be regarded as caused by carbon monoxide, and yet there are some clear instances on record of very much the same form of poisoning which were clearly due to the fumes of gasoline. For instance, there were 42 cases of gasoline poisoning in a tunnel in Montreal in 1913. The men were asphyxiated, unconscious, with flushed faces; rapid and deep breathing, and in two instances, in convulsions. They recovered consciousness, complaining of severe frontal headache, and the next day they seemed all right. The air of the tunnel was analyzed and gasoline fumes were found but not carbon monoxide, nor did a spectroscopic examination of the men's blood show any carbon monoxide.

Potts described in 1914 a case of poisoning which closely resembled those caused by carbon monoxide, but here too gasoline fumes were responsible. This man worked for four months filling automobile tanks with gasoline. He was ill for about two months with intense headache, vomiting, and sometimes double vision. One day while at work he fell to the ground in a faint and when aroused he complained of headache, his left side was weak, and there was some incoordination in his left arm. He improved but did not recover the strength of his left arm nor of the muscles of the eye.

The other gases which may be present are probably of far slighter importance. Sulphureted hydrogen begins to produce a toxic effect when present in the proportion of 1.5 parts to 10,000 of air and is dangerous when the quantity reaches 5 parts, but it is doubtful whether this gas plays an important part in coal-gas poisoning except perhaps in the manufacture of illuminating gas or in the gas from coke by-products or in certain conditions in coal mining. Ethylene has been regarded as possibly an important element in coal gas because it is extremely destructive to plant life, but the evidence seems to show that it is fairly harmless to man.

Hydrocyanic acid, or cyanogen, is present in the gas from coke by-products and may be present in illuminating gas and in blast-furnace gas. A recent report from Germany[21] is interesting as pointing to the presence of some unknown poisonous fumes in blast-furnace gas. In a plant situated in the Saar Valley dry scrubbing of the furnace gases had been substituted for wet. The report, which is made by a factory inspector, states that after this change was made several men were overcome by gas from the scrubbers, but although the acute symptoms were quite like those of ordinary carbon-monoxide gassing, the men did not recover completely, but there was very decided mental impairment which necessitated treatment in the insane asylum. The report was made some three months after the accident, and during that time there had been no improvement in their condition. No cases of this kind had ever been observed at the plant while the wet scrubbing was used, showing that some compound or compounds which were formerly removed by the wet process remained after the dry scrubbing. The management suggested that possibly some arsenical or cyanogen compound might be responsible.

[21] Derdack. Zentralblatt fur Gewerbehygiene, 1920, vol. 8, p. 90.

SOURCES OF CARBON-MONOXIDE GAS.

The sources of carbon-monoxide gas in human environment are very numerous, but by far the most important is the burning of carbon-containing material with an insufficient supply of oxygen. Much the largest number of cases of carbon-monoxide poisoning occur as the result of breathing air in which the products of such combustion are present. Coal gas, which is a product of incomplete combustion, consists essentially of carbon monoxide and carbon dioxide, the mixture of which is heavier than atmospheric air. These two gases are odorless, but almost always they carry with them enough odorous bodies to give warning of their presence. The actual composition of coal gas varies greatly according to its source. The following are a few analyses given by Lewin:

Glowing anthracite coal (results of seven analyses): Per cent of carbon monoxide, 0.16, 0.19, 0.26, 0.3, 0.44, 0.56, 0.62.

Coal from burning wood (average of eight analyses): Carbon monoxide, 0.34 per cent; carbon dioxide, 6.75 per cent; oxygen, 13.19 per cent; nitrogen, 79.72 per cent.

Brown coal in the form of briquettes, burning slowly, yielded the following: Carbon monoxide, 10 per cent; carbon dioxide, 90 per cent.

In the course of coking coal the percentage of carbon monoxide produced varies according to the character of the coal, the percentages in German coke works running from 3.9 to 7.1.

Blast-furnace gas is very rich in carbon monoxide, resulting from reduction of the oxide ores by means of glowing coke, and in addition there is the carbon monoxide formed by the burning of the coke. German blast-furnace gas contains from 24 to 25.97 per cent. American analyses usually demonstrate about 26 per cent, though sometimes as high as 30 per cent.

Power, producer, and generator gas contain different amounts of carbon monoxide, according to the source and method of production, the limits being from about 22.8 to 26 per cent.

The detonation of explosives produces large quantities of carbon monoxide, the burning of explosives a smaller quantity. German experiments have shown that the explosion of celluloid forms a gas containing 45.7 per cent carbon monoxide, while the burning of celluloid films has been known to give off gas containing 26.3 per cent. The explosion of gunpowder results in a gas containing only 3.6 to 9.26 per cent carbon monoxide, but the gas from the explosion of pyroxylin contains 46.87 per cent, of dynamite 34 per cent, of trinitrotoluol 57 per cent, and of picric acid (lyddite, melinite) 61 per cent. The gases that are found in mines and tunnels after explosions produce their effect chiefly through their carbon-monoxide content, although if there is much hydrogen sulphide present this may also have a toxic action.

Several analyses have been made of the gas from open braziers filled with glowing coke, and it was found that in a well-ventilated room the air 15 to 25 centimeters (5.9 to 9.8 inches) above the burning coke contained 0.83 to 1.4 parts of carbon monoxide per thousand parts of air; in a poorly ventilated room, 1.3 to 1.6 per thousand. It was found that the highest percentage of carbon monoxide in a room heated with a brazier of coke was to be found up under the ceiling

because the heat carried the gas up. The amount found at this height was sometimes six times as great as that near the floor. This fact is important in connection with the use of salamanders by painters to dry out the walls of new buildings while painting is going on, for a painter may breathe enough carbon monoxide while up on a scaffold to make him dizzy so that he falls to the floor.

The smoke from locomotives that collects in tunnels has been analyzed and in one Italian tunnel a large amount of carbon monoxide was found. This was the Ronco Tunnel on the Turin-Genoa line, where an average of 1.9 per cent carbon monoxide was found, with 3.6 per cent as the maximum. Two analyses made in American tunnels showed far less carbon monoxide. The Fulton Tunnel of the Pennsylvania Railroad yielded an average of only 59 parts of carbon monoxide per million parts of air and a maximum of 267 per million (0.0059 and 0.0267 per cent). The tunnel of the Baltimore & Ohio Railroad under the city of Baltimore yielded only 25 parts of carbon monoxide per million parts of air.

Illuminating gas varies in composition in different cities, the proportion of carbon monoxide depending on the amount of water gas which is added to the coal gas (see p. 36). When made from cannel coal, illuminating gas contains about 4.5 per cent carbon monoxide. The gas used in London has from 4 to 7.5 per cent; that in Paris, 5 to 6.6 per cent; that in Bordeaux, 10 to 12 per cent; and the gas used in German cities averages about 7.3 per cent. The addition of water gas and the consequent increase in the carbon-monoxide content are more common in this country than in any other, the average amount of carbon monoxide in the gas in American cities being usually between 27 and 30 per cent, far higher than in any other country. Pittsburgh uses natural gas, which is said to have not more than 13.25 per cent carbon monoxide.

The most conspicuous cause of death from carbon-monoxide gassing at present is connected with the testing, repairing, and use of automobile vehicles, for the exhaust gases from their engines contain fairly large proportions of carbon monoxide (see p. 41). Analyses of these gases made by J. N. Schumacher, chemist for the city of Chicago, gave an average of 9.3 per cent carbon monoxide. German reports give from 3.7 to 7.0 per cent.

The principal sources of industrial poisoning from carbon monoxide, with the per cent found in each, are as follows:

	Per cent.
Steel manufacture, blast furnaces	26
Making illuminating gas:	
Coal gas	5 to 8
Water gas	Up to 30
Making coke (by-products)	6 to 40
Use of producer or power gas (for smelting zinc, lead, etc.; metallurgical plants of all kinds; foundries; glass works; laundries; bakeries; brick and cement kilns; enameling porcelain; enameling sanitary ware; heating and steam power plants)	23
Exhaust gases from motor engines	9.3
Mining explosions and mine fires	2.7 to 47.4

The British statistics[22] divide the industries in which carbon monoxide is a danger into four groups. Their reports for six years, from 1908 to 1913, inclusive, give the following figures:

MORTALITY IN BRITISH INDUSTRIES EXPOSING WORKMEN TO CARBON-MONOXIDE GAS, BY SOURCE GROUPS, 1908 TO 1913.

Source.	Number of cases.	Deaths.	Per cent mortality.
Blast-furnace gas	130	20	15.4
Power, producer, and suction gas	140	11	7.9
Coal gas	68	9	13.2
Other gases	37	6	16.2
Total	375	46	12.3

During the years 1914, 1917, 1918, and 1919 the number of cases increased and the severity also increased, as shown by the higher mortality rate. While in the earlier years the average number of cases per year had been 62.5, in the later period it was 75. The mortality in the earlier period was 46 out of 375 cases, or 12.3 per cent, while in the later period it was 52 out of 300 cases, or 17.3 per cent. Gassing from blast-furnace gas furnished the highest mortality, no less than 22.8 per cent for the later period, while the cases caused by coal gas had a mortality of only 10.6 per cent and by power gas of 12.9 per cent.

There are no statistics in the United States at all comparable to these, but the information that is available has been collected and is presented under the industries in which the gassing occurred, namely, the steel works, manufacture of illuminating gas, and metal and coal mining.

MANUFACTURE OF STEEL.

The material for this study was obtained in the steel towns of the Chicago and Pittsburgh districts and in South Bethlehem.

The modern blast furnace gives off 150,000 to 200,000 cubic feet of gas per ton of fuel consumed. The charging is done automatically and the gases are no longer allowed to escape into the air, but are utilized for fuel, having about one-half the heating value of coke. They pass through "downcomers" and mains to be freed of dust and on into scrubbers and washers, where a stream of water removes various by-products, of which benzol is the most poisonous.

Since the purpose of the blast furnace is to bring about reduction of iron ores by means of carbon monoxide formed by the burning of coal or coke, the quantity of this gas in the blast furnace may be large. When the heat in the furnace is between 600° and 700° C (1112° and 1292° F.) combustion with air results chiefly in the formation of carbon dioxide, but from that point up to 1000° C. (1832° F.) carbon monoxide is produced in increasingly large proportions, and above this point practically all the carbon is given off in this form. As the zone of fusion is at a temperature of from

[22] Annual Reports, Chief Inspector of Factories and Workshops. London, 1913 and 1919.

1200° to 1600° C. (2192° to 2912° F.) it is easy to see how much risk of gassing there is at the top of the furnace and how much more dangerous is the old type of top-filler furnace, some of which are still in use in the larger plants, and many in the smaller ones.

Two statements concerning the composition of blast-furnace gas were given by men connected with large plants in Illinois and in Pennsylvania, essentially the same though varying slightly in the proportions:

COMPOSITION OF BLAST-FURNACE GAS IN TWO LARGE PLANTS.

Compound.	Plant 1.	Plant 2.
	Per cent.	*Per cent.*
Carbon monoxide	26.0	27.5
Carbon dioxide	11.0	10.0
Hydrogen	.....	2.5
Ethylene	.3	.....
Methane or marsh gas	1.0	.5
Nitrogen	57.0	59.0
Oxygen	.2	.5

Another company official from an Ohio plant said that the escaping blast-furnace gas might run as high as 50 per cent carbon monoxide.

Figures as to carbon-monoxide gassing have been furnished by the Illinois Steel Co., which has three large plants near Chicago. The records of this company show the following number of cases of gassing during two periods. The first period was from 1912 to 1915, inclusive. Among 1,112 men employed at the blast furnaces and in the boiler house the average number of cases of carbon-monoxide gassing per year, cases severe enough to require medical care, was 66, and the average number of deaths per year 3.25, making a mortality of only 5 per cent, which is decidedly lower than the British rate.

During the five years 1916 to 1920, inclusive, the records of the large plants of the Illinois Steel Co. were as follows:

GAS POISONING IN THREE PLANTS OF THE ILLINOIS STEEL CO., 1916 TO 1920.

Year.	Gary.			South Chicago.			Joliet.			Total gassed.	Total deaths.
	Average number employed.	Number gassed.	Deaths.	Average number employed.	Number gassed.	Deaths.	Average number employed.	Number gassed.	Deaths.		
1916	8,684	7	1	8,121	19	1	4,039	7	.....	33	2
1917	10,553	20	7	9,483	24	.....	3,898	10	.....	54	7
1918	11,339	18	.....	10,103	37	2	3,323	2	.....	57	2
1919	9,618	35	1	7,439	59	1	3,034	12	.....	106	2
1920	10,825	8	(1)	8,684	13	(1)	3,844	.....	(1)	21	(1)
Total.	51,019	88	9	43,830	152	4	18,138	31	.....	271	13

[1] No deaths up to June 4.

The grand total, 271 cases in five years with 13 deaths, or a mortality of 4.8 per cent, is far lower than the mortality in Great Britain from blast-furnace gas—22.8 per cent for the period 1914–1919.

Nevertheless, extensive and disastrous accidents do still occur from the escape of carbon-monoxide gas in various parts of American steel plants. A wholesale poisoning of some 55 men during the fall of 1919 in a plant in Pennsylvania illustrates very strikingly what may occur when gas with this composition pours without warning into the air of an inclosed space in which men are working. For the details we are indebted to Dr. Francis D. Patterson, of the Pennsylvania Department of Labor and Industry.

The men were engaged in relining a blast furnace which had been cut off for 22 days from the gas mains while the repairs were in progress. In order to prevent the gas which was passing through the mains from reaching this particular furnace, water seals were used, although the company had been warned not to place entire dependence on water seals, but to use goggle valves. The men in charge, however, believed that they had an entirely efficient system of water sealing, for instead of the usual depth of 3 feet of water they used approximately 5 feet. This apparently was efficient as long as the water was maintained at that level. A watchman was placed at the water seal to see that everything was working properly by watching the overflow pipe, for as long as the water continued to flow from the overflow pipe the seal was full and there was no danger of the gases surging through. If, however, the supply of water failed or leaked out, an excessive gas pressure, as high as 26 inches for instance, might allow the gases to burst through, and once the water seal was broken the gas might continue to flow through the seal.

On this particular day water seals had been placed in the main line which was in operation, on either side of the line leading to the furnace under repair, in order that the water seal at this furnace could also be repaired. The latter was drained after the seals on the two neighboring furnaces had been filled, and a watchman was placed on guard at each seal. At about the lunch hour the man on one of these seals went to the foreman and asked to be allowed to go and get some tobacco. The foreman sent another workman in his place to guard the seal, an ignorant man, who, as was shown at the inquest, could not speak English intelligently and who was quite ignorant of the extremely dangerous nature of blast-furnace gas and the grave responsibility with which he was charged. He noticed at once that the seal was not working properly, as water was not running from the overflow pipe, but not realizing the danger he did not give any warning to the men working in the furnace; instead, he went first to the pump house and then to the boiler house to see what was the trouble with the water seal. Examination made subsequent to the accident showed that the water in the seal had fallen and the gas had broken through. The concentration of carbon monoxide in the gas when it forced its way through the water seal to the top of the furnace through the downcomer pipe was estimated at 10 to 15 per cent at the very least. The result was the gassing of some 55 men and the death of 25. It was possible to secure the records of the surviving 30, who were incapacitated for varying periods, as follows: Ill for 3 days 6 men, 4 days 8 men, 5 days 3 men, 6 days 1 man, 7 days 1 man, 8 days 1 man, 9 days 6 men, 10 days 2 men, 11 days 1 man, 15 days, 1 man.

Eighteen months later inquiry was made as to the condition of these men, and although it was not possible to secure personal inter-

views with them it was found that they were at that time in the employ of the same company, and according to the statement of the company physician none showed any effect of the gassing. Even if a careful examination of the nervous system had not been made in these cases, it was evident that the survivors of the accident did not suffer enough injury to impair their working powers.

In 1916 the United States Bureau of Mines made a study of the danger spots in the steel industry, so far as gassing accidents were concerned. Their report describes some 120 cases of asphyxia, usually fatal, either from the direct effect of the gas itself or from an accident which occurred because of the loss of consciousness brought on by the gas. The sources of the gas in these accidents are the following:

Bustle pipes	6	Gas outside of boilers	16
Furnace stacks	1	Downcomers	3
Blast-furnace tops	17	Mains	34
Hot-blast furnaces	4	Holders and washers	12
Cleaning boilers	4	Miscellaneous	23

Some of the more interesting instances have been selected from this report. A man was overcome with gas on the bustle-pipe platform and was drowned by falling into a water trough. An electrician was asphyxiated while changing carbons on an arc light on the sheave-wheel platform. An oiler was killed by falling from the sheave-wheel platform to the changing platform when partially overcome by gas. Seven men were gassed while attempting to make repairs on the small bell rod inside a receiving hopper. A rigger, sitting in a boatswain's chair and tearing down the skin wall in a well, was overcome with gas which was being drawn in from a leaky burner through an open burner door, and he was killed by falling to the bottom of the well. A stove cleaner entered the dome of a stove the hot-well doors of which had been opened to cool the stove, but the burner door had not been closed, and gas from the burner, which was leaking badly, killed him. A boiler cleaner also was fatally gassed on entering a dust chamber before the leaks had been stopped. Another fatal case was attributed to the leakage of gas into a coal boiler from another boiler through cracks in the partition walls. Two boiler-house men were enveloped in a cloud of steam on the top of the boiler. Becoming bewildered, they tried to escape the steam by retreating to the front of the boiler, where there were no steps down, and by the time other men had succeeded in closing off the steam and had come to look for them one had been fatally gassed from the leaky burners beneath. In attempting to close an explosion door beneath a boiler-house roof blown open by a slip 12 men were overcome and 2 of them died.

The largest number from any one department in this list came from the work in the mains (34). This is found in all statistics of blast-furnace gas poisoning. Apfelbach found more cases among cleaners of cold mains than in any other one department, and 23 out of 68 cases reported by the British factory inspectors for 1918 were of men cleaning mains. The dust in the mains holds the carbon monoxide, and it is released as soon as the dust is disturbed.

All of the cases given above are of acute severe poisoning. In many instances it is not possible to ascertain whether loss of consciousness was instantaneous, although sometimes, even when the

accident has been fatal, there are evidences that the man made some effort to escape. Apfelbach was able to interview 300 American steel workers who had been acutely gassed, and found that in about one-third of them loss of consciousness came on without warning. In the others the prodromal symptoms were throbbing and pressure in the temples, ringing in the ears, weakness in the legs, a feeling of "caving in" at the knees, or sluggishness of movement, or even a feeling of being glued to the spot. Less often a sweetish taste acted as a warning, or dry throat, or palpitation of the heart, or distress in the stomach, or nausea. According to this same observer, the breathing of blast-furnace gas does not cause coma as often as does illuminating gas. He saw only 65 cases of typical coma in 261 cases of gassing in steel workers. The others had only stupor or mental confusion. Glaister also says that there is more serious coma in men who are gradually poisoned by gas in mines or by producer gas than in steel men who are suddenly exposed to enormous doses.

A physician in charge of one of the great American steel mills, a man who had had many years' experience with this sort of work, described a typical case of gassing as follows: The first stage, which comes on quickly, is one of confusion or stupor or actual loss of consciousness. The physician does not see the man till some 5 or 10 minutes later, when he has been hurried in a motor ambulance to the hospital, which is on the grounds of the plant. By this time the stupor, unless it is very deep, has begun to pass off, and the man is often slightly delirious. This increases after he has been put to bed, and it is sometimes necessary to put him under restraint because of his maniacal excitement. This condition lasts for a few hours, rarely over night, and he then recovers consciousness with an intense throbbing headache, nausea, and more or less gastric pain. In the experience of this physician such cases recover with varying promptness, but always completely. He has never observed any aftereffects.

It is easy to obtain histories of acute gassing in the steel works, but impossible to discover anything further, either from the physicians or from the men themselves. Every effort was made to cover this part of the investigation thoroughly, for it was believed that since the reports from Great Britain, Germany, and France showed that permanent damage to the heart or the nervous system sometimes followed gassing in steel works in other countries, although not nearly so often as gassing in coal mines, it must be possible to discover some such instances in American steel towns where many thousand workmen are employed and where instances of gassing are not uncommon. The physicians connected with steel works in the Chicago district, the Pittsburgh district, and in South Bethlehem were interviewed, but although they were all quite frank as to the occurrence of very severe and even fatal gassing, they had none of them anything to say about remoter effects from such an accident—pneumonia or cardiac weakness or loss of memory or paralysis. Then the inquiry was extended to the other physicians in these towns, men not connected with the steel works and not bound by loyalty to the companies. It was supposed that through them some such cases would come to light, but their testimony was quite as negative as that of the company doctors. It was not easy to approach the workmen themselves, for the great strike was only recently over and they were in

a very timid and suspicious state, unwilling to answer questions of any kind. South Chicago was the only one of these towns which still openly maintained union headquarters and where it was possible to talk to some of the blast-furnace men. They, too, stated that no matter how badly a man was gassed, if he did not die he recovered completely. They had never heard of an instance of loss of memory or mental aberration or paralysis resulting from a gassing accident. In all these steel towns the clergymen and the charity workers were visited and questioned, for it seemed more than probable that they would be able to tell of cases of this sort if any had occurred, but no history was obtained from any of them. That this was not due to a desire to conceal facts was evident by the frankly prolabor attitude of several of them, who freely denounced the policy of the companies with regard to the 12-hour day, the 7-day week, the working conditions, and the personal relations between employers and men, but even they did not believe that gassing accidents ever resulted in permanent damage of any kind.

Now, this evidence is, of course, purely negative, but it seems convincing. If one goes into a lead smelting community, one can always get histories of cases of lead palsy, and lead colic, and sometimes lead convulsions simply by talking to townspeople, druggists, clergymen, and shopkeepers, to say nothing of the nonindustrial physicians. Such cases become matters of ordinary gossip. It seems impossible that anything so conspicuous and unusual as a mental breakdown, after a gassing accident to a steel worker, should occur in a fairly small community without anyone hearing of it and spreading the tale. For some reason, probably because of the sudden excessive exposure to carbon-monoxide gas, such as is found in the steel works, the damage to the central nervous system that comes from oxygen starvation does not take place. The accident occurs suddenly, and the man is quickly removed from the poisonous atmosphere, so that the duration of oxygen deprivation is very short and his blood rids itself of carbon monoxide very rapidly. A longer exposure means death. Only one instance of damage to the brain as a result of an accident of this kind has come under observation, and that was Apfelbach's which has been already described. Watkins, of the Public Health Service, has found that the air where furnace men are working may easily contain as much as 0.01 per cent of carbon monoxide. He would regard 0.01 per cent as the limit of danger, but the usual view is that anything less than 0.03 per cent is harmless.

COAL AND METAL MINING.

The material concerning carbon-monoxide poisoning in mining was gathered in the copper regions of Arizona and Montana, and in the coal regions of Illinois and Pennsylvania. All available data from the United States Bureau of Mines were also utilized.

The gaseous impurities in the air of coal mines and metal mines come from the use of explosives in blasting; from mine fires, due not only to the burning of the wood used in construction, but also to the combustion of the pyrite ores or native sulphur; from accidental explosions, especially of coal dust; from the gases given off by shale; from the exhalations of men and animals.

The normal proportion of oxygen in the atmosphere is 20.93 per cent. In the air of good mines it is rarely lower than 19 per cent, but in certain mines where the coal and shale is of such a character as to oxidize quickly, it may fall to 18 per cent. Oxygen is also taken up by decaying timber, and in the neighborhood of crushed timber the air may be impoverished to such an extent as to cause discomfort to the men. Another cause of oxygen disappearance is the burning of lamps. The following gases are found at times in mine air, the first two practically always in small proportions even under normal conditions: Carbon dioxide, which is produced in excess by blasting, by mine fires, by oxidation of organic matter, coal, and shale, and by animal breath; carbon monoxide, caused by blasting and by mine fires; nitrogen oxides, NO_2 and N_2O_3, produced when explosives are incompletely detonated and burn instead of discharging; ethane, C_2H_6, from natural gas; sulphureted hydrogen, from heating of sulphurous coal in mine fires, and, rarely, from natural sources, such as sulphur springs or the action of acid waters on sulphite ore, or by the reducing action of bacteria on sulphates in water, so that dangerous quantities may be liberated by stirring up stagnant water in old mine workings; sulphur dioxide, from the burning of pyrite ores or native sulphur; and hydrogen, formed by fires and by explosions.[23]

Since blasting is a normal process of mining, the gases formed by the explosion of the different substances used are of greater importance than those formed by any accidental occurrence. The tests made by the Bureau of Mines of different compositions used in blasting show that the following poisonous gases (the nonpoisonous are omitted) are produced in widely varying proportions. The column showing the percentages of carbon monoxide is the most important.[24]

PERCENTAGE OF POISONOUS GASES FORMED BY THE EXPLOSION OF VARIOUS SUBSTANCES.

Explosive.	Per cent of—			
	CO_2.	CO.	NO_2.	H_2S.
30 per cent nitroglycerin dynamite	22.9	28.4	.....	.....
40 per cent nitroglycerin dynamite	27.3	26.9	.....	.....
50 per cent nitroglycerin dynamite	24.4	31.2	.....	.....
60 per cent nitroglycerin dynamite	22.2	34.6	.....	.....
60 per cent low freezing dynamite	8.9	47.4	.....	.....
40 per cent ammonia dynamite	41.4	3.8	.....	5.4
40 per cent gelatin dynamite	50.8	3.0	.....	4.1
40 per cent burned gelatin dynamite	19.4	13.7	11.9	.....
5 per cent granulated nitroglycerin powder	51.3	2.7	.....	15.7
FFF black blasting powder, tested in gauge	49.7	10.8	.....	8.7
FFF black powder, when used in coal	19.2	28.2	.....	6.8

It is obvious that since these gases are formed by the ordinary processes of blasting, there is far more danger in mines where blasting goes on all day than in those where the firing of the shot comes at the end of the shift and the men do not have to return to the gallery for some hours. If the blasting is continuous, the gases from

[23] Rice, George S. In Mining Engineers' Handbook, sec. 23. New York, 1918, pp. 1386–1391.
[24] Idem, p. 1390.

one explosion may affect the men working at quite a distance from it. According to Bureau of Mines' tests, carbon monoxide in proportions running from 3.23 to 9.59 per cent has been found as much as 350 feet away from the site of the blasting. After an explosion in an Alabama mine [25] a gang sent in to do recovering was waiting at a base. The whole party was almost overcome by carbon monoxide and was saved only by a stream of fresh air, yet the men's lamps were burning brightly and nobody had noticed anything wrong till suddenly several of the men sank down unconscious.

In the instructions issued by the Bureau of Mines, the following statements are made: Anything above 0.15 per cent carbon monoxide is dangerous and 0.4 per cent may be fatal. For continuous exposure, 0.03 per cent is to be considered unsafe, as the action is cumulative. In an atmosphere with 0.04 per cent carbon monoxide the blood finally reaches one-third saturation with carbon monoxide. In an atmosphere of 0.08 per cent it reaches one-half saturation, and in one of 0.16 per cent it reaches two-thirds saturation. But in all these cases the accumulation of carbon monoxide in the blood is slow. In one experiment in which 0.2 per cent carbon monoxide was used, 50 per cent saturation was not reached till after 70 minutes. When the blood has reached 20 per cent saturation, there is a tendency to dizziness and shortness of breath on exertion. At 50 per cent the man can hardly stand and slight exertion causes unconsciousness.

A few words must be said as to the other gases formed in blasting. Carbon dioxide is toxic in its effect, although its action is produced partly by the lack of oxygen when carbon dioxide is present in large quantities. A change in respiration is said by Haldane to begin when there is 3 per cent carbon dioxide in the air. Breathing changes to panting at 6 to 7 per cent; the face is flushed and the pulse rapid. At 10 per cent breathing is very difficult and after that the narcotic effect begins, with confusion of mind. Animals die sometimes when the proportion of 25 per cent has been reached, but they may survive even 50 per cent. The miner's candle goes out when the percentage of oxygen has fallen to 17 per cent with 2 per cent carbon dioxide. Such an atmosphere is not dangerous. Death comes when the oxygen has fallen to 5 per cent and is due to this, not to carbon dioxide poison.

Death from nitrogen oxide fumes is said to be a not uncommon occurrence in the mines of the Rand in South Africa. According to Irvine,[26] many cases occur each year in these mines from the custom, which still generally exists, of blasting a second time shortly after the first blasting. This practice is very dangerous, as it exposes the miner to an atmosphere highly charged with dust and with the fumes of carbon monoxide and other gases. Exposure to 0.05 per cent of nitrous fumes was found by Haldane to cause death in mice, but not till after 24 hours. The gas does not produce any startling effects at first, so that the man has little warning of danger. An illustration of its effect was given by Johnson [27] in the Colorado Journal of Medicine. In a western tunnel the air was filled with nitrous fumes by a change in the ventilating current. The men experienced choking, nausea,

[25] Rice, George S. In Mining Engineers' Handbook, sec. 23. New York, 1918.
[26] Irvine. Transvaal Medical Journal, 1912–13, vol. 8, p. 30.
[27] Quoted by Rice, George S. Mining Engineers' Handbook, sec. 23. New York, 1918, p. 1401.

profuse perspiration, and headache. They revived in the open air, but later began to cough blood and mucus. Nine of the 13 died within three days and the others, including some of the rescuers, were ill for months.

Sulphureted hydrogen is poisonous in small quantities. Lehmann says that 0.07 per cent is deadly to man in one hour. In larger quantities it produces unconsciousness, and death comes on very rapidly from paralysis of respiration.

The next commonest source of carbon monoxide and other gases in mines is fire from the burning of coal dust or of timbers, or the slow combustion of the coal itself, the gas seeping into the working part of the mine because it has been incompletely walled off. Slow-burning fires, without explosion, are common in the coal mines of Illinois, Iowa, and Missouri, which are nongaseous mines. The burning areas are often shut off and ignored, and then carbon monoxide finds its way through leaks. These fires also occur in abandoned mines in the thick-bed anthracite region. Fires may start spontaneously in the Arizona and Montana copper sulphide mines also, in old stopes, and the gases formed consist not only of carbon monoxide and carbon dioxide from the burning timber, but also of sulphur dioxide from the sulphide ore. In fighting mine fires carbon monoxide is the great danger, and these fires are most common in coal mines where gob fires are always occurring.

The spontaneous explosion of coal dust results in the formation of carbon monoxide in dangerous quantities. Another source of this gas is the internal combustion engine, such as is used for gasoline-driven pumps and locomotives. The exhaust from these contain carbon monoxide and dioxide according to the carburetor adjustment and the size of the engine. Tests made by the Bureau of Mines show that under the worst conditions the carbon monoxide in these exhaust gases is about 13.5 per cent, but under normal running conditions rarely over 6 per cent. However, even under normal conditions it would be necessary to have a current of air sufficient to dilute this down to 0.02 per cent, the safety limit.

Mine gas is an increasing danger in the United States as the mines grow deeper, for the deeper the mine the more the gas accumulates, the greater the difficulty of maintaining adequate ventilation, and the greater the possibility of men being trapped in inaccessible places. Statistics of the Bureau of Mines contain the fatalities which have occurred since 1870, but it is not possible to discover how many of these were due to the effect of gas. Bulletin 115 of the Bureau of Mines contains the fatalities between 1870 and 1914, and there are two headings under which deaths by gassing are grouped. Suffocation from mine gases caused 263 out of the 52,187 total fatalities between 1870 and 1914 (49,733 from 1870 to 1913 and 2,454 during 1914). Suffocation by powder gas caused 127 deaths between 1870 and 1913. The other headings under which it is reasonable to suppose are included deaths from gases are gas explosions and burning gas, coal-dust explosions, and gas and dust explosions combined, and mine fires, burned, suffocated, etc. Under these headings, together with the heading "suffocation from mine gases," we find in Bulletin 196 the cases which occurred between 1914 and 1919, inclusive. The men killed by gas explosions and burning gas made up from

3.68 to 13.53 per cent; coal dust and gas explosions were responsible for 0.69 to 6.66 per cent; suffocation from mine gases from 0.48 to 0.71 per cent; mine fires from 0.05 to 1.01 per cent. The number of employees during these years was between 720,000 and 763,000.

So far as one can discover from these reports, the deaths are attributed to the principal factor in the accident. Thus, in Bulletin 115, it is stated that mine fires were responsible for 1,053 deaths between 1867 and 1912, but no statement is made as to what actually killed the men, whether it was burning or gassing from the products of combustion. In all probability the latter is the more important of the two. Naturally nonfatal accidents are described in even less detail. The statement is made that between 1911 and 1914 about 30 men in a thousand suffered from accidents incapacitating them for 20 days or more, and about 150 were incapacitated from 1 to 20 days, but there is no way of knowing how many of these were gassing accidents.

According to Hayhurst,[28] who made a thorough study of the health of coal miners in Illinois and Ohio, there is not so much carbon monoxide in American coal mines as in the English, because our mines are not so deep nor are they so dry, and dryness leads to dust explosions resulting in the production of 4.5 to 5 per cent carbon monoxide. In Illinois coal mines blasting is not continuous, the shooting being done at the end of the shift. The same thing is true in the Arizona copper mines, but in Montana copper mines blasting is continuous, and according to the Bureau of Mines there is much more carbon monoxide in these mines. There are some coal mines in Ohio where blasting is continuous, and the miners often complain of daily headache.

Gassing in mines is usually gradual, although in serious accidents it may be rapid, almost instantaneous. Men have been found dead with placid expression and no evidence of suffering or struggle, sometimes even with their picks in their hands, or their luncheon. Glaister says that even after the miner has had warning of disaster by the feeling of weakness in his legs and arms, he may sometimes keep on working because his intellect is so much dulled that he has not the will to stop. Lewin tells of three miners who were killed by the gas following blasting, even though the mine ventilator was going. They went into a stope soon after blasting with dynamite and were found dead on the floor. Examination showed that carbon monoxide mixed with the dioxide had settled heavily near the floor.

These facts, scanty as they are, cover the available information on gassing in American mines. Visits to coal-mining regions in Illinois, Pennsylvania, and Alabama did not result in any important addition to the facts gained from the reports of the Bureau of Mines and from Hayhurst's study. Just as in the steel towns, it was easy in these coal regions to hear of cases of severe gassing, although they seemed to be not nearly so frequent as in steel work. It was also easy to find men who complained of headache and general discomfort and misery at the end of their day's work, but it was not possible to get any histories of cases of pneumonia or mental disease or paralysis or heart weakness or any other organic disease which was attributed by the physicians or by the men themselves to the effects of the gas.

[28] Hayhurst, E. R. Journal of Industrial Hygiene, 1919–20, Vol. I, p. 360.

We do not know how to explain this. The English literature is full of such histories and so is the German and French, and there seems no reason why similar cases should not occur among American miners. Even if it is true that there are not so many accidents from gas in American mines, still it seems incomprehensible that none of those which do occur should cause the damage which like accidents have been shown to cause in European mines. The slow absorption of the gas, the long-continued exposure which is usually characteristic of mine gassing, is supposed to set up just those changes in the cells of the brain and spinal cord which result in loss of memory and of mental power and various kinds of neuritis and paralysis. This brief survey of gassing in the coal mines does not make it possible to explain why the situation that was found differs so much from the situation as described by Glaister and Logan in England and by Lewin in Germany.

In the copper mines of Arizona carbon-monoxide poisoning is unknown. The custom in that region is to have all the blasting or shot firing done at the end of the shift, so that the miner leaves as soon as he has lighted the fuse, and before the next shift comes on the gas has been carried off by the ventilators. In Montana not only are the mines deeper and the ventilation more difficult, but it is customary to have blasting going on continuously. In this region gassing is perfectly well known, but here also it is held by miners, as well as by physicians and managers, that no effects of the accident persist after the man has recovered from the acute symptoms.

In comparing the results of studies in this country with the studies made by the British in collieries it must be remembered that men of foreign birth and language are dealt with here, while the British deal with men of their own nation and language. It is excessively difficult to get information concerning possible psychical symptoms in a miner who speaks English imperfectly or not at all, who has no family or intimates, and who passes muster as entirely normal provided he can carry on his day's work as well as he did before the accident. A lawyer with many years' experience under the Illinois compensation law told of the difficulty he had in determining injury of this kind in Slavic miners whose English was restricted to a few words necessary for the performance of their day's work. Even when he could convince himself that the victim of an accident was in a condition of mental dullness, was slow to respond, was easily confused and upset, and was unable to make a decision promptly, he could not get enough evidence as to the man's mentality before the accident to make it possible for him to prove that this condition was of recent origin. This may really be the explanation of the failure to discover in the coal and metal mining districts visited the sort of injury following gassing accidents which the British find common enough to call "characteristic of colliery accidents."

ILLUMINATING GAS.

There is great variety in the composition of illuminating gas as used in different cities in the United States and at different times of the year. For many years past the gas used for illuminating in this country has been what is known as "enriched coal gas," containing from two-thirds to three-fourths of water gas. The water gas is

added from motives of economy, and the proportion is larger during the winter months. Coal gas, made by the destructive distillation of coal, less often petroleum or wood, is luminous because of the large proportion of methane and of hydrogen it contains. Water gas is made by passing steam over incandescent coke; and as it contains far more carbon monoxide and less hydrogen and methane, it is rich in heating power but poor in illuminating power. The flame is blue, and in order to render it luminous it must be carbureted, that is, enriched with gases derived from hydrocarbons and burning with a yellow flame. These hydrocarbons are ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), and benzol (C_6H_6). Carbureted water gas, then, is much more poisonous than ordinary coal gas, because it contains a decidedly higher proportion of carbon monoxide, and also a larger proportion of light oils, the most dangerous of which is benzol.

The composition of coal gas and of carbureted water gas is usually given as follows:

COMPOSITION OF COAL GAS AND WATER GAS.

Element.	Coal gas.	Water gas.
	Per cent.	*Per cent.*
Carbon monoxide	4–10	26–30
Carbon dioxide	6	3
Light oils	5	12–16
Hydrogen	46	31
Methane	40	18–20
Oxygen	0.5	0.5
Nitrogen	2	2.5

The large proportion of carbon monoxide in American illuminating gas is usually taken as the explanation of the frequency of illuminating-gas poisoning, which, according to McNally, held the fourth place in the death records of Cook County, Ill., for 1916, being responsible for no less than 501 deaths. But the large proportion of hydrocarbon illuminants in water gas is also of great significance. In one of the cities visited in the course of this inquiry the statement was made that in manufacturing the illuminating gas, 2 gallons of light oils were added to 10,000 cubic feet of gas, and that this oil consisted of three parts benzol and one part toluol. The resulting gas was said to contain benzol in the proportion of five parts per thousand parts of gas.

In another city the coal gas used contains from 0.5 per cent to 1.0 per cent of benzol, one-third as much toluol, and one-fifth as much xylol. This coal gas is mixed with water gas in varying proportions, but usually sufficient to bring its carbon-monoxide content up to from 27 to 29 per cent, probably about one part of coal gas to two or two and a half of water gas, which would dilute the benzol decidedly, for water gas does not contain benzol. Still, even one-third or one-fourth of the above quantity of benzol is enough to constitute a menace. According to the experiments made by Rambousek,[29] as small an amount of benzol as 1.5 parts in 100,000 parts of air is poisonous to animals, and 5.5 parts per 100,000 is enough to render them uncon-

[29] Rambousek, J. Industrial Poisoning. Translated by T. M. Legge. London, 1912, p. 205.

scious. The above analyses show a proportion of 500 parts per 100,000 parts of gas. The accidents caused by illuminating-gas poisoning, the unconsciousness and delirium, and the nervous symptoms which follow may be due, not to the carbon monoxide, but to the benzol and toluol. Lewin found that even a slight poisoning with benzol might be followed by aftereffects such as giddiness, nausea, headache, distress in breathing, and a sense of oppression in the heart. Fortunately, the increasing expense of hydrocarbon oils promises to bring about a return to the use of coal gas, which is so much safer, having both a lower carbon-monoxide content and a smaller quantity of benzol than water gas.

The manufacture of illuminating gas is seldom attended with accidental gassing. Fatal accidents are almost unknown. The employees of gas companies who suffer most from gassing are the testers of meters and the men doing extension work; that is, making connections for new lines and working in ditches and trenches and manholes. In one city an official of the gas company said that they expected the men in extension work to get gassed, but that the only thing to do was to have someone watch at the top of the ditch, and when the man staggered and fell, pull him out and send another in.

The American Gas Institute has a committee on accident prevention and this committee has reported some 11,000 accidents in the industry between 1915 and 1919. There were 30 deaths, only 4 of which were caused by gas. The records for 1919 cover about 1,000 accidents occurring in 77 plants. Thirty of these were men overcome with gas, but none of them died. The opinion held by this committee is that practically all cases of gassing recover within 48 hours, with no permanent effects.

SMELTING AND COKE BY-PRODUCTS.

In one of the industrial towns of northeastern New Jersey a large copper works uses producer gas, and cases of carbon-monoxide gassing are not uncommon. Of seven physicians interviewed there, three had had such cases. One of them told of an accident involving three men, all overcome by the gas fumes, but while two recovered completely the third suffered from mental impairment and great exhaustion for some days. When he had regained his mental powers and his strength he went back to work, was overcome again, and developed the same symptoms. He was then transferred to other work. This was the only case of such aftereffects noted in that town.

In a town in La Salle County, Ill., a visit was made to a great zinc smelter, where metallic zinc is produced and also sublimed zinc oxide, the latter being obtained from the fumes of the furnaces, which pass through flues to a bag house and there deposit the white oxide. With the zinc oxide there passes a varying quantity of carbon monoxide, but the bag house is equipped with a mechanical shaking apparatus and the men do not have to go in to do this. When bags must be repaired the current is shut off. Apparently carbon-monoxide gassing does not constitute a danger there, although there is a rumor to the effect that birds flying through the openings in the walls of the building and coming out on the other side sometimes fall to the ground overcome by the gas.

In the making of coke the by-products are tar, naphthalene, benzol, and toluol; the gases given off are carbon monoxide, carbon dioxide, cyanogen, hydrogen sulphide, sulphur dioxide, and marsh gas or methane. This is according to the superintendent of a large plant near Pittsburgh. Here the great danger is benzol, and carbon monoxide is relatively negligible. The gases carrying tar and the lighter distillates pass to furnaces where the tar is condensed, then sulphuric acid is added to form ammonium sulphate, and then oil "scrubbers" catch in heavy oils the light distillates, benzol, toluol, and xylol. The danger points for carbon monoxide are probably, as in steel manufacture, at the feed door, which in this plant was at the top of the furnace, and in cleaning and repairing work.

UNUSUAL SOURCES.

It would be impossible to describe all the many ways in which accidental carbon-monoxide poisoning may take place in industry, for dozens of instances could be given. A few have been selected, especially from American literature, in order to give an idea of the way in which these disasters may occur. Dr. Louis I. Harris,[30] of the occupational disease clinic of the New York City Department of Health, has seen about 220 cases of acute gassing in New York industrial establishments which could be traced to gas flames or furnace gas. An unusually striking instance was the following: In three lofts devoted to clothing manufacture there were 125 employees. At about 2 o'clock in the afternoon on a certain day some of the employees in each shop became suddenly ill with nausea and vomiting, headache, dizziness, and weakness, especially in the legs; several were actually overcome, and three were sent to hospitals, but the greater number recovered in a few hours, although two were very weak for several days. The department of health, suspecting carbon monoxide as the cause, found that all of the 73 cases were working in the rear of the three lofts near the back doors, which had been left open into a hallway leading to the roof. The skylight also had been left open and a shift in the wind had blown gas from the chimneys down into the hall and the workrooms.

Dr. R. P. Albaugh,[31] while director of the division of industrial hygiene of the Ohio State Department of Health, relates a very unusual occurrence in a construction camp. Thirty white and 30 colored men were living in a bunk house constructed on an old dump where dirt, slag, scrap, mill waste, ashes, and cinders had been deposited for a period of about five years. In December, 1916, during a week's time, 14 men were severely gassed and 3 died. After it had been shown that these were not cases of food poisoning, but that some gas was present in the air of the bunk house, affecting even the physicians and rescuers, a search was made for the source of the gas. It was found that about 10 days before a little steam seemed to be rising from the edge of the dump about 50 feet from the bunk house. It was thought that the dump might be on fire, although no ashes or cinders had been deposited there for the last six months. A trench

[30] Harris, L. I. Paper read before American Medical Association, Atlantic City, 1919. See extract from this paper in MONTHLY LABOR REVIEW, November, 1919, p. 263.
[31] Albaugh, R. P. Journal American Medical Association, 1917, vol. 68, pp. 1033–1035.

was dug around the part thought to be on fire, and it was found that the dump was frozen to a depth of about 2 feet, but at 5 feet red hot cinders were encountered. Other trenches were dug, and one of them, which extended under the camp building, also contained hot cinders. While working in one of these trenches six men suffered from headache, dizziness, and weakness of the knees to such an extent that they had to be helped out of the trench and two were taken to the plant hospital.

The deaths and prostrations could undoubtedly be traced to the carbon monoxide formed by the incomplete combustion of cinders and other material in the dump. Because the surface of the ground was frozen the gas found its only outlet under the camp buildings where the ground was not frozen and where the cinders were soft and porous, especially under the kitchen sink where the hot water ran down.

Two other instances of carbon monoxide from ashes and cinders have come to light and, singularly enough, both occurred out of doors, where one would suppose the gas would be rapidly diluted beyond the fatal point. One was a man who was raking hot ashes from a copper works in Perth Amboy, N. J. He died in the city hospital, supposedly of "marsh-gas poisoning," and when inquiry was made as to this diagnosis, marsh gas (methane) being quite nontoxic, the explanation given was that the man was working in a marsh and was killed by gas, therefore it must be marsh gas. Two men who died from gassing while raking cinders were reported by Apfelbach,[32] and they also were working out of doors.

McNally[33] tells of two carpenters who went into a burning cooper shop to get their tools and 20 minutes after were found dead, killed by the carbon monoxide from the smoldering wood. Carbon monoxide was demonstrated in the blood.

Cases of carbon-monoxide poisoning have been reported from copper smelting in which producer gas is used, in lead smelting, and in the smelting of zinc and the production of zinc oxide, which is obtained from fumes carried through pipes and which is deposited in long cotton bags. The carbon monoxide from the furnaces passes along with the zinc and is encountered both in the mains and in the bag house.

The explosion or burning of celluloid in factories or in moving-picture houses when the films catch fire gives rise to large quantities of carbon monoxide and is responsible for the greater number of deaths in such accidents.

CHRONIC GASSING AMONG GARAGE WORKERS.

It has already been shown that the exhaust gases from motor-car engines contain on the average about 9 per cent of carbon monoxide. Apfelbach made five analyses of the carbon-monoxide content of the air in motor garages and found an average of 0.042 per cent. It must be remembered in this connection that the Bureau of Mines places the safety limit at 0.15 per cent. Schumacher gives

[32] Apfelbach, George. Personal communication.
[33] McNally, Wm. B. Journal American Medical Association, 1917, vol. 69, p. 1588.

the composition of gas collected from the exhaust pipes of motor cars as follows:

Carbon monoxide, 9.3 per cent; carbon dioxide, 6.7 per cent; oxygen, 1.4 per cent; nitrogen, 82.2 per cent; illuminants, 0.3 per cent.

These analyses, made more than five years ago, probably do not represent the composition of the gases at present, for there has been an increasing use of coal-tar benzol as motor fuel, and it is probable that the amount of benzol vapor is at times very considerable, since some of the cheaper gasolines contain fairly large quantities of benzol.

An effort was made to determine how much chronic gassing could be discovered in employees of storage and of repair garages. It was not possible to subject these men to a physical examination nor even to make an examination of the blood which would include an estimation of the number of red blood corpuscles. The method chosen was to examine the blood for carbon-monoxide gas. If it were present, the conclusion would be inevitable that the men were absorbing while at work an appreciable amount of this gas, and also of the other constituents which are known to be present along with the carbon monoxide but which can not be detected in the blood. The test that was adopted is simple. It is the so-called tannin precipitation test. A drop of blood from the ear is diluted with three parts of distilled water, which at once lakes it—that is, dissolves the red corpuscles, producing a clear red fluid. This is then dropped into a small glass tube containing three times as much of a 1 per cent solution of tannic acid. A precipitate forms, and after a few hours this flocculent precipitate, if the blood contains carbon-monoxide gas, is a pinkish color, while if the blood is normal the precipitate is brown. It is easy to detect this difference in color, and the test is therefore simple, rapid, and accurate.

The examinations were made in Boston garages during the months of January and February when the thermometer ranged from 25° to 50° F. The conditions in the garages varied according to the ventilation and according to whether the plants were for storage only or for repair work. As a rule, repairing involved decidedly more contamination of the air than storage, but one storage garage proved to be quite as full of fumes as any of the repairing plants because it was unventilated and not only were cars going in and out continually but one to three cars were "running idle" all the time.

The effect of the gas was well known to every man interviewed, although not all had personally suffered from it. The symptoms described were headache, weakness in the legs, sometimes constipation, less often nausea and dizziness, and sometimes vomiting. Some of the drivers complained of headache if they were obliged to remain in the garage for several hours. The symptoms were always aggravated by cold weather because then windows and doors were kept closed.

Even in the better-ventilated shops, where the men experienced no discomfort from the gases, positive evidence of carbon monoxide was obtained. In garage No. 17 approved methods for carrying off the exhaust gas from engines were in use, but every man in the place gave a positive test for carbon monoxide.

The following are the results obtained in 17 storage and repair garages:

No. 1. Repair garage. Cloudy, damp day, 55° F. Ventilation from windows in ceiling and walls.

A. F. H. Mechanic 8 years. Suffers from headache and constipation, especially in cold weather, even if window is open, for the gas does not escape. Negative test.

K. F. H. Mechanic 5 years. Occipital headache and gastric distress in cold weather. Negative test.

No. 2. Storage garage. Rainy, muggy day, 50° F. Windows closed, door opened part of the time. Two or three cars running idle and several going in and out all the time so that the air was smoky.

A. T. Eight years employed. No symptoms except when the gas is very heavy; none at present. Positive test.

I. W. Only one hour inside the garage. No symptoms at the moment but he has headache when the gas is heavy. Doubtful test.

J. J. M. Seven months in this garage. He has no chronic symptoms but two weeks before during a cold spell the gas came into his office from the adjoining storage room. He had an attack of dizziness, weakness of the legs, headache, and was sick at his stomach. He could barely reach home, but was all right after about three hours. Positive test.

No. 3. Repair and storage. Damp, cloudy weather, 40° F. Windows closed, swinging doors open part of the time, air slightly smoky.

F. A. H. Mechanic for 13 years. He complains of stomach trouble with occasional vomiting and nausea, weakness in the knees, sometimes headache. He has these symptoms more or less every day, especially when the smoke is heavy and toward the end of the day's work. Positive test.

A. D. Mechanic for 10 years. He has occasionally a splittting headache and weakness in the legs. Positive test.

F. H. Twelve years in auto work. He has no complaint of ill health. Negative test.

No. 4. Storage garage. Clear and cool, 40° F. All the windows and doors are kept closed because the heating system is poor.

J. G. H. Employed for 6 weeks. He has headaches, especially at the end of the day, and in cold and moist weather attacks of nausea. Positive test.

L. M. B. Twenty years in auto work. He has headaches and weakness in the legs when the smoke is even moderately bad. He had not been working on this day. Negative test.

No. 5. Storage garage. Clear and cool, 40° F. The ceiling is high but the ventilation insufficient and the air smoky.

W. M. Employed for 3 years. He complains of headaches. Positive test.

R. C. R. Employed 10 days. No symptoms. Positive test.

J. A. Driver. Negative test.

W. D. H. Driver. Negative test.

No. 6. Repair garage. Warm and damp, 60° F. The ventilation was good at the time, air clear.

F. H. Mechanic 12 years. On duty only half an hour when test was made. Negative test.

No. 6. Storage garage. Weather cloudy and damp, 45° F. Modern garage with ventilation from side windows and skylight, but the air is smoky.

W. H. Only one hour inside the garage this morning. Negative test.

J. H. M. Only one hour inside the garage this morning. Negative test.

No. 7. Storage garage. Moderately low rooms. Ventilation through one window, skylight, and open doors. Air slightly smoky.

S. H. Fifteen years employed. He has headaches occasionally, especially on cold days. Positive test.

J. B. Fifteen years employed. Never has suffered from the gas, no matter how much there is in the air. Positive test.

R. S. Eight years employed. Complains of headache. Positive test.

No. 8. Storage garage. Weather clear and cold, 30° F. Ventilation through one window, large open elevator shaft, and doors. Very little smoke in the air.

E. F. A. Seven years employed. No symptoms. Positive test.

R. S. V. Driver for 10 years. If he remains in the garage long he gets a headache. He had just come into the garage when the test was made. Negative test.

No. 9. Storage and repair. Cloudy, moderately cold weather. Storage rooms on two floors, large, with good window ventilation and only slightly smoky. Two small repair rooms.

G. M. H. Employed 14 years, but in the office. Negative test.

O. A. Mechanic in repair room, 4 years. He often has headache and dizziness. Positive test.

C. W. W. Foreman of repair room, 4 years employed. Very rarely any symptoms. Negative test.

C. C. Mechanic, 5 years employed. Occasionally has attacks of dizziness. Positive test.

R. R. G. Mechanic for 20 years. He is, according to his own account, very susceptible to the gas, suffering from headaches and dizziness. Positive test.

G. G. Mechanic, employed a year and a half. No complaint. Positive test.

F. J. G. Mechanic for 20 years. He has indigestion and headache, but does not attribute them to the gas. Positive test.

No. 10. Small storage garage. Cloudy, moderately cold weather. Ventilation from door and large open elevator shaft. There is only a little smoke in the air.

B. F. Fourteen months employed. No complaint. Positive test.

J. M. Three years employed. Occasional headache. Positive test.

No. 11. Storage garage. Clear, dry, windy day, 60° F. Ventilation good; doors open; no smoke.

W. B. Ten years employed. Occasional headache on cold days when the doors are closed. Doubtful test.

No. 12. Storage garage. Weather as under No. 11. Well ventilated from window, skylight, and open doors. Very little smoke.

W. R. Three years employed. He occasionally has headaches. Just before the test was made he had been working outside for half an hour. Negative test.

W. F. Employed 12 years. He has headaches and dizziness sometimes. He had been outside for several hours just before the test was made. Negative test.

No. 13. Storage and repair. Weather cool, foggy, cloudy, and very damp. The repair shop in the second floor is large, but with a low ceiling. There are windows on two sides, but only one is partly open. An open elevator shaft communicates freely with the first floor, which is used for storage. An ozone machine, with a small fan, was placed in the center of the room. Cars running; air very smoky.

E. J. D. Fifteen years. Complains of headaches. Positive test.

W. F. R. Mechanic 7 years. Complains of headaches. Positive test.

A. P. Mechanic 8 years. Headaches and indigestion. Positive test.

S. M. Mechanic 1½ years. Headaches and dizziness. Positive test.

A. G. B. Mechanic 3 years. Headaches. Positive test.

R. B. Mechanic 3 years. Headaches and dizziness. Positive test.

M. L. H. Mechanic 10 years. Headaches and dizziness. Negative test.

O. J. G. Mechanic 6 months. Headaches occasionally. Positive test.

W. G. Mechanic 3 weeks. Headaches. Doubtful test.

P. J. R. Mechanic 3½ years. Headaches. Negative test.

The symptoms reported by this group of men were more marked and more general than in any other garage. All the men complained of headache, which came on usually toward the end of the afternoon, and most of them suffered daily from headache, except in summer, when the weather is clear and all windows and doors open. Cold and damp days are especially bad. The owner said that the ozone machine had made a decided improvement in the efficiency of the men, but this was not borne out by the evidence of the men themselves, who thought that there was no improvement after the installation of the machine.

No. 14. Basement repair shop. Weather cold and clear. The air was fairly thick with smoke and odor of exhaust gas.

W. D. Headache when the weather is cold and damp. Positive test.

J. N. Headache when the weather is cold and damp. Positive test.

T. M. Headache when the weather is cold and damp. Positive test.

No. 15. Storage garage. Weather cold and cloudy. Air in the garage seems clear. All work had been over for three-fourths of an hour when the test was made.
T. M. Positive test.

No. 16. Repair garage. Clear, dry weather, 20° F. The ventilation is poor, all windows and doors being closed, and the "smoke" is fairly thick.
F. G. Mechanic 7 months. He has headache followed by gastric distress and nausea, and when he is working on his back under the car he sometimes vomits. Positive test.
F. A. Mechanic 7 months. He has headache, and when the smoke is bad he has nausea and pain in the stomach. Positive test.

No. 17. Repair and storage shop. Weather clear and windy, 40° F. Large, moderately high repair room with all windows and skylight closed but with open doors into well-ventilated storage room. There is not much smoke, for flexible tubes are used to attach to exhaust and carry off gas through holes in walls.
W. L. D. Mechanic 7 years. Headaches and stomach trouble. Positive test.
H. G. D. Mechanic 7 years. Headaches. Positive test.
P. Mechanic 15 years. Headaches. Positive test.
C. A. R. Mechanic 6 years. Headaches and stomach trouble. Positive test.
L. J. D. Mechanic 5 years. "Gas headaches" and stomach trouble. Positive test.

The above records give the results of 55 tests on garage workers and show that 36 had absorbed carbon monoxide from the exhaust gases in the air. This number, equal to about two-thirds, does not tell the whole story, for if the records of those that gave dubious or negative tests are examined it is found that several of them had not been exposed to the gases for more than an hour before the tests were made. Thus of the 3 with doubtful results, 1 had been inside the garage only an hour. Of the 16 with negative tests, 1 had been at work only half an hour, and 2 for only one hour, 3 were drivers, who were in and out of the garage all the time, 1 worked in the office, 1 had just been outside for half an hour and another for several hours. This means that of the 19 who failed to give clearly positive tests, only 9 were employed in garage work and had been inside for more than an hour just prior to making the test.

CHRONIC GASSING AMONG LINOTYPISTS.

The two industries which seem to offer the greatest opportunity for constant absorption of small quantities of carbon-monoxide gas are the tailoring trades and the printing trades. In the former it is the pressers using gas-heated irons who are exposed; in the latter, the linotypists, on whose machines the lead pots are heated by gas flames, unless an adequate system of ventilation carries off the gas fumes. It was planned to include in this study both pressers and linotypists, but conditions in the clothing industry were too unsettled to permit of such an inquiry at the time, and it had to be confined to the linotypists. The study was carried on in Boston and covered three newspaper plants. It was made possible by the cordial cooperation of the Typographical Union officials and the chairmen of the various chapels. The results which are given below show that the contamination of the air in machine composing rooms is demonstrable although slight. In no case did the investigator fail to find at least one positive test, although the proportion of positives was nothing like so high as it was among the garage workers. Probably no two days would yield exactly the same results in any one plant, for the condition of the air in the different parts of the room

would undoubtedly vary from day to day. It seems safe to conclude from these tests that the ill health complained of by many printers may be in some part due to the gas in the air and that the discomfort, headache, dullness, loss of appetite, especially at the end of the day's work, and the chronic constipation—a frequent complaint of printers—may be aggravated by the small quantities of carbon monoxide in the air they breathe.

The following results were obtained in these newspaper plants:

No. 1. 12.30 to 2 a. m. Weather warm and rainy. Composing room high and well ventilated, but no exhaust system for the lead pots.
F. H. T. Five years employed. Complains of gastric trouble and headaches. Negative test.
J. T. P. Nine years. No complaint. Negative test.
J. C. S. Eight and a half years. No symptoms. Negative test.
D. S. Nine years. No symptoms. Negative test.
A. E. W. Ten years. No symptoms. Negative test.
M. C. H. Seven years. Headaches and gastric trouble. Negative test.
C. W. A. Twenty years. No symptoms. Negative test.
E. F. S. Twenty-five years. No symptoms. Negative test.
P. J. S. Twenty-six years. No symptoms. Negative test.
F. B. Five and a half years. No symptoms. Negative test.
R. B. Five years. Indigestion. Negative test.
L. C. Ten years. Indigestion. Negative test.
C. W. Thirty years. No symptoms. Negative test.
H. E. H. Ten years. No symptoms. Negative test.
E. F. B. Twenty-five years. No symptoms. Negative test.
S. J. O. Twenty-five years. No symptoms. Negative test.
J. H. G. Thirty-five years. Gastric ulcer. Negative test.
E. F. N. Eight years. Lead poisoning. Doubtful test.
L. D. Eighteen years. No symptoms. Doubtful test.
F. A. B. Thirty-seven years. Lead poisoning. Doubtful test.
W. C. Five years. No symptoms. Doubtful test.
D. J. L. Thirteen years. No symptoms. Positive test.

No. 2. 2 p. m. Weather clear and cool, 25° F. Room not very high, windows all closed, but there were three electric fans. No odor of gas in the air.
M. J. C. Five to six years. No symptoms. Positive test.
J. J. T. Twenty-eight years. No symptoms. Negative test.
B. J. T. Ten years. Severe headache at times when the air is bad. Negative test.
W. P. B. Twenty-five to 30 years. Headache and constipation. Negative test.
W. J. S. Fifteen years. Headaches. Negative test.
H. L. A. Twenty-seven years. Negative test.
A. G. Fifteen years. No symptoms. Negative test.
J. S. Seventeen years. No symptoms. Negative test.

No. 3. 3 p. m. Clear day, temperature 40° F. There are two small low rooms communicating with each other. The lower room contains 15 linotype machines, the upper room is the composing room, and in one corner is a large gas-heated melting pot which runs for a few hours in the morning. A draft ventilator is attached, but is reported as out of order most of the time. There is no exhaust system for the linotype pots. The linotype room has several windows partly open.
W. H. Thirty years. No symptoms. Negative test.
W. T. Thirty-five years. No symptoms. Negative test.
W. G. Thirteen years. No symptoms. Negative test.
F. H. M. Sixteen years. No symptoms. Negative test.
F. W. B. Thirty years. No symptoms. Negative test.
G. W. S. Thirty years. No symptoms. Negative test.
H. R. S. Two years. No symptoms. Negative test.
T. J. W. Two years. No symptoms. Negative test.
H. F. C. Forty years. No symptoms. Negative test.
J. C. G. Twelve years. No symptoms. Negative test.
J. B. Thirty-eight years. No symptoms. Negative test.
J. H. R. Thirty-five years. No symptoms. Positive test.

W. F. R. Six years. No symptoms. Positive test.
O. C. Two months. No symptoms. Positive test.
J. A. M. Twelve years. No symptoms. Positive test.
D. M. Twenty-four years. Headaches, lead poisoning. Positive test.
T. J. F. Thirty years. Headaches and stomach trouble. Positive test.

The total figures for the linotypists are 8 positive out of 47 tested, or 17 per cent. This does not include the 4 doubtful cases, which are classed with the negative.

SUMMARY.

Industrial carbon-monoxide poisoning is said to be increasing in all civilized countries because of the increasing use of power and producer gas, the increasing use of motor engines, and the increasing depth of mines with the consequent difficulty of ventilation and seriousness of accidents. British statistics show that the average number of cases per year increased during the last quinquennium from 62.5 to 75 and the mortality from 12.3 to 17.3 per cent.

Studies in European countries, especially Great Britain and France, show that industrial carbon-monoxide poisoning when not fatal is sometimes followed by serious effects, such as pneumonia, cardiac weakness, mental disease, or paralysis. Such aftereffects are seen most often in coal miners.

Chronic carbon-monoxide poisoning is described, though not clearly, by the French, English, and Germans. It is supposed that the ill health complained of by cooks, bakers, laundresses, ironers, pressers in tailor shops, painters working in rooms dried by salamanders, etc., is caused by the coal gas in the air.

Inquiries made in the United States show that acute carbon-monoxide poisoning occurs in steel manufacture, in making illuminating gas, in making coke (by-products), in using producer gas for industrial processes (especially in smelting), in coal mining, metal mining, zinc smelting, and in garages when the exhaust gases from engines accumulate.

American statistics as to the number of cases and of fatalities are available only to a very slight extent. The figures from one of the steel companies show a decidedly lower mortality (4.8 per cent for 1916 to 1920) than the British mortality from blast-furnace gas (22.8 per cent for 1914 to 1919). The figures from the American Gas Institute show that among some thousand accidents during 1919 only 30 were due to gas and none was fatal.

No statistics are available for carbon-monoxide poisoning in coal mines or in metal mines, the reports of the Bureau of Mines not distinguishing this cause of death and disability from others.

A careful search in steel towns and in coal mining and metal mining towns failed to confirm the statements made by foreign authorities as to serious aftereffects from gassing accidents. Only very rare instances of such a character were discovered. It is not possible in our present state of knowledge to explain why experience in this country differs so much from that of European observers. A more thorough study should be made of this aspect of industrial carbon-monoxide poisoning.

The suggestion is made that some of the obscure features of poisoning by this gas may be cleared up when it is known just what

other constituents besides carbon monoxide are present in a given industrial gas, and just what effects might be produced by these other gaseous bodies. It is especially suggested that small quantities of benzol may be really the active agent in cases attributed to carbon monoxide.

Chronic carbon-monoxide poisoning may be looked for in industries in which small quantities of the gas are more or less continuously present in the air.

Of 55 garage employees, mechanics and storage men, 36, or about two-thirds, were shown to have absorbed in their blood carbon monoxide in demonstrable quantities. Of the remaining 19 only 9 had been at work inside the garage for more than an hour when the test was made.

Of 47 linotypists in newspaper plants where the gas from the lead pots is not carried off by an adequate suction apparatus, 8, or over one-sixth, showed the presence of carbon monoxide in their blood. The actual effect of such constant absorption of small quantities of this gas should be studied further.

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