MALADIES CAUSED BY THE AIR WE BREATHE: INSIDE AND OUTSIDE THE HOME

BY THOMAS OLIVER


COLL. REG. MED. LOND.
MDXVIII
Ο ΒΙΟϹ
ΒΡΑΧΥϹ Η
ΔΕ
ΤΕΧΝΗ
ΜΑΚΡΗ

MALADIES CAUSED BY THE AIR WE BREATHE
INSIDE AND OUTSIDE THE HOME

MALADIES CAUSED BY THE AIR WE BREATHE INSIDE AND OUTSIDE THE HOME

BY

THOMAS OLIVER, M.A., M.D., LL.D., F.R.C.P.

PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF DURHAM; PHYSICIAN TO THE ROYAL INFIRMARY, NEWCASTLE-ON-TYNE

BEING

The Harben Lectures for 1905

DELIVERED IN THE

LECTURE THEATRE OF THE ROYAL INSTITUTE OF PUBLIC HEALTH

LONDON
BAILLIÈRE, TINDALL AND COX
8, HENRIETTA STREET, COVENT GARDEN
1906

PREFACE.

In the hope that these Lectures may prove of interest and assistance to other workers in the field of Industrial Hygiene they are issued in this collected form.

7, Ellison Place,
Newcastle-upon-Tyne.
January 21, 1906.

MALADIES CAUSED BY THE AIR WE BREATHE INSIDE AND OUTSIDE THE HOME.

LECTURE I.

Before proceeding to the agreeable task that is before me, allow me to convey to you, Mr. President and the Council of The Royal Institute of Public Health, my warmest thanks for the honour conferred upon me in inviting me to become the Harben Lecturer for this year. In searching for a subject, and after having reviewed the titles of the lectures given by my distinguished predecessors in this chair, I have thought that our time might be profitably occupied in considering some of the maladies caused by the air we breathe inside and outside the home, in the factory and mine, and by working in compressed air.

Our health is largely determined by the character of the air we breathe. Indoor occupations contrast unfavourably with a life spent in the open air. There is something repellent in the odour of the atmosphere where human beings are crowded together, and in the stagnant air of close, ill-ventilated dwellings. As proof of the bad effects of having breathed such an atmosphere we have only to recall the sense of languor, of mental and physical tiredness, and the headache which many persons experience. It is ours to make the most of the life that is given us, and yet men and women cannot always control their surroundings. There are in operation such influences as heredity, place of birth, education and opportunity, which not only help to form our character, but shape our destiny. Some men are so overwhelmed by these that they are enslaved by them. Born and bred in the slums of a large town, for example, they never rise above the depressing influences of their surroundings. It is the submerged portion of our population that it is so difficult to cater for in matters of hygiene as well as of social welfare.

The better educated and better housed working classes are not altogether ignorant of the laws of health. If men and women are to rise from sleep refreshed, with a feeling of fitness for their daily work, it is absolutely necessary that the air breathed during sleep should be abundant and as pure as possible. What is the standard of purity to be aimed at? The atmosphere is composed of 20·93 per cent. of oxygen, 79·04 per cent. nitrogen with argon, and 0·03 to 0·04 per cent. of carbonic acid; while expired air contains 16·4 per cent. of oxygen, 79·2 per cent. of nitrogen, and 4·4 per cent. of carbonic acid with a small quantity of water. Respiration not only makes the air poorer in oxygen, but richer in CO_2, warmer and moister, and although in expired air there is a larger amount of organic matter, it yet contains fewer micro-organisms. The amount of oxygen in atmospheric air varies. While present to the extent of 20·9 per cent. in ordinary air, it may rise to 23·6 per cent. in the air where vegetation is active, owing to the decomposition of carbon dioxide by vegetable growth ; hence the desirability of having in our large towns open green spaces as purifying agents.

Although nitrogen forms the principal constituent of atmospheric air it is a harmless gas; it simply plays the rôle of a diluent. It is oxygen in moderation that is required. By it heat is produced within our bodies, and our food material oxidized. Healthy nutrition and the development of muscular energy can only be secured by the presence of oxygen. Overcrowding diminishes the available quantity of oxygen, and loads the atmosphere with impurities. In order to prevent this the cubic capacity of single-roomed houses in the slums of our large cities is frequently marked on the door, as well as the number of persons who can be accommodated therein with propriety.

What is done by the Sanitary Authority for the home is equally done for man in the factory by the Home Office, whose regulations require 250 cubic feet of air per individual during ordinary working hours and 400 during overtime—*i.e.*, beyond a ten-hours' day. Factory owners are obliged to remove dust as far as possible by means of fans, but upon the factory workers themselves is thrown, to some extent, the responsibility of the maintenance of ventilation. That object is defeated if in cold weather they close the ventilating-shaft, or stop the running of the fan. The air in the workroom ought to be plentiful and of a proper temperature, for it is impossible for good work to be done if the air is cold. Factory hands can also aid in preventing the contamination of the air by micro-organisms, by attention to personal cleanliness, and the use of spittoons containing antiseptics for the reception of expectoration.

The atmosphere of the factory and workshop is rendered impure by the use of artificial lights, and often, too, by the character of the work that is done. Notwithstanding the various changes that occur in this country through the increase of its population, and the ever-enlarging number of factories that keep discharging into the atmosphere smoke and poisonous fumes, the gaseous composition of the air alters but very little. In this respect the reparative power of Nature would seem to be inexhaustible, and thus we find man and beast, blade and flower, living and thriving side by side, the one set the complement of the other.

The breathing of an atmosphere vitiated by CO_2 and the volatile products given off from the lungs and skin of man is not attended in an ordinary way by any immediate risk to health, and yet when persons are constantly living under such conditions the constitution must become impaired, for the formation of healthy blood is hindered and resistance to disease is diminished. It is the partial pressure of CO_2 in the pulmonary alveoli that regulates the ventilation of the lungs. In the alveolar air there is at ordinary atmospheric pressure about 6 per cent. of CO_2. If the air that is inspired contains an excess of CO_2, say 3 per cent., the alveolar air will still contain 6 per cent. of CO_2, for, as Haldane has shown (*British Medical Journal*, August 13, 1904, p. 314), the lung ventilation will be so increased by the action of the respiratory centre as to bring the percentage of CO_2 to 6 without the person breathing this air being aware of any change. So far, therefore, as CO_2 in the air of the homes of the people is concerned, Haldane is not disposed to attach the evil importance to breathing it that many sanitarians do. The experience of our very poor people certainly shows that when the air of their dwellings has become gradually polluted they acquire a kind of tolerance to it, whereas other individuals suddenly introduced into the atmosphere have such unpleasant symptoms as a feeling of malaise, headache, vertigo, nausea, and syncope. Where the air is still more poisoned, there may be profuse perspiration, thirst, pains in the chest, and dyspnœa.

Animals suffer equally with men. According to Rossignol, the horses of the French cavalry several years ago exhibited a high mortality—viz., 180 to 197 per 1,000—but after the stables were enlarged and their ventilation improved, the numbers fell to 6 per 1,000. It is a well-known fact that the cows which in our large towns are shut up all winter in sheds die in larger number from tuberculosis than those in the country that are occasionally taken out of doors.

There is something in the unrenewed air of barracks, prisons, and ill-ventilated dwellings that is inimical to the life of man and beast. What is that something? While CO_2 spreads itself uniformly through a room in accordance with the law of diffusion of gases, and is readily controlled by ventilation, it is different with the watery vapour and organic matter that have been given off by the lungs. It is volatile organic matter which has the offensive odour that clings to certain articles of clothing. By many this volatile organic matter is believed to be poisonous. It has the power of slightly reducing potassium permanganate.

According to Haldane and Lorrain Smith, the injection into animals of large doses of the water condensed from expired air is not followed by any bad effects. This is contrary to the experience of Brown-Sequard and D'Arsonval (*Académie des Sciences*, February 11, 1889), who found that the volatile alkaloid contained in expired air, and which they called anthropotoxine or zootoxine, is capable of causing the death of rabbits. When injected either into a vein or under the skin the liquid containing this poison caused death of seventeen out of eighteen animals, while the injection into the lungs of a small quantity (8 to 12 c.c.) of liquid obtained by condensation of the vapour given off in expired air caused death through inflammation of the lungs. The poisonous property was not found to be due to the presence of microbes, for expired air is generally pretty free from micro-organisms, and besides, the liquid was still toxic after it had been exposed to a temperature of 100° C. Formanek (*Archiv. für Hygiene*, xxxviii., 1900) believes the toxic substance in expired air to be ammonia, and to it, as well as to the presence of CO_2 he attributes the poisonous properties of expired air.

Our adult population is very much what its childhood has made it. The housing of the poorer working classes is one of the pressing problems of our time. To this may be added the desirability of removing factories from the congested districts of large cities into the country, and the general adoption of means to prevent the excessive escape of smoke and effluvia from factories and workshops into the air. In a booklet recently published by T. C. Horsfall (Manchester

University Press), called the "Example of Germany," comparisons are made between English and German town life, not favourable to the former. It is stated that there is observed a much larger proportion of tall, well-developed men and women in German than in English towns, and that nowhere in Germany are there to be seen such "undersized, ill-developed, and sickly-looking people as are to be found in the poorer districts of London, Manchester, Liverpool, Birmingham, and all other large British towns"—nowhere, in a word, are there to be seen the rags and shabbiness, and that total disregard of personal and domestic cleanliness, which are such a blot upon the page of our national life. In England drink and gambling are no doubt responsible for much of these. Both nations drink freely, but somehow or other there are fewer signs of drunkenness abroad than at home. There is a higher domestic training in Germany than in Britain, and a greater tendency to be influenced by the laws of sanitation. The discipline of early life has much to do with this. What is true of the person and of the class to which he belongs is also true of municipalities. With the exception of Essen, in none of the large German towns is there anything like the quantity of smoke and soot emitted from chimneys that we see at home. It may be that the character of the coal is different, but apart from this there is greater economy in the use of fuel, and a wider adoption of measures for the consumption of smoke. I am not contending that townspeople who breathe a smoky atmosphere suffer seriously in health from this alone, for carbon particles when inhaled produce none of the irritating effects upon the lungs which are caused by the harder particles of dust of stone and steel. There are æsthetic reasons why soot should be excluded as far as possible from the atmosphere, for sootiness means dirt, and since bedrooms are made dirtier by soot, it is hardly likely that housewives will be disposed to open the windows of sleeping-rooms for the purpose of airing or ventilating them. Another drawback to smoke is that it causes the moisture in the air to become condensed, and this favours the production of fog. During the combustion of coal and wood for domestic and factory purposes, oxygen is removed from the air, and there are thrown into the atmosphere such impurities as soot, tarry matter, CO, CO_2, ammonium sulphide, sulphur, sulphurous acid, and watery vapour. While the gases in the atmosphere become rapidly diffused, the suspended carbon and other products of combustion when viewed from a distance are seen to hang like a pall or cloud upon a town. Add to gases the effluvia and fumes given off by offensive and dangerous trades, and we have an atmosphere surrounding our large manufacturing centres which cannot but be prejudicial to human life and to the physical development of the race.

Usually impure air and overcrowding go hand in hand with absence of sunlight and want of brightness. In a letter to the Registrar-General, Dr. Farre some time ago showed that in Metropolitan districts, where 57 square yards were allowed to each person, the death-rate from phthisis per 100,000 was 478, where 78 square yards were allowed the death-rate was 451, and where 217 square yards were granted the death-rate was 354. The mortality from diseases of the respiratory organs, and from tubercular phthisis is in direct proportion to the density of the population, no matter in what town or country the observations are made. This has been shown to be the case in London, Glasgow, and elsewhere. The evils of overcrowding are well enough known, for overcrowding is a thorn in the side of all municipal enterprise. Dr. A. K. Chalmers, Medical Officer of Health for Glasgow, has shown how much higher is the death-rate in one-apartment houses compared with that in tenements of two and three rooms, and more particularly is this the case as regards infantile mortality. A short while ago a midnight visit was paid by Professor Carnelly, Mr. J. S. Haldane, and Dr. A. M. Anderson, to the homes of the poorer working classes in Dundee so as to obtain specimens of the air that is breathed by the working classes during the night, at a time when the rooms were fully occupied, and when the doors and windows were closed. It is interesting to remark that the gentlemen who were engaged in this midnight raid, between 12.30 a.m. and 4.30 a.m., were received with distinct civility.

In one-roomed houses occupied by two persons the amount of CO_2 present was 6·3 per 10,000 volumes of air, the organic matter was 7·8 as measured by the volumes of oxygen required to oxidize organic matter in 1,000,000 volumes of air, and the total number of micro-organisms 6 per litre of air, whereas in one-roomed houses occupied by 10 people the numbers were 32·1 of CO_2 as opposed to 6·3, 38·1 of organic matter as opposed to 7·8, and the number of micro-organisms 120 as against 6.

In two-roomed houses occupied by four persons the CO_2 was 7·1, organic matter 5, and micro-organisms 8, but when 10 persons were present the numbers were 13·2 CO_2 as opposed to 7·1, 30·2 organic matter as opposed to 5, and the number of micro-organisms 121 as against 8. Taking four-roomed houses with one person to each room, the numbers were 4·5, 1·1, and 0·5, but when three persons were present they were 11·7, 12, and 22.

There is, therefore, a marked increase in the amount of CO_2 and organic matter and in the number of micro-organisms as the cubic space per person diminishes, or, in other words, as overcrowding takes place. In Dundee it was also observed that the death-rate rose in a similar manner, and that the mean age at death was lowered. It is in the case of children especially that the increased rate of mortality is most noticeable. The mean age at death in better-class houses is almost twice as great as that in one-roomed houses, so that persons living in one-roomed houses have the chance at birth of living only half the length of time of those born in the better-class houses, a difference of prospect so astounding that here at any rate is provided material for reflection alike to the city councillor, the Medical Officer of Health, and the social reformer.

While no constant relationship exists between the quantities of CO_2, organic matter, and number of micro-organisms, there is yet a general relationship, so that high percentages of CO_2 are generally found to be accompanied by a corresponding increase in the amount of organic matter, if not always with a rise in the number of micro-organisms. It is well to remember that no micro-organisms are given off by the lungs of healthy persons. Taking various districts of the city, Dr. Chalmers found that while in one district the death-rate in houses of all sizes was 31·1 per 1,000, it was among the one-apartment population 41·2; in another district the numbers were 25·8 and 35·9 respectively; while in yet another district where the death-rate in houses of all sizes was 17·8 per 1000, it was in one-apartment houses 33·1, or about double. Mr. Carl Freudenberg, a manufacturer in Weinheim (*Zeitschr. für Wohnungswesen*, January 10, 1904), made an inquiry respecting the dwellings of 2,900 persons who died in Mannheim in the years 1901 and 1902. In over 300 cases consumption was the cause of death. Dividing the families into five classes he found that in families which had occupied six rooms or more the deaths from pulmonary consumption formed 10·3 per cent. of all the deaths; in those occupying four or five rooms, 22·2 per cent; in those occupying three rooms, each room having less than two occupants, the deaths from pulmonary consumption were 23·4 per cent. of all the deaths. Where three rooms were occupied, each room with two or three occupants, the death-rate from phthisis was 34, and that in families occupying three rooms, but with more than three occupants in each room, the percentage of deaths from pulmonary consumption rose to 42·2 of all the deaths. While we cannot but attribute to overcrowding its proper share in favouring the spread of tuberculosis, we must not altogether lose sight of the attendant influences of poverty, poor feeding, and insufficient clothing, in spreading the disease.

What occurs in the home occurs equally in the factory and workshop where there is overcrowding. Overcrowding and its attendant want of cleanliness make tubercular infection easier. Apart from direct infection there is not the least doubt that living in an atmosphere vitiated by the products of human life and activity reduces the vitality of the individual and predisposes him to lung disease. It is not the CO_2 of the expired air nor the ordinary volatile organic matter given off from the body of man that alone constitutes the danger. The main danger comes from breathing an atmosphere containing fine dust which has risen from the dried and crushed expectoration left upon the floor by tuberculous subjects. Weichselbaum took some such dried expectoration, pulverized it, and made a spray of it. Of seventeen dogs that inhaled this, all of them developed tuberculosis, while in a control experiment with other forms of dust none of the animals suffered at all. In 1898 Cornet published the results of an interesting series of experiments as showing the important pathological part played by desiccated dust in the air. Having spread a carpet upon a floor, he caused to be strewn upon it the sputa of tuberculous patients. When the carpet was dry he swept it two days in succession with a rude broom in such a manner as to detach and raise the bacilliferous dust. Cornet had previously placed 254 guinea-pigs in the room at heights varying from 7 to 134 centimetres above the carpet. All the guinea-pigs contracted tuberculosis, the disease commencing in each instance in the respiratory organs. Cornet, who had practised upon himself this dangerous sweeping, caused tuberculosis to develop in a guinea-pig by inoculating the animal with material removed from the tampons of cotton wadding which he had placed in his nostrils, and which had arrested the tubercle bacilli.

As an indication of the prevalence of tubercle bacilli and of the harmful character of the dust that reaches the organism by the respiratory channels, allusion need only be made to certain experiments conducted by Strauss.

Collecting plugs of cotton wadding which had been placed in the nostrils of twenty-nine healthy subjects who were frequenting hospitals, he obtained positive proof of tuberculosis in one-third of the guinea-pigs he had inoculated therefrom. These experiments demonstrate the comparative ease with which tubercle bacilli suspended in the air may reach the respiratory organs of man. All medical men are agreed upon the frequency of tubercular phthisis in prisons and barracks. The mortality from tubercular phthisis is particularly high in some foreign prisons where the cellular system prevails. It may be that the clothes the prisoners wear are imperfectly disinfected, or that the bacilli cling to the walls or roof of the cell, for it is generally during the first two years of prison life that tubercular lung disease declares itself.

It is difficult to assign to air vitiated by respiratory products and to infection the particular rôle played by each in the propagation of pulmonary consumption. Impure air paves the way for the operation of the tubercle bacillus. Only a few years ago the mortality from phthisis in one of the crack regiments stationed in London was appallingly high, but the death-rate immediately fell as soon as the ventilation of the barracks was improved. The death-rate from phthisis of young soldiers in the French army is still so high as seriously to engage the attention of the authorities, who attribute this "white peril" to barrack life.

It is not so many decades since gaol or typhus fever decimated the inmates of our prisons. This fever has ceased to be the scourge of prisons since John Howard showed the relation of gaol fever to overcrowding and imperfect ventilation. All these circumstances indicate that there is a risk attendant upon the herding together of large numbers of the human race. Admitting the microbic origin of pneumonia, we are familiar with the tendency for this disease in some of its types to linger in the dormitories of large schools, the micro-organism apparently finding in the aerial conditions therein something that favours its longevity and increases its virulence. In the Transvaal the mortality among the gold-miners from dust diseases of the lung has been high, but of late there has been a proneness on the part of the native labourers to pneumonia. Although their occupation is not without some influence, Sansom the Medical Officer of Health, Witwatersrand, maintains that the disease is the result of overcrowding in the compounds, deficient air-space, and the absence of sunlight from the dwellings.

The lead-miners in England suffer from phthisis out of all proportion to coal and ironstone-miners, and while this is partly due to the fact that lead-mines are not so well ventilated as coal-mines, and that the miners return to the working too soon after the use of explosives, there is—or, rather, was some time ago, for lead-mining has diminished in this country—something in the mode of life of the men which throws light upon their high death-rate from phthisis. Lead-mining is usually carried on in out-of-the-way places where the population is scanty. As there are very few houses for the miners close to their work, the men, fatigued at the end of the day, have often to travel home several miles from the mine, frequently in their wet clothes, and over moors swept by bitterly cold winds in winter. Small wonder, therefore, that the catarrhal affections of the lungs and bronchi which they suffer from as the result of this exposure should prepare the soil for the reception of tubercle bacilli. In order to avoid this exposure to the weather, and to spare the men unnecessary fatigue, the owners of lead-mines erected sleeping-houses or barracks for the workmen close to the mines, where the men could stay for a few days in succession, returning to their homes for the week-ends. These barracks are often hot-beds of tubercle. The windows of the sleeping-rooms do not open, and, as a consequence, there is no ventilation. In the dormitory of one of the barracks the beds were arranged in two tiers, 3 feet 6 inches apart, and were no sooner emptied of their occupants of one shift than they were filled by those of another. The air of the dormitory was close and unwholesome, and as many of the miners were the subject of bronchial catarrh and tubercular phthisis, they expectorated upon the floor. In one of the remote dales of the county of Durham Dr. William Robinson found 166 miners occupying one of the lodging-shops. Twenty miners slept in one room 16 feet by 13½ by 9¾ feet, so that each man had 124 cubic feet of air, while the regulations of the Local Government Board require not less than 400. There was no fireplace in the room, and the windows were so fastened that they could not be opened. Small wonder, therefore, that 50 per cent. of the lead-miners in this particular district die from tubercular phthisis and diseases of the respiratory organs.

Comparing these lead-miners with the neighbouring farmers and agricultural labourers, it was found that, while the death-rate from phthisis among the miners was 4·7, it was among the farming population 0·6.

I had occasion recently to visit a lodging-house occupied by foreign workmen at a mine. The number of the inmates was out of all proportion to the cubic capacity of the building. The mess-room in which the food was cooked and eaten, and which served also as the recreation-room, opened directly into the dormitory, which was occupied by a series of wooden partition beds placed close side by side, arranged in two levels like berths on a steamer. The ventilation of the dormitory could only be effected by opening two or three small windows. This method of housing workmen is altogether wrong, both from an economic as well as from a health and moral point of view, and quite apart from the loss of the sense of dignity which it entails upon the men. How is it possible for men to feel refreshed and fit for work after sleeping under conditions such as these?

There is not always in this country the attention given by employers of labour to the housing of single and married men in railway and engineering enterprises carried on in remote parts of the country that there ought to be. Compare with what I have stated the excellent barrack accommodation that is provided at Brigue and Iselle for single men by the contractors for the Simplon Tunnel. At the tunnel upwards of 3,000 men are employed, and, as the engineering and mining operations have had to be carried out at a considerable distance from any centre of habitation, Messrs. Brandt and Co., of Zurich, the contractors, were obliged to build several wooden houses for the accommodation of single men, also for married men and their families. I had the opportunity of visiting these workmen's dwellings with Mr. Sulzer-Ziegler, the managing-director, and Dr. Volante, of Iselle. The barracks for the single men are two-storied buildings, down the centre of which on each floor runs a corridor, from which on either side there is immediate access to the sleeping-rooms, some of which contain only three, or at the most four, open beds, carefully kept and freely supplied with clean blankets and sheets. Each workman had decorated the particular portion of the room round his own bed as he cared to. In the centre of the floor there was a table, so that the room, which was bright and cheerful owing to the windows being large and easily opened, could be used as a writing-room by the men. There was, in a word, that privacy secured to the workmen and that regard for decency which are so conspicuously absent in similar buildings provided by many employers in our own country. It has paid the Swiss contractors to have provided good accommodation for the workmen and to have arranged for their comfort, for the health of the men has been good, and there has been, with one exception, a total absence of those labour disputes which so frequently mar and retard large and important engineering operations.

IMPURITIES OF AIR DUE TO THE USE OF ILLUMINANTS.

In the home and in the factory there are chemical impurities added to the atmosphere other than those given off from the respiratory organs, especially during the short days of winter.

"An ordinary flat flame gas-jet consumes about five times as much oxygen and produces about three times as much CO_2 as an adult man. . . . All gas contains a certain proportion of sulphur . . . and the sulphuric and sulphurous acids arising from this may make the air of a room decidedly unpleasant. If, however, the gas is fairly purified from bisulphide of carbon, and particularly if incandescent mantles are used, no trouble should arise from this source, provided the CO_2 in the air does not exceed about 20 volumes per 10,000" (Haldane).

The standard of ventilation is usually based upon the proportion of CO_2 in the air, but it is difficult to say what the amount should be. The standards proposed by different writers vary—*e.g.*, while Pettenkofer suggested 10 volumes of CO_2 per 10,000 of air as desirable from a health point of view, since any excess beyond this caused the air to smell unpleasantly, De Chaumont proposed 12 per 10,000 of air; and Haldane, Anderson, and others have suggested 13 volumes per 10,000 for schools, and 10 for sleeping-rooms during the night.

In the report of the Departmental Committee, composed of Dr. John Haldane, Messrs. E. H. Osborne and C. R. Pendock, the Home Secretary was recommended to utilize the power possessed under the Factories and Workshops Act, 1901, to fix such a standard that the proportion of carbonic acid at breathing level should not be greater than 12 volumes to 10,000 of air during daylight or where electric light is used, and that after dark or before the first hour after daylight, where gas or oil is used for illuminating purposes, this proportion should not exceed 20 per 10,000. The standards recommended by Haldane and Osborne of 12 volumes of CO_2 by day and 20 by night per 10,000 as the maximum legal limits for factories have not commended themselves to the Association of Certifying Factory Surgeons. Taking 4 volumes of CO_2 as the proportion in outside air and 6 as the proportion in inside air per 10,000, the Association of Certifying Factory Surgeons gives it as its opinion that 9 volumes of CO_2—*i.e.*, an additional 5 volumes of CO_2 per 10,000 in excess of that found in outside air—would be a fair proportion to allow during daylight, and that double this amount might easily be allowed during gaslight.

Mention is made in the Factory Surgeons' Report of the observations of Wilson, which showed that prisoners occupying cells the whole day and night were healthy and of a good colour, with a proportion of 7·2 volumes per 10,000, whilst prisoners employed outside, and occupying cells at night only, were all pale and anæmic through breathing an atmosphere of 10·4 volumes per 10,000.

Sir Henry Roscoe's Committee in 1897 recommended a standard of 9 volumes per 10,000 for cotton cloth factories, and at the time expressed the opinion that this was too lenient from a medical point of view. From those and other opinions equally divergent it is apparent that a fairly wide and reasonable margin can be allowed. On the one hand, it is not desirable to adopt such a low standard of atmospheric purity as to perpetuate the bad conditions that prevail in certain factories; nor, on the other, is it wise to insist upon conditions that are with difficulty attainable by employers. Offenders as factories are in regard to the percentage of CO_2 present in the air, schools are usually worse, for the ventilation of schools is often anything but satisfactory.

The object aimed at by ventilation and the provision of as pure air as possible in the home, the school and factory, is the removal of CO_2 from the blood. At the end of an expiration there is always about 6 per cent. of CO_2 present in the air left in the alveoli of the lungs. Hard, muscular work increases the amount of CO_2 that is being taken by the blood from the tissues to the lungs, and while in the performance of physical work the individual may take deeper breaths, and respire more frequently than when at rest, the ventilation of the lung cannot be so complete unless the air that is breathed is, comparatively speaking, free from CO_2. It is the presence of this gas in the blood that stimulates the respiratory centre. The slight excess of CO_2 which is passed into the blood during muscular effort stimulates the respiratory centre, and by causing deeper breaths to be taken thus provides for its own removal.

During hard physical exercise there are added to the blood other products than CO_2. There are, for example, the products of muscular waste which are the cause of fatigue. These have to be eliminated from the body, and since they require a longer time for their removal, the desirability of sleeping in well-ventilated rooms is at once apparent. A slight excess of CO_2 in the blood soon makes itself felt, but since during hard labour the lungs rid themselves of the surplus gas by the deeper respirations that are taken, there is none of the gasping and the sense of difficulty of breathing that are experienced in heart and lung disease, where this gas is in excess in the blood.

It is not required that I should deal at length with the escape of sewer air into the home or factory. Fresh sewage, when free from pathogenic organisms, however objectionable it may be, is not causative of disease, but when stagnant it gives off foul emanations, the effect of breathing which may be headache, sore throat, and a sense of tiredness. The vital resistance is reduced, so that the individual becomes more liable to microbic disease than he otherwise would. There is a wider spread danger than that due to the entrance of sewer gas into the sleeping-room of a particular dwelling. During the stagnation and fermentation of sewage in drains, the moist air, on rising to the ventilation outlet, meets there the colder external air and becomes misty and is condensed. In the droplets thus formed pathogenic germs are entangled, and since these may be wafted some distance, they aid in the aerial spread of disease.

In addition to the air we breathe being rendered harmful by the products of respiration, the combustion of coal, and gases from drains, it may be contaminated also by dust of an organic and inorganic nature. The inorganic dust is soot, and that which rises from the roads and streets through the running of carriages and motor-cars, etc. Since many of the streets have become paved with wood, complaint is made, and with reason, of the irritating effects of the dust upon the throat and eyes. It is a question how far these circumstances may not be responsible for the large number of cases of pneumonia we have had during this summer.

The large quantities of dust, with its attendant organic impurities, that is being thrown into the atmosphere by the ever-increasing use of motor-cars and other causes is creating a condition of matters that, if unattended to may be followed by consequences, not only prejudicial to the individual, but to the climate of our country. From motor-cars there are, in addition, given off the unpleasant vapour of petrol and the products of the incomplete combustion of hydro-carbons, the effects of the inhalation of which upon some people are headache, depression, and languor.

The dust that is raised by wheeled traffic into the atmosphere carries with it germs of every description from the pulverized dry excrement of animals. In the atmosphere these germs, owing to their lightness, remain suspended for a period, their number depending upon the character of the soil and roadway, the traffic, the density of the population, and the habits of the people, also the prevalence of strong winds. Micro-organisms flourish in the air of low-lying, damp, hot places. In the country, on hillsides, and especially near the sea, microbes do not multiply so rapidly.

The air of the densely-populated parts of a town, owing to the stirring up of dust, is more likely to contain a larger number of microbes than the less densely populated districts, and the numbers vary with the season of the year. Comparatively speaking few in winter, microbes increase in spring, multiply rapidly in summer, and begin to fade away again in autumn. It is fortunate for man that most of the micro-organisms that are present in the atmosphere are harmless. Those that are pathogenic are a menace to health by the ease with which they reach the respiratory organs.

It is estimated that there are from 600 to 700 times fewer microbes in expired than inspired air. What has become of the microbes? Fortunately for man his body has been provided with such natural means of defence as the ciliated epithelium of the respiratory passages, the thick tenacious mucus of the bronchi, and with an ever watchful and active army of phagocytes, which kill and destroy the myriads of micro-organisms that are constantly being inhaled. The air that escapes from the lungs during expiration has been to a large extent, therefore, filtered of its micro-organisms.

Man is a social animal; he loves to congregate. Town life is supplanting village life not only in this, but in other countries. At times there comes to most of us a longing desire to return to the freedom of country life. We feel that we are being beckoned back to those agricultural conditions that welcomed the advent of man. Thanks to strong winds, dispersing the impurities of the atmosphere, and rain, by washing down micro-organisms and dust, the air is rendered clearer. There is, too, a slow process of evolution going on in the soil, the importance of which we must admit, even though we cannot at present understand or explain it.

Since the discovery, in 1896, by M. Henri Becquerel, of the rays in uranium which bear his name, and of radium by M. and Mme. Curie, in 1900, the phenomena of radio-activity have attracted considerable attention. From uranium there are constantly emanating α, β, and γ rays, which produce distinct electric and photographic effects. The β, or Becquerel rays, are believed to be projected particles charged with negative electricity, or, in other words, negative corpuscles or negative electrons.[1] The negative corpuscles of the Becquerel rays convert some of the molecules of a gas into electrified ions, and they produce their effects, in all probability, through the nitrogen of the atmosphere. Newly-fallen rain and snow exhibit radio-activity.

A year or two ago it seemed as if radium and its congeners were likely to play an important part in the treatment of disease. To-day, do we know anything of the rôle they play in the evolution of life? It is to the radio-active emanations of the medicinal waters of Bath and Buxton that the curative effects of these waters are attributed, and to the loss of this radio-activity that the waters when transported and drunk away from their source are, comparatively speaking, useless.

Radiations, we know, can alter the proteids of our tissues. It is impossible, therefore, to say what are the transformations of vegetable and the lower forms of animal life produced by radio-active substances in the soil, how chemical impurities are destroyed, and how the vitalizing energies of the earth are renewed. The discovery of radium has opened up new fields of physical, chemical, and physiological observation. Elster and Geitel (*Physikal. Zeit.*, 1902) have demonstrated that from the atmosphere close to the soil radio-active substances can be obtained, and that at high altitudes the radio-activity of the atmosphere may be three times greater than that in the plains. It is known that the potential differences between the positive air and the negative earth increase with altitude. The action of Becquerel rays from the soil upon the human body is still unknown, but there is a healthfulness about mountain air we all admit and appreciate. The healing power of pure mountain air has been demonstrated by Dr. Oscar Bernhard of Samaden in the Upper Engadine, who found that chronic ulcers which refused to heal under any circumstances, closed in with rapidity when the patients were removed to a high altitude and the wounds exposed to sunlight.

Before the widespread application of the Listerian or antiseptic treatment of wounds was carried out, as it is to-day, Dr. Ludwig, of Pontresina, had in 1873 proved that indolent surgical wounds and ulcers healed when patients were treated at high altitudes.

In radio-active phenomena there is a field for fuller investigation. If, as already shown, some of the results are the removal of pathological conditions, what part does radio-activity play in conditions that are purely physiological? It is not only a question of the air we breathe, but one of the altitude at which the air is inhaled, one,

[1] "The Recent Development of Physical Science" (Whetham, 1904), p. 203.

too, of an atmosphere electrically charged by radio-active emanations from the soil and of life spent in the sunlight.

We have spoken at considerable length of the harmfulness of dust, but we would not be inappreciative of what we owe to dust in a finely divided state, and the important part it plays in creating for us the beauty of the landscape, the blueness of the sky, and in making the earth more habitable. It is by dust particles in the air reflecting the rays of light that we get colour. Close to the earth's surface these particles of dust are large and coarse, hence by their reflecting all the rays of light no special colour is produced; but higher up in the atmosphere these particles become smaller and smaller, and, since they are found to be pretty evenly distributed all over the world and reflect the blue or violet rays of sunlight, there is produced the sky-blue colour of the atmosphere. "The blueness of Italian skies is due to the fact that, with the Mediterranean on the one hand and the snow-white Alpine heights on the other, there is not furnished such a large quantity of atmospheric dust in the lower strata of air as in less favourably situated countries, and thus the blue rays, reflected by the more uniformly fine dust of the higher strata, remain undisturbed" (Alfred Wallace, "The Wonderful Century," p. 173).

It is not alone in the production of colour and beauty that the useful function of dust is portrayed. Dust plays an important rôle in the formation of mists, clouds, and gentle, beneficial rain. Unless particles of solid matter are present in the air to act as nuclei upon which condensation can occur, there would be no mist, cloud, or rain. Without dust our skies would be other than they are, and Nature would have fewer pleasures for us. Opposed to the æsthetic and utilitarian functions of dust must be placed the facts of every-day life, as seen in the enormous quantities of dust that are being thrown off from the roadways of the country and the streets of densely populated cities, also of the huge quantities of smoke ladened with the unconsumed particles of carbon that are disgorged into the atmosphere from factories. To-day more dust and smoke are probably being thrown into the atmosphere which encircles this island than at any previous stage of its history—a circumstance which cannot but have some effect upon the climatic features of our country. Scattered through the atmosphere there will always be a sufficient amount of dust to act as centres of condensation of aqueous vapour, but the presence in excessive quantities of the heavier particles of dust at lower levels must lead to the formation of denser clouds. Is it the case that within the memory of living man there have been in our country a considerable increase in the amount of cloud and a corresponding decrease in the amount of sunshine? In many parts of England—but I speak for the banks of Tyneside and the neighbourhood of Newcastle, where, for example, formerly flourished the almond-tree in the open air—smoke and dust have made arboriculture, not so much a matter of difficulty of growth, as one of shortened existence. The approach of autumn is more early felt by the trees in our large towns than by those in the country, where the leaves do not wither so soon, and where they hang longer on the branches.

Our cloudy skies are the result of the increased amount of dust in the atmosphere; hence by some meteorologists is expressed the fear that the climate of our country is becoming deteriorated, the beauty of the landscape destroyed, and its surface less productive, owing to the loss of sunshine, which plays such an important part in the development and the enjoyment of life.

LECTURE II.

In the previous lecture we dealt with some of the impurities of the air of the home and of the streets. This afternoon we will consider some of the effects produced on man by breathing poisonous gases accidentally or otherwise evolved during certain processes of manufacture. The atmosphere is contaminated by gases, chemical vapours, and dust given off by factories. Smoke and fumes act harmfully in two ways—physically, by causing the atmosphere to become cloudy; and chemically, as shown in the deleterious action of acid and poisonous vapours upon vegetation. It is only necessary to walk or drive through a mining county where coke, for instance, is made, to see how the vegetation of a district can become blighted under the influence of the gases evolved from coke-ovens, or to recall the fact of birds after flying over blast furnaces falling down dead from carbon monoxide poisoning, also of the poisoning of cattle after browsing in the neighbourhood of lead-smelting works. Smoke and the fumes discharged into the atmosphere from certain factories can therefore become more than an inconvenience to the public—they may be a source of danger to health.

Carbonic Oxide or Carbon Monoxide (CO).

This gas, formed during the incomplete combustion of carbon, is often present to the extent of 7 to 10 per cent. in ordinary illuminating gas. Carbonic acid, when passed over red-hot coal, loses one part of its oxygen and becomes carbon monoxide. This is the source of the blue flame seen on the surface of ordinary coal-fires; the carbonic acid produced in the lower part of the fire, where there is excess of air, is, on its passage through the red-hot coal higher up, reduced to carbon monoxide. Escaping in large quantities from coke-ovens, it is this gas which, when inhaled, has caused the death of tramps attracted on a winter night to the proximity of coke-ovens by the inviting warmth, and who, overcome by the narcotizing effects of the gas, have passed tranquilly into their last sleep. It is the carbon monoxide present in coal-gas which has been the cause of so many fatal accidents when this gas has escaped into a bedroom overnight. Carbon monoxide is colourless and inodorous. It has an affinity for the colouring matter of the blood 250 times greater than that of oxygen, so that once blood is fairly saturated with it the hæmoglobin can no longer take up oxygen from the air, and, as a consequence, the individual dies asphyxiated. Blood can take up only a moderate quantity of carbon monoxide, but so poisonous is the gas, and so strong is its affinity for hæmoglobin, that even a very small percentage is extremely poisonous. The symptoms of carbon monoxide poisoning may be only slowly produced; 0·1 per cent. of the gas in the air will cause headache and difficulty of walking, owing to a powerlessness that steals over the limbs. There may not be any loss of consciousness, and the symptoms will gradually disappear if the patient is brought into the fresh air or if oxygen is supplied to him. Exposure to higher percentages of carbon monoxide may cause death very rapidly. An atmosphere containing not more than 0·17 per cent. of the gas has proved fatal to animals, but in a general way, in order to cause death, the gas must be present to at least 0·4 per cent.

Sources of Carbon Monoxide Poisoning.

Poisoning by this gas occurs in men employed at iron-smelting furnaces, in the manufacture of coal-gas and of soda by the Leblanc process, in the distillation of coal-tar, during the explosions in coal-mines, in cement and brick works, and during the incomplete combustion of fuel in domestic houses.

It is, too, a large constituent of water-gas. Carbon monoxide is present in tobacco smoke, and in that given off from lamps.

In persons who have been poisoned by the gas, decomposition of the body is sometimes retarded.

Carbon Monoxide in Coal-mines.

It is CO which is largely responsible for many of the deaths that occur in coal-mines after an explosion. The other sources of the gas in mines are underground fires and the use of the higher explosives. Carbon monoxide is a product of the incomplete combustion of coal; it is not, therefore, a normal constituent of mine-gas. When an explosion of fire-damp has occurred in a coal-mine, carbon monoxide is present as a constituent of the *after-damp*. It is this gas which so frequently overtakes the miners in the pit, and is so fatal in its consequences. Since small quantities of CO do not always cause immediate poisoning, coal-miners who have penetrated into the deeper recesses of a pit may go on working for a length of time—half an hour or more—without experiencing any unpleasant sensations, and it is not until the miners try to make their way into one of the main passages again that they find they are unable to walk owing to incomplete loss of power in their limbs.

The imperfect explosion of dynamite, through faulty detonators and fuses, is a source of carbon monoxide gas in the mine. Under these circumstances the dynamite partly burns and then explodes, and, as a consequence, carbonic oxide and nitric oxide are formed instead of the usual products—carbonic acid, nitrogen, water, and a small quantity of oxygen. Nitro-glycerine, when properly detonated, gives off no measurable quantity of CO, but when it is burnt in the presence of its own gases there may be as much as 35 per cent. of CO present in the product.

Blast Furnaces and Carbon Monoxide Gas.

The subject of asphyxiation of blast-furnace workmen has been discussed at a recent meeting of the Iron and Steel Institute. In his paper Mr. Thwaite showed the necessity for the adoption of measures to protect the workmen. Apart from the presence of CO, there is nothing in blast-furnace gas that is specially detrimental to health. Crude blast-furnace gas, as it leaves the furnace and flows along the gas-flues, has a perceptible odour and is visible, owing to the siliceous, calcareous, and other materials that are suspended in it. Even when freed from these suspended particles, the gas is still visible, owing to the moisture it contains. It is not until all the impurities have been removed that the gas becomes invisible and inodorous, and eludes detection by sight and smell. The gas can penetrate brick walls, the rapidity of permeability being regulated by the density of the gas and by temperature. Blast-furnace gas can travel by the subsoil and enter houses several yards away from the furnace, and cause poisoning of the inmates. The moister the subsoil the less the permeability, but when the ground is dry, as it usually is in the neighbourhood of a flue, the gas can travel considerable distances. As it travels onwards it is being filtered all the time, thereby losing much of its impurity, but none of its dangerous properties.

Escape of Gas during Blast-furnace Charging.

In charging open-top blast furnaces gassing of the men occasionally occurs, but with what are called the closed-top furnaces the men are not so likely to suffer, since the time required to lower and raise the bell is too short for serious effects to be produced. Modern methods of closing the throat of blast furnaces, especially that known as the double charging-bell method, have reduced the proportions of the gas escape and its poisonous effects. Having recently seen, through the kindness of Dr. C. Stanley Steavenson of Middleton St. George, two cases of carbon monoxide poisoning in blast-furnace men, I shall briefly relate them.

J. H., aged 38, a blast-furnace charger, was one day, when at work, overcome by a heavy, sleepy feeling, and he became unable to walk; he was not dizzy, but had headache without sickness. Since that particular day he has been quite unable to follow his occupation. His speech has become slow and syllabic, and he has still some unusual nervous symptoms. On the slightest cause, often without any reason, he bursts out into hilarious laughter, almost imbecile in character, and with no relation to immediately preceding events. Questions asked of him are properly answered. He complains of pains in the limbs, slight rigidity of the muscles, and of a numbness of his fingers. In walking his legs are lifted with difficulty, the right foot flops a little, and the gait is slow and stepping; the left knee-jerk is extremely exaggerated, and the grasp of both hands is feeble. The pupils are dilated, and there is slight nystagmus. The colour of the face is good; there is tremor of the tongue, and the gums are swollen, but do not present any coloured line. Eyesight is good. The condition of the heart, lungs and abdominal viscera, including the kidneys, is satisfactory. The mental symptoms resemble those observed in general paralysis.

The second case, D. M., is that of a man aged twenty-nine, healthy-looking, also a blast-furnace charger. One day, when at work, he too was suddenly overpowered by sleepiness: he could walk, but he felt as if he was lifting his feet too high and too quickly from off the ground. He felt dizzy and had headache, but did not vomit. That evening he slept heavily, and next morning all appetite for food had gone. He still tried to follow his occupation, but so complete was his distaste for food that the meals he carried to the furnace with him were usually brought home untouched. On a few occasions, previous to this particular one, when charging the furnaces, he nearly fell, owing to the inhalation of the gas. Consciousness was never lost at these times, but he felt as if he were intoxicated, and as if he had no control of the muscles below his knees. His speech has become slow and syllabic, and he is unable to follow his employment, owing to marked paresis of the muscles. The grasp of both hands is feeble, and the knee-jerks are exaggerated. The gums are ulcerated: his internal organs including the kidneys, are healthy. In the earlier part of his illness the extensor muscles of the wrists were extremely weak and powerless.

In order to ascertain to what extent carbon monoxide is present in the gas that escapes from blast furnaces, I wrote to the manager of one of the largest ironworks in the North of England, and he gives me the following:

$$CO_2 = 12{\cdot}4$$
$$CO = 27{\cdot}5$$
$$CH_4 = 0{\cdot}2$$
$$H_2 = 2{\cdot}7$$
$$N = 57{\cdot}2$$

I was also informed that the proportion of CO is frequently higher, seldom lower, than the figure given. It is the carbon monoxide which is the dangerous constituent of blast-furnace gas. Foremen of blast furnaces are familiar with "gassing" of the men; some of the men become unconscious for a brief period after charging a furnace, but in a few days they are usually well again. In the two patients whose illness I have reported the nervous symptoms resembling those observed in general paralysis still persist, although it is now more than twelve months since the men became ill. The question suggests itself as to whether there might not have been some poison in operation in addition to that of carbon monoxide; but in discussing this subject with ironworks' managers I am informed that there is no lead present in the ores that are used, and any trace of arsenic that might be present would pass into the iron as As_2O_3, and not give rise to symptoms. Patients suffering from the chronic effects of carbon monoxide gas-poisoning are said seldom to live longer than two years. The gas which escapes from blast furnaces where the two men worked, whose histories I have recorded, was on two separate occasions analyzed and found to contain:

	A	*B*
CO_2	= 4	7
CO	= 36	32
H_2	= 2	5
S	= trace	—
As	= 0·1	—
N	= 58	55·3

The percentage of CO present in blast-furnace gas is certainly high. While CO is given off during the charging of the furnaces it also flows away at the end of a slag-tapping, and although present only in very small proportions—not more than 1 per cent.—still, as the gas is liable to accumulate in dangerous quantities near the furnace boshes, it is advisable that isolated workmen should not be allowed to remain near the boshes when the blow-out period of slag-tapping is taking place.

Illuminating Gas and Water-gas.

It was in 1840 that Tourdes of Strasburg drew attention to the poisonous properties of ordinary coal-gas. In one family six persons had been asphyxiated, of whom five died.

Illuminating gas contains as much as 83 per cent. of hydrogen and carburetted hydrogen, 5 per cent. or more of carbon monoxide, a certain proportion of oxygen, nitrogen, and carbonic acid. Owing to its unpleasant odour, the gas, if present in the proportion of 1 in 500, can be immediately detected. It is interesting to remember that where coal-gas which has escaped from a pipe in the street finds its way into a house, the gas in percolating through the soil loses its odour and carburetted hydrogen. Becoming thus proportionally richer in carbon monoxide, it is therefore more dangerous.

From the main pipes that run through the subsoil of towns there is often a loss of 10 to 15 per cent. of coal-gas; this gas may percolate into the sewers or escape into houses and become a source of danger. Soil that has become impregnated with illuminating gas becomes black; the vegetation on its surface dies. Workmen employed in breaking up the soil may become poisoned by the gas. There is also the danger of an explosion if a light is brought into a confined space, such as a room into which gas has escaped. Eleven parts per 100 give a highly explosive mixture; up to 30 per cent. the mixture is still explosive, but it ceases to be explosive after 60 parts per 100.

Gréhant (*La Semaine Méd.*, Decembre 28, 1904) caused three dogs to respire atmospheres containing coal-gas in the following proportions: 1 in 10, 1 in 30, 1 in 300. The animal submitted to 1 in 10 died in twenty-four minutes; its blood contained 18 c.c. of CO per 100. The second dog, after having breathed a mixture of 1 in 30, became very ill at the end of seventy-five minutes, when its blood was found to contain 17·5 c.c. of CO, very nearly the toxic dose. The third animal respired for two hours the mixture 1 in 300, when Gréhant found in the blood only 4·4 c.c. per 100—*i.e.*, about one-fourth of the toxic quantity. From his experiments the French physiologist concluded that the addition of 10 litres of illuminating gas to 290 litres of air formed a dangerous mixture for a dog, and would probably cause death in man.

Accidental poisoning by ordinary coal-gas usually takes place during the night. The victim is not awakened out of his slumber: he sleeps on, and becomes more and more deeply narcotized. The escaping gas may come from the pipe in the room, or it may enter the sleeping-chamber by the chimney from an adjoining house. When it comes from a broken pipe outside it may lose its characteristic odour by filtering through the soil. In stoves in which slow combustion takes place CO is formed; everything which prevents combustion favours the production of carbon monoxide and increases its asphyxiating powers. When a mixture of air and CO, 1 in 100—a distinctly toxic compound—is caused to encircle an Argand burner, the carbon monoxide in the mixture burns almost completely, and is converted into carbon dioxide, so that the air, which was previously very toxic, can now be respired for some time by an animal without any immediate accident, and without any person being able to establish in the blood the presence of carbon monoxide. The combustion of the gas itself tends to rid the air of the carbon monoxide, but in practice these conditions are never quite realized.

Water-gas

is made by passing steam over red-hot coke; the carbon of the coke combines with the oxygen of the watery vapour forming carbon monoxide, while the hydrogen is liberated. As carburetted water-gas is a cheap commodity, it is occasionally added in considerable quantity to ordinary gas, and since water-gas frequently contains 30 per cent. of carbon monoxide, its escape into occupied places becomes a source of great danger. In a paper recently read before the Royal Society of Dublin, Professor McWeeney states that the carbon monoxide which is present in the ordinary coal-gas to the extent of 5 to 6 per cent. rose in the gas supplied to Dublin to 17 per cent. through the addition of carburetted water-gas. During the first four years that water-gas was introduced into Dublin there were ten cases of gas-poisoning, seven of which proved fatal. In one of the houses in which poisoning of the inmates had occurred no gas had been laid on, and yet one of the sufferers died. The gas had effected an entrance into the house from the soil outside owing to a break in the main-pipe in the street, 18 inches below the surface, caused by a passing vehicle. The soil smelt strongly of coal-gas. In another house the husband, wife, and child were all found dead owing to the detachment of a rubber tube connected with a "penny in the slot" meter. In another instance one of the patients rescued lived three days; but, in spite of oxygen inhalations, he never regained consciousness. His temperature gradually rose to 108° F. before death.

The use of "geysers" for the rapid heating of bath water is attended with danger if their construction is faulty. Fatal accidents have occurred through their use.

Large as has been the number of fatalities in this country from the use of water-gas, it is small compared with what it has been in America. In the United States the illuminating gas is nearly all water-gas; hence the number of deaths, accidental and suicidal, from this source has been appalling in America.

Symptomatology of CO Poisoning.

The slower the poisoning the more pronounced are the symptoms. When a person has been exposed to carbon monoxide for some time, he begins to feel giddy, there is throbbing in his temples and ringing in his ears, he has headache, and there steals over him a heavy sleepiness accompanied by a sense of fatigue and of inability to stand upright and to walk. He feels as if he were intoxicated by alcohol. Respiration may be quickened, and the heart's action, which was at first excited, gradually calms down. Miners who have breathed the gas accidentally in the mine may realize that they are in danger, and yet be quite incapable of taking themselves away from the source of danger, owing to the gas producing a peculiar powerlessness of the lower extremities. In severe cases there may be convulsions, with loss of consciousness.

After a person has recovered there is frequently observed inability to swallow. Before consciousness has been regained there is often slight tremor of the muscles. The patient awakes as if from a profound sleep, and, like a person who has just recovered from a severe epileptic fit, he does not immediately recognise his surroundings, nor is he able to reply to questions. By degrees this dazed condition passes off. Blood-stained mucus may be observed escaping from the mouth; râles may be heard in the bronchial tubes. It is upon the nervous system that the poison chiefly expends itself. Muscular movement, which was at first stimulated, becomes subsequently depressed, or there occur convulsive movements of the extensor and flexor muscles of the limbs, paraplegia, monoplegia, or hemiplegia, accompanied by loss of power in the muscles of the eyeballs. There is frequently loss of sensation. Of the mental after-effects, loss of speech is one of the most noticeable. Occasionally there are symptoms of softening of the brain. In the worst forms, during the acute stage the individual appears to be under the influence of a strong narcotic poison, he becomes more and more unconscious, and in this condition he dies.

Pathology of Carbon Monoxide Poisoning.

While the face of a person who has died of carbonic oxide poisoning may be pale, it is frequently observed to be livid or rosy-looking, as in health. The expression is placid, the pupils dilated. Occasionally traces of fæces and urine are observed about the body. Where the body has lain for some time, and signs of decomposition are present, there can be seen red patches of skin. If the body is examined shortly after death, the venous as well as the arterial blood is often bright-red, and in acute poisoning the muscles, when cut into, exhibit a bright cherry-red colour, which in the slower form of intoxication is replaced by a peculiar grayish pallor. On microscopical examination, the muscular fibre is often found to be fatty and granular. Small hæmorrhages may be observed here and there in the skin, the muscles, lungs, and brain; there may be hyperæmia of the membranes of the brain, or softening of the corpus striatum. Blood-stained serum may be present in the pleural and pericardial sacs, and while in the right side of the heart there may be a considerable quantity of blood there is little in the left; the lungs are hyperæmic or œdematous; hæmorrhages may be observed in the mucous membrane of the stomach and intestines. In the slow form of carbon monoxide poisoning the kidneys are grayish-red in colour, and exhibit a few yellow-white spots; nerve-fibres are degenerated, and the blood, on spectroscopic examination, exhibits two characteristic bands between the D and E lines, the yellow and the green, which, unlike those given by oxyhæmoglobin, do not undergo any alteration on the addition of such reagents as Stokes' fluid or ammonium sulphide.

Carbon monoxide when inhaled does not cause irritation of the lungs. There is no dyspnœa. Sugar may be found in the urine, due to vaso-motor paralysis of the arteries to the liver. Senff found in his experiments upon dogs that when he shut off the circulation to the liver no sugar appeared in the urine, but in animals whose hepatic circulation was not interfered with there occurred glycosuria. Hasse found sugar present in the urine in the following quantities: ·2, ·4, ·6, and 1 per cent. in man; 1·5, 3·4, and 4·2 per cent. in animals.

When animals have died from experimental carbonic oxide poisoning, the external parts of the brain have been found to be hyperæmic. In the deeper forms of poisoning, extravasations of blood may be found in the white and gray matter of the brain, in the central ganglia, and on the surface underneath the membranes.

It is not known in what order the various organs are affected. Some physiologists maintain that cardiac muscle, nerve ganglionic cells, and nerve fibres are the most sensitive to carbon monoxide gas, but as to whether there exist different degrees of affinity in the various organs for carbon monoxide it is difficult to say. The stability of the compound formed by carbonic oxide with the colouring matter of the blood, and which is known as carboxy-hæmoglobin, explains the mechanism of CO poisoning. As the carbon compound replaces the oxygen in the hæmoglobin, the corpuscles can no longer perform their physiological functions, and, as a consequence, oxygen ceases to be carried and given up to the tissues. Asphyxia is the result. Notwithstanding the stability of the compound formed, the carboxy-hæmoglobin can lose its carbon monoxide under the influence of a large excess of oxygen. It is thus that the good results of artificial respiration and of the inhalation of oxygen in carbon monoxide poisoning are obtained.

Treatment of Carbon Monoxide Poisoning.

The patient should at once be taken into the open air, and until a cylinder of oxygen can be brought artificial respiration should be immediately resorted to. Even when the respirations have fallen to one in the minute, life may yet be restored by keeping up artificial respiration and by the administration of oxygen. Bleeding with transfusion may have to be resorted to in severe cases. Transfusion of healthy blood has brought an animal back to life after the breathing had ceased for seven minutes, but this is unusual.

Prevention of CO Poisoning by Water-gas.

In a memorandum by the Chief Inspector of Factories, dated September, 1904, which deals with the use of water-gas and other gases in factories, prominence is given to certain recommendations of the Departmental Committee which reported in 1899 upon the prohibition of the manufacture and the distribution for heating and lighting purposes of any poisonous gas that does not contain a distinct and pungent smell. In the manufacture of Mond gas it was recommended that the quantity of CO in the gas should be limited to 14 per cent., and that the gas should be strongly scented. Between the years 1899 and 1903 there were reported to the Home Office fifty-one cases, including seventeen deaths, of poisoning by carbon monoxide on manufacturing premises traceable to leakages from pipes conveying gas, the cleaning of tanks or flues before sufficient time had been allowed for the gas to escape, underground flues, etc.

The Home Office now requires that printed bills calling the attention of workpeople to the deadly nature of the gas and the best means of rendering first aid shall be posted on the walls, also that persons with diseased heart or lungs should not be allowed to be in charge of an engine worked by gas, that the valves and connections of engines should be frequently inspected for leakage, and that all flues should be well flushed out by fresh air previously to being entered. Cylinders of oxygen ought always to be at hand, and while in the event of accident medical aid must be summoned, no time should be lost by the workmen in resorting to artificial respiration. Free ventilation is necessary. The wearing of respirators is of no avail against CO poisoning, nor can workmen become acclimatized to the gas. In mine-work, and in cases where it is necessary for rescue purposes that men should enter an atmosphere charged with carbonic oxide gas, the rescuers must have a rope securely tied round their waist. In addition, they should be provided with a special rescue appliance, whereby they can breathe air or air and oxygen, and be thus independent of the poisonous atmosphere that surrounds them. When men feel the symptoms of CO poisoning creep over them they ought at once, if they possibly can, to move into fresh air, and the warmer the air the better, since cold air aggravates the symptoms.

Nickel Carbonyl and Carbon Monoxide Poisoning.

Nickel carbonyl is made from nickel copper oxide obtained in Canada. In England a few workmen have died presumably from the carbon monoxide gas that has escaped during the manufacture of nickel carbonyl. Sometimes the men have died rapidly, at other times death has not supervened for a few days. The illness has been of an obscure nature, and as regards the cause of death opinions are still divided. Nickel carbonyl is a very volatile fluid ; it boils at 43° C.

(109·4° F.). It is obtained from finely divided nickel oxide by first passing hydrogen over it, and after the water has been removed from the nickel compound, carbon monoxide is brought into contact with the residue. The fluid nickel carbonyl is a deadly poison. When CO is added, as already mentioned, the compound formed is nickel carbonate. Nickel carbonate is as poisonous as CO, since it enters into combination with the hæmoglobin of the blood.

In one man, a nickel carbonyl worker, who died after three days' illness, the lungs were found to be œdematous and intensely congested. In another workman, part of one of the lungs was inflamed and consolidated, as in pneumonia. In the minor forms of poisoning there is usually complaint of giddiness, and there is unsteadiness of the gait in walking. Men have complained of a lingering taste of the gas in the mouth, of difficulty of breathing, and of pain in the chest. In the case of some of the men who had died rather suddenly, and whose lungs were free from inflammatory changes, it was believed that the cause of death was carbon monoxide poisoning, but there were no traces either of this gas or of nickel carbonyl found in the blood of the men, although traces of CO were found near the leaking machinery where the men had worked. In other cases, where the men were supposed to have died from pneumonia, there was nothing, we are told, in the appearance of the lung that caused it to look different to ordinary pneumonia. In some of these instances death may have been due to nickel carbonyl, or to one of its decomposition products, such as carbon monoxide, but it is still a debatable question as to how far this gas is capable of causing pneumonia. As to what is really the cause of death in nickel carbonyl poisoning, an answer at present cannot be returned. There is the opinion that it is carbon monoxide that is the cause of death, and to this Dr. Mott lends the weight of his authority. The most authentic information we possess as to the changes found post-mortem in the human brain and central nervous system is that which has been furnished by Dr. F. W. Mott. In one man, who died after eight days' illness consequent upon exposure to nickel carbonyl, there were found hæmorrhages in the white matter of the corpus callosum, also hæmorrhages and numerous degenerated fibres in the corona radiata. Hæmorrhages had also taken place into the superior peduncle of the cerebellum, and around the area of softening there was a distinct zone of leucocytic invasion. The cells of the respiratory nucleus in the medulla oblongata showed distinct chromolytic changes.

Fig. 1.—Brain: Hæmorrhages in Corpus Callosum in a Nickel Carbonyl Worker.

(Photograph lent by Dr. F. W. Mott.)

Fig. 2.—Brain: Hæmorrhages in Cortex and White Substance of Brain in a Nickel Carbonyl Worker.

(Photograph lent by Dr. F. W. Mott.)

[To face p. 36.

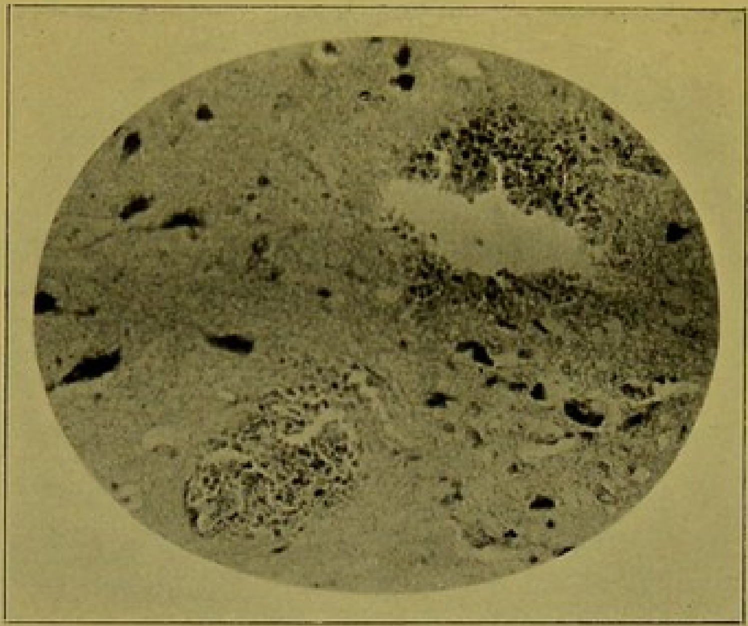

Fig. 3.—Nickel Carbonyl Poisoning. Medulla of Rabbit with two Hæmorrhages. (T. Oliver.)

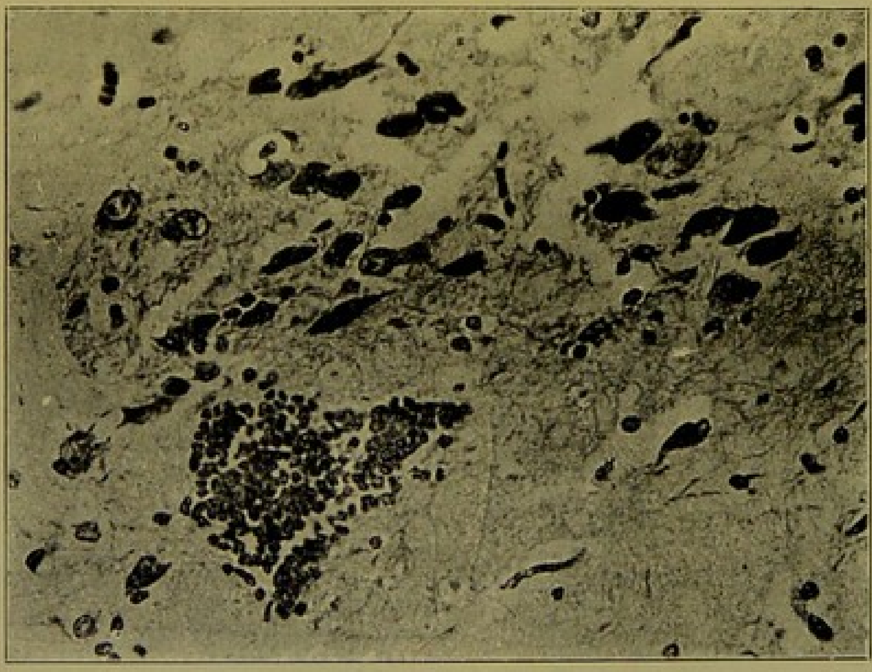

Fig. 4.—Nickel Carbonyl Poisoning. Medulla of Rabbit showing Hæmorrhage. Cells show Acute Chromolytic Changes. (T. Oliver.)

[*To face p.* 37.

In the accompanying photographs of sections of the human brain[1] and of that of the rabbit, the hæmorrhages alluded to in the text descriptive of nickel carbonyl poisoning are well shown.

I am informed that 100 c.c. of nickel carbonyl will give off 73·6 litres of carbon monoxide. The theory, therefore, is that CO is the cause of the poisoning. In one of my experiments I placed a healthy rabbit in a large bell-jar, the inlet and outlet tubes of which were open so as to secure fairly free ventilation. Ten drops of nickel carbonyl were allowed to fall just beyond the inside of the inlet tube. As no apparent effect followed, other 5 drops were placed therein. After ten minutes' exposure, as no effects had been produced, the animal was removed and placed upon the grass, where it ran about as if nothing had happened to it. Two days afterwards the experiment was repeated. Although at the time of the first exposure no apparent effects had been produced, some change had really taken place, for the animal was afterwards listless, and refused its food. At the second experiment 10 drops of nickel carbonyl were placed inside the bell-jar, which was ventilated as previously, and in a minute or two afterwards the animal wakened up out of its listless condition, became somewhat restless, and its breathing quickened, but beyond these nothing was observable. After an exposure of twelve minutes the animal was removed. At first it ran about briskly, but it soon became quiet and seemed disinclined to move. All that day it remained quiet and preferred to remain immobile. Next day it was found dead in its hutch. On making a post-mortem examination, the heart was found to be healthy. The left lung was the seat of patchy engorgement; at one place the lung was semi solid, as in the early stages of pneumonia. The liver and kidneys presented nothing abnormal. To the naked eye the brain showed neither hæmorrhages nor softening either on its surface or on section, but on microscopical examination the medulla was found to be the seat of minute hæmorrhages, and the nerve cells showed chromolytic changes. The urine contained a large quantity of albumin, but no sugar. On examining the blood spectroscopically no change had taken place: oxyhæmoglobin was present, but no carboxyhæmoglobin. The interesting point to remember is that the animal had only been exposed to 30 drops of nickel carbonyl spread over three days, and that it died on the fourth day.

[1] I take this opportunity of expressing my sense of indebtedness to Dr. F. W. Mott and to the Metropolitan Asylums Board, in whose pathological laboratories the sections were cut, for their permission to make use of these photographs.

In Dr. Mott's case the poisoning was probably chronic, or the man, at any rate, had received small doses of nickel carbonyl extending over a length of time, for the lesions were old enough to produce advanced Marchi degeneration in the brain below and above the thrombosed and hæmorrhagic areas. There were signs of thrombosis of vessels of old and recent date, and they resembled those described by Sachs as occurring in CO poisoning.

The salts of nickel are not well-known from a physiological point of view. The experiments of Gmelin and of Anderson Stuart (*Journal of Anatomy and Physiology*, October, 1882), have demonstrated that nickel sulphate, when introduced into the stomach, acts as an irritant poison, while its injection into the blood is followed by cardiac paralysis that is fatal. Nickel itself is poisonous, possibly through its influence upon the brain and nervous tissue.

Carbonic Acid: Carbon Dioxide (CO_2).

Carbonic acid is formed when carbon compounds are burned in excess of air. It is the gas given off by animals during expiration. It is a colourless, inodorous gas, with a slightly acid taste when dissolved in water. Applied to the mucous membrane of the nose it produces a peculiar prickling sensation. The gas is neither combustible itself nor can it support combustion. When present in excess in the air we breathe, it causes poisonous symptoms by preventing the escape of carbon dioxide from the lungs. Three to four per cent. of CO_2 in the air causes difficulty of breathing, 6 per cent. causes palpitation and headache, and 11 per cent. unconsciousness. When present in an atmosphere to the extent of 25 per cent., life is terminated in a few hours. Air which contains a fairly large percentage of CO_2 generally causes a degree of panting or difficulty of breathing, and by this circumstance the presence of CO_2 in excess may be suspected.

Sulphuretted Hydrogen (H_2S).

In the *Lancet*, January 24, 1903, I reported upon fatalities to workmen caused by breathing sulphuretted hydrogen gas in a graving dock near Newcastle-upon-Tyne. Four men died suddenly after inhaling the gas. It is unnecessary to recapitulate the details of the cases. The fatal ending came with appalling suddenness to three of the men within a few minutes of each other. Two of them were overpowered by the gas and lost their lives while trying to reach a suffocated fellow-workman. I made a post-mortem examination upon two of the bodies. In one case the face was pale yet cyanosed. On opening the internal cavities no odour of H_2S was detected. The right side of the heart was flaccid and empty; the left ventricle was hard, contracted, and empty. The lungs were œdematous and pale. The blood was dark and fluid. In the second case the face was cyanosed, while the hands and arms were pale. There was no odour of H_2S in the body. The right heart was flaccid and empty, and the left was hard, contracted, and empty. The lungs were pale and œdematous, and the liver dark. The blood was dark and liquid. On spectroscopic examination the blood gave the ordinary bands of oxyhæmoglobin between the yellow and the green, and as the hæmoglobin was readily reduced by ammonium sulphide, it was at once apparent that the men had not died from carbon monoxide poisoning. In the bottom of the caisson in which the men had been working there were 2 to 3 feet of water, which on boiling gave off 12·2 volumes of sulphuretted hydrogen per 100 volumes of water.

In order to test the toxicity of H_2S I exposed a healthy dog to an atmosphere containing 0·02 per cent. of H_2S. This produced no effect upon the animal, nor was inhalation of atmospheres containing 0·045 and 0·075 per cent. followed by any result. When the dog was placed in an atmosphere containing 0·15 per cent. of the gas, it shortly afterwards became rigid, and fell apparently lifeless, breathing having ceased. On removing the animal, a feeble beat of the heart could now and then be heard. By means of artificial respiration the animal was soon restored, and in two and a half minutes it was quite itself again. Later on the dog was placed in an atmosphere containing 0·15 per cent. of H_2S, when in one minute forty seconds apparent death occurred, preceded by strong muscular spasms and cessation of breathing. The heart continued to beat. On exposing the dog to fresh air the animal recovered. In all the experiments the same events invariably occurred. A very few seconds after exposure to the gas the animal would take two or three deep, gasping inspirations, and would fall down apparently dead in a condition of extreme rigidity and of suspended respiration. If removed at once, it could be restored to life by means of artificial respiration. It was noticed that with each succeeding exposure to H_2S, but not exceeding 0·2 per cent., the animal became more quickly and more profoundly affected, and that it required longer time to recover. As a consequence of successive exposures to H_2S the respiratory mechanism of the animal became so deranged, and the automatism of the centre so disturbed, that even after recovery it was some time before the respiration became rhythmic. The animal, too, seemed dazed and intoxicated: it could not stand unsupported; its limbs were rigid.

Sulphuretted hydrogen causes death by its action upon the respiratory centre. There is no warning, the effect is more or less sudden, and the death is painless. Death may be preceded by muscular rigidity and convulsive tremors; the breathing may become deep and gasping, and subsequently arrested. Although respiration is suspended, the heart may still continue to beat quickly but feebly and irregularly. Both sides of the heart are generally found after death to be flaccid and empty, and the blood on spectroscopic examination shows the two bands of oxyhæmoglobin, and is readily reduced by ammonium sulphide.

With the view of ascertaining whether blood exposed to H_2S would exhibit a spectrum peculiar to H_2S that might be helpful for diagnostic purposes, Dr. Bolam and myself took defibrinated blood and passed H_2S gas through it for one minute. By this time the liquid had become chocolate-coloured, and later on it became greenish. The defibrinated blood thus treated gave the spectrum of methæmoglobin—viz., one band in the red and two in the green. On adding ammonium sulphide to the altered liquid and heating it, no reduction was immediately effected, but by degrees the colour became greener, and reduction took place. In order to determine the length of time required for H_2S to convert the hæmoglobin of the blood into methæmoglobin, defibrinated blood was exposed to the gas for twenty seconds. On examination, the two bands of oxyhæmoglobin were found, but in allowing the liquid to stand it became dichroic, appearing green by reflected and red by transmitted light. Having thus stood for a few minutes the liquid now gave the spectrum of methæmoglobin.

In a third experiment H_2S was passed for only five seconds. At first the blood was unaltered and the spectrum was that of oxyhæmoglobin, but in four minutes afterwards traces of methæmoglobin appeared, and in another minute—*i.e.*, five minutes after removal from exposure to the gas—the spectrum of methæmoglobin was distinct. It is clear, therefore, that methæmoglobin is not immediately formed after exposure of the blood to sulphuretted hydrogen, and that is why methæmoglobin is not found in the blood of workmen who have succumbed to H_2S. The gas poisons so quickly that time is not given for the conversion of oxyhæmoglobin into methæmoglobin to occur.

Every now and then we read of men, when working in the sewers of large towns and in cesspools, being overcome by foul gas, and falling down dead. The death is sudden. They fall as if struck by lightning. In many of the sewers there may be a mixture of gases—*e.g.*, CO as well as H_2S—both of which may act with alarming rapidity. Dupuytren and Thénard found air containing 0·66 of H_2S per 1,000 of air to be poisonous to birds, 1·25 per 1,000 poisonous to dogs, and 4 per 1,000 poisonous to horses. Lehmann reports the case of three men who breathed an atmosphere containing 0·2 of this gas per 1,000 of air. Within eight minutes the men suffered from intense irritation of the eyes, nose, and throat, and within half an hour they could no longer remain in the atmosphere. Air containing 0·5 of H_2S per 1,000 is, according to Lehmann, the utmost that can be breathed with safety; 1 to 1·5 per 1,000 destroys life rapidly. Some men can bear H_2S better than others. There is an idiosyncrasy to it which is not observable with CO. Other gases are present in sewers, which render the presence of H_2S not so readily noticeable. The gases emanating from sewers have been found to contain sulphuretted hydrogen, ammonium sulphide, carbon dioxide, nitrogen dioxide, and phosphoretted hydrogen. There is not the least doubt that the sudden death of workmen in sewers is due to H_2S. Where there are traces only of sulphuretted hydrogen in the sewers, the workmen complain of vertigo, headache, and malaise. These disappear when the men come out into the fresh air. Occasionally a workman falls down dead in the sewers, as if the subject of an apoplectic seizure. In addition to the presence of H_2S in sewers, there may also be CO, owing to the escape of coal-gas from a leaking pipe into the sewer; hence the advisability, from a diagnostic point of view, of making a post-portem examination of the body of a man who has suddenly died in a sewer, and of the necessity of making in all such cases a spectroscopic examination of the blood. Setting aside the theory of Liebig, that poisoning by sulphuretted hydrogen is due to the formation of sulphide of iron in the blood by the abstraction of iron from the red blood corpuscles, sulphuretted hydrogen causes death in two ways—(*a*) suddenly, the victim falls down dead, as if struck by lightning, death being due to the action of the gas upon nerve centres; (*b*) more slowly, where death comes by coma. In this form the blood is dark, and its hæmoglobin may be altered; the urine may contain sugar or albumin. Reference has already been made to the effects produced by H_2S upon the nervous system, whereby its activities are for the moment arrested; but it may be also that the gas produces a profound impression upon the expansions of the pneumogastric nerves in the lungs, and thus reflexly stops the breathing. By this means a fatal accident might be very rapidly induced without the gas reaching the respiratory centre by the blood. It is the rapidity with which death comes that is the explanation in these cases of the absence of any definite spectrum in the blood and of any characteristic pathological lesions in the body.

Bisulphide of Carbon (CS_2).

Bisulphide of carbon is a colourless, volatile liquid, with a disagreeable and repellent odour. It is useful in the arts, owing to the rapidity with which it parts with its sulphur. Carbon bisulphide is used in the vulcanization of india-rubber and caoutchouc. When combined with the sulphur given up by carbon bisulphide, caoutchouc becomes softer, and readily adheres to surfaces with which it is brought into contact. In the vulcanization of rubber by what is known as the cold method, chloride of sulphur is made to play a subordinate part with the bisulphide of carbon. Vulcanization plays an important part in the manufacture of fine rubber goods, such as children's toys, tobacco-pouches, waterproof garments, etc., by rendering them soft and less liable to be influenced by temperature. Carbon bisulphide ; has not only an unpleasant odour, it is a dangerous compound. Workpeople who are exposed to small quantities of it suffer from headache, giddiness, and vomiting, symptoms which often disappear on going into the open air. On the other hand, a lengthened exposure to larger quantities of the vapour may be followed by symptoms of a serious nature. In addition to violent headache, there may be loss of sight, complaint of noises in the head and ears, vertigo, vomiting, and profound lassitude. Occasionally the workpeople lose their power of walking; they stagger as if intoxicated.

Two types of carbon bisulphide poisoning are recognised. In (1) the symptoms resemble those due to excitement of the brain and nervous system ; the patient is talkative, or is the subject of hysterical laughter, irritability of temper, and unexplained outbursts of anger, or he becomes maniacal, and under the influence of delusion commits suicide. In (2), the other form of poisoning, the symptoms are more slowly developed. There are gradual weakening of the memory, difficulty in finding words, indifference to surroundings, anæsthesia, analgesia, loss of sight, paralysis of muscles, especially of the hands, arms, and legs, due to multiple neuritis, and in women a tendency to abortion. Laboulbène mentions as one of the results of exposure to the vapour a peculiar condition of the skin, which he names "melanodermie sulphocarbonnée," in which there are black, irregularly shaped patches disseminated over the skin, due to alterations of the blood.

The prevention of carbon bisulphide poisoning can be, to a large extent, secured by free ventilation of the workrooms. As the vapour is heavier than that of the atmosphere, artificial means should be adopted for its removal in a downward direction away from the workpeople. Caustic solutions which are capable of absorbing and rendering harmless CS_2 vapour should be placed upon the floor. As it is very inflammable, no naked lights are allowed in the workrooms, and in order to secure the freest ventilation some of the workrooms have no outside wall, but communicate directly with the open air. This renders the work extremely cold in winter. The workpeople should not indulge in alcohol; no food should be eaten in the factory; overalls ought to be worn when at work.

Mine Gases.

One of the most important gases which the miner has to face in the pit is methane (CH_4), mine or marsh gas. When vegetable or animal matter undergoes decomposition in the absence of air, but in presence of water, methane is formed. It is this gas which escapes in bubbles when the mud of marshes is stirred. Marsh-gas is frequently present in large quantities in coal-seams, and often hisses out with considerable loudness when a reservoir of the gas has been struck by the pick of a miner. It is a lighter gas than oxygen and nitrogen; it is colourless and without odour; it does not support combustion, but is itself combustible, burning with a clear blue flame in excess of air, and forming carbonic acid and water. When mixed with ordinary atmospheric air or oxygen and ignited, it explodes, hence the name given to it of *fire-damp* by miners. The maximum explosive force is obtained when the methane reaches 9·38 per cent. Below 6 per cent. the mixture is not explosive. It is unnecessary to do more than briefly allude to the detection of this gas by the bluish cone of light or cap inside the Davy safety lamp. Physiologically speaking, methane, like nitrogen, is an indifferent gas. So long as there is plenty of oxygen present to support respiration considerable quantities of methane can be borne with impunity. The gas is of interest on account of its explosive properties when mixed with air or oxygen.

To the above let me add a few words upon what is called "gassing" of the men in mines, as a result of the use of the higher explosives. When these explosives burn instead of detonating properly large quantities of nitrogen oxide are given off, inhalation of which may not be followed by the immediate development of symptoms, and yet men may succumb to an acute inflammation of the lungs twenty-four hours after exposure to the fumes. The men suddenly collapse, become cyanosed, and resemble patients in the last stages of pneumonia. After death the lungs are found to be acutely congested. In the coal-pits of the North of England it is not uncommon to find men, whose duty it is to fire the cartridges, overcome by the nitrous fumes when the ventilation is imperfect. They complain of severe throbbing headache, palpitation, a sense of extreme restlessness, muscular weakness; they have often to be taken to the surface, fresh air having been found to be the best restorative. Occasionally the men suffer in health for some time afterwards. They are nervous and unstrung, and quite incapable for work. In not a few there is tachycardia, with a systolic bruit heard over the mitral area. The symptoms of "gassing" under these circumstances resemble those observed in patients to whom a small dose of nitro-glycerine has been administered, and are probably to be explained in the same way—viz., by sudden dilatation of the peripheral bloodvessels.

LECTURE III.

Caisson Disease or Compressed-Air Illness.

In our previous lectures we dealt with the effects of breathing impure air in the home, the factory, and mine. To-day we will discuss the subject of compressed-air illness or caisson disease.

What engineering science has accomplished for the comfort of man and for civilization another tongue than mine must tell. Human ingenuity is stimulated by human requirements, and often rises superior to them. The extension of railways and the intercourse of nations have forced man to brush aside physical difficulties that well-nigh seemed insuperable, so that to-day we can point with pride and admiration to several large railway-bridges as monuments of engineering skill and daring. When, 100 years ago, it was found necessary to build a bridge, and to have sustaining piers in the centre and sides of a river, in the bed of which no rock existed, it was the custom to drive huge wooden piles downwards into the soil, so as to obtain a basis of support upon which the piers could be built. These wooden piles have, no doubt, answered well, but the ravages of time and tide have necessitated the renewal of these and the strengthening of them by wooden piles outside. To-day the bed of a river is attacked by engineers in quite a different manner. Men work on the bed of a river and below it in iron cylinders or caissons, into which compressed air is driven, and, as excavation proceeds, the caisson sinks by its own and superadded weight, until solid rock is reached, or such a condition of soil is attained capable of sustaining the caisson, which, when subsequently filled with concrete, becomes the substructure of the pier of the bridge. Although these operations are carried out in harmony with physical laws, yet the conditions under which the men work are unnatural, and are therefore attended with considerable risk to the workmen. Under certain circumstances the men suffer from what is known as "caisson disease" or "compressed-air illness."

In its simplest form a caisson, when in position, is an iron cylinder, somewhat bell shaped and open at its lower extremity, while its upper opening is closed by a chamber, out of which an iron door leads into a smaller chamber. The smaller chamber is known as the "air-lock." This communicates externally by means of an iron door with the outside air, and is the chamber by which workmen enter and leave the caisson. Atmospheric air, under considerable pressure, is pumped into the caisson. By this means water is kept out of the caisson, so that men can work in it on the bed of a river. The entrance into the caisson, or working chamber, is through the air-lock. The workmen enter the air-lock, and the outer door is closed. By means of a stopcock compressed air is turned on into this chamber from the caisson, and when the pressure inside the air lock equals that inside the caisson, the inner iron door, which separates the two chambers now opens practically of itself, and the men, entering the caisson, descend the iron ladder.

During the few minutes spent in the air-lock before entering the caisson the men are undergoing what is called "compression." The stopcocks inside the air-lock are manipulated by trained men, stationed outwards. To workmen who have been taken on for the first time the process of compression can be extremely disagreeable. Owing to the rising pressure inside the air-lock the drum of the ear is often forcibly driven in, when there occurs not only deafness, but severe earache and headache, attended by dizziness. By swallowing air, men who are used to the work are able to prevent this; for by diverting some of the air up the Eustachian tube, the middle ear is inflated, and this air, acting as a pad, prevents the extreme depression of the membrana tympani. In some cases where such preventive measures have not been employed the drum of the ear has ruptured. During compression the blood keeps absorbing the gases of the air until their tension in the blood becomes equal to that in the compressed air. Once this equilibrium has been attained, immunity from immediate troubles is secured to the workmen. They can work in the caisson for a few hours without experiencing any inconvenience. In compressed air of over 2 atmospheres the men cannot whistle or talk very loudly, but they can do as much work in a given time inside the caisson as they can outside; they are not so readily fatigued; they can climb up the iron ladders more quickly and with greater energy than they would climb the same length of ladder outside. When in the caisson, which is illuminated preferably by the electric light, since lamps give off a good deal of smoke and consume available oxygen, the men are employed in excavating the bed of the river and in shovelling the soil into iron buckets, which, when filled, are pulled up to the chamber above, where men open a sliding floor and allow the buckets to pass into the material lock, whence, by manipulating the door on the roof, the buckets are lifted by a crane and emptied. So perfectly do the movable doors fit, and so adaptable are the manipulations, that there is, practically speaking, no escape of the compressed air.

When the men have finished the work of the shift they ascend the ladder, enter the air-lock, and close the door behind them. In the air-lock the pressure for the moment is the same as in the caisson, but by turning a stopcock the air is allowed gradually to escape into the external atmosphere, and as the pressure falls the men undergo what is known as "decompression." When the pressure inside the air-lock has fallen to that of the external atmosphere, the outer door is opened and the men leave the chamber, enveloped in a thick cloud of fog or mist, for during decompression the air in the air-lock becomes extremely cold and saturated with aqueous vapour. It is during decompression, and immediately after it, that serious symptoms are apt to develop. In small caissons only two or three men can work at a time, but in large engineering undertakings, such as the building by the Cleveland Bridge and Engineering Company of the new high-level bridge that will span the river Tyne, and where much of my experience of compressed-air illness has been gained, thanks to the kindness of the Company and the Manager, Mr. F. Davis, the caissons are very large. Those in use at Newcastle-on-Tyne are the largest of their kind that have been employed anywhere. In them thirty-five men can work at one time. The caissons measure 113 feet in length and 35 feet in width; the working chamber is 9½ feet high, and has a cubic capacity of 23,142 feet. These huge caissons, in shape not unlike inverted pudding-dishes, have three shafts leading into them, each one of which is provided with its own air-lock for men and also its own material lock, and with an iron ladder leading downwards to the bell-shaped expansion, where it becomes continuous with a rope ladder.

The history of the use of compressed air scarcely comes within the scope of these lectures, and yet it may interest this audience to know that in the very early ages, almost coeval with the dawn of commerce, compressed air was employed in submarine work. Probably it is only a legend, but the story goes that Alexander the Great descended to the bottom of the sea in a vessel called a *colympia*, provided with a glass window, and which was therefore the forerunner of the diving-bell of to-day. Three hundred years B.C. the Phœnicians used the diving-bell. It was reserved to Smeaton and Brunel, in 1779, to make the continuous operations of the diving-bell possible by the transmission of compressed air through tubes from pumps. The employment of caissons is of modern date. A little over half a century ago a French engineer named Triger first employed caissons in order to reach a bed of coal that lay underneath the river Loire, and from that day till now caissons have played an important part in large engineering undertakings in all parts of the world. From the workman's point of view, the air in the caissons ought to be as pure as possible, hence the desirability of having them lit by electricity rather than by lamps or candles; also the necessity of having enormous quantities of atmospheric air pumped into the caisson, and a free escape provided for the surplus air. The greatest amount of sickness among the men has occurred when the supply of air was least, or when, as on the Tyne, the workmen were penetrating a layer of soft coal impregnated with gas. At the Blackwall Tunnel, Snell[1] found that, while the estimated cases of illness for 100 days was 80·9 when less than 4,000 cubic feet of fresh air per man per hour were supplied, and 22·5 when 4,000 to 8,000 cubic feet were supplied, the numbers fell to 8·5 when upwards of 8,000 cubic feet of air were supplied.

It is generally held that the number of cubic feet of air insisted upon by Snell is excessive, but it answered well in the case of the Blackwall Tunnel. It is ordinary atmospheric air that is pumped under pressure by large engines into caissons. In view of a possible breakdown on the part of the engines, there ought always to be more than one engine and at least a double set of tubes. Where compressed air is being sent into a caisson, or is being used for rock-drilling in mines, there is danger of the air which is supplied becoming contaminated by the decomposition products of the oil which is used to lubricate the engine. On the Tyne a layer of cold water is kept circulating round the cylinder of the engine, so as to keep the temperature low and only high-flash oils of 560° F. are employed. By this means the compressed air is kept free from unpleasant odours and from the decomposition products of overheated oil. The surplus air escapes in tremendous volumes from the cutting edge of the caisson, or that part which rests upon the soil; but should perchance the bell-shaped expansion of the caisson settle down upon a bed of clay and no air escape, as occurs in what is called a "water-tight" stratum, it is absolutely necessary to have safety-valves in the upper part of the shafts to regulate the pressure; otherwise, owing to the increasing pressure, the caisson might burst and the results be disastrous. On

[1] "Compressed-Air Illness:" E. Hugh Snell, M.D.

one occasion in France a caisson burst, and the inmates were immediately killed. Safety-valves therefore are provided on the engine itself, which has a "cut-out" that acts immediately when the pressure has risen too high, and thus shuts off the engine, while in addition, as already stated, there are safety valves or outlets in the upper part of the shafts close to the air-locks. The safety-valve in the shafts of the caissons employed on the Tyne is so arranged as to act automatically whenever the pressure inside the caisson reaches ½ pound more than the maximum pressure the men have been working at on that particular day. If, for example, the men have been working at low tide, under a pressure of 30 pounds, and at high tide under a pressure of 35, the safety-valve will act when the pressure rises to 35½ pounds. In large caissons, such as those used on the Tyne, with three shafts, when the lower part of the caisson is resting on a water-tight stratum and no air is escaping, the contractors generally use two of the shafts for pumping in air, and they open the valve in the third shaft. By this means air is carried down to the bell expanded portion of the caisson where the men are working, circulates through it and the foul air escapes by the third shaft. In smaller caissons where only two or three men are working on a "water-tight" stratum, it is the custom to carry the compressed air down to the bottom of the caisson by a tube, and to allow the foul air to escape by a valve close to the air-lock in the upper part of the shaft. By these means the ventilation of the caisson is secured. Owing to the enormous weight of the caissons and the fact that they keep sinking as excavation of the bed of the river proceeds, it is necessary to protect the workmen against risks to life by the caisson tilting over on one side, or by it suddenly sinking into the soil and crushing the men between the soil on the one hand and the roof of the working chamber on the other. Strong iron girders therefore span the interior of this part of the caisson, and the men are never allowed to work under these girders. In the middle of each girder is a large circular opening, through which the men can pass from one portion of the working chamber to the other. In small caissons, where the roof is high, girders are not required; the caisson keeps sinking, and is steadied by the large amount of concrete that encircles it. The weight which a caisson has to support is sometimes enormous. Mr. Frank Davis, the manager of the Cleveland Bridge Company, informs me that some of the caissons on the Tyne, with their superposed concrete, weigh upwards of 10,000 tons.

When the proper depth in the bed of a river has been reached and the necessary excavations made, the caisson is filled in internally with concrete. It thus becomes the substructure upon which the masonry is reared, and ultimately becomes one of the piers of the bridge. During the act of concreting a certain amount of carbonic acid gas is given off, and as the air no longer escapes by the bottom of the caisson, it is caused to circulate and to escape by an outlet tube in the upper part of one of the shafts. There is no necessity for either telephonic or telegraphic communication between the men inside the caisson and those outside, for there are always in large shafts two men in the upper chamber who are in touch with the men below, and whose duty it is to guide the passage of the iron buckets filled with soil through the first doors of the material lock. The men in the air-lock can readily communicate with those outside if need be. Accidents happen but very rarely inside caissons; still, there ought always to be inside the caissons a sling or other suitable appliance whereby injured men could be hoisted to the level of the air-lock should the occasion arise. As the caissons sink fresh lengths have to be added to the shafts, but the air-locks must always be above high-water-level mark.

The pressure of the air within the caisson is regulated by the depth at which the men are working, the length of the cylinder, and in tidal rivers by the circumstance as to whether the water-level mark is high or low.

It requires 1 pound pressure of air to displace 2 feet 4 inches of water; 10 metres of water are equivalent to 1 atmosphere, so that for every 33 feet of water a pressure of $+15$ pounds to the square inch, or 1 atmosphere, is required to keep the water out of a caisson or diving-bell. When men are working at a depth of 100 feet it requires a pressure of $+3$ atmospheres, or 45 pounds, to keep the water out of the caisson. In the case of a diver who is clad in an "open" suit the same conditions apply, but as it is only the head of the diver that is protected by the helmet, his abdominal viscera are apt to be subjected to considerable pressure. The air that is pumped into the helmet of a diver who is dressed in an "open" suit escapes below from under his jacket, whereas in the case of a diver clad in a "close" suit the whole dress is air-tight, owing to the fact that the helmet is screwed on to the complete suit, and as a consequence the surplus air which is pumped to the diver escapes through a valve in his helmet, the valve being so arranged as to allow of the ready passage

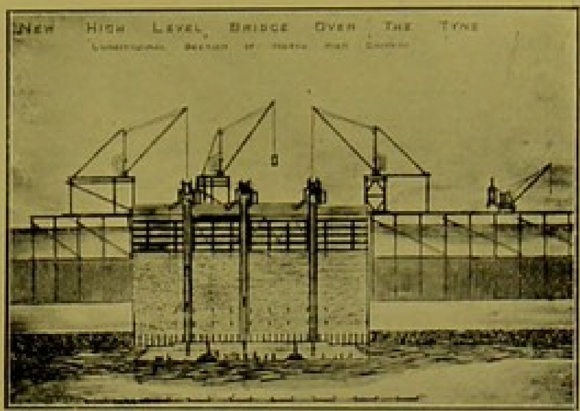

Fig. 5.—Caisson with Three Shafts resting on Bed of River Tyne. Men seen in Working Chamber excavating the Soil.

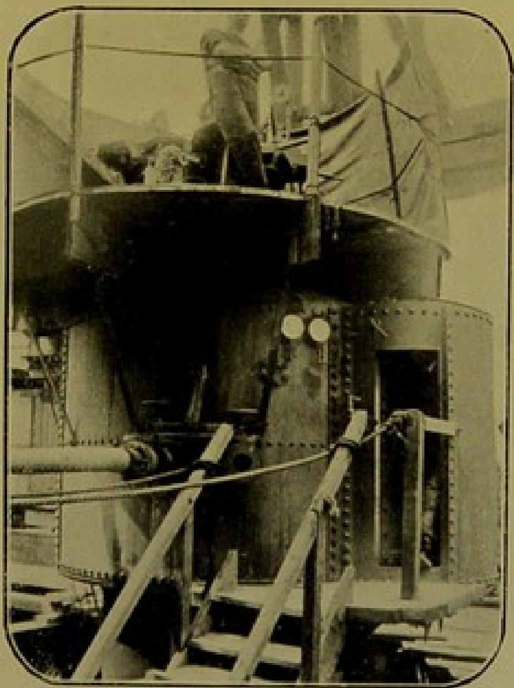

Fig. 6.—Top of Shaft of Caisson, showing on Right Open Door leading into Air-lock.

[*To face page* 50.

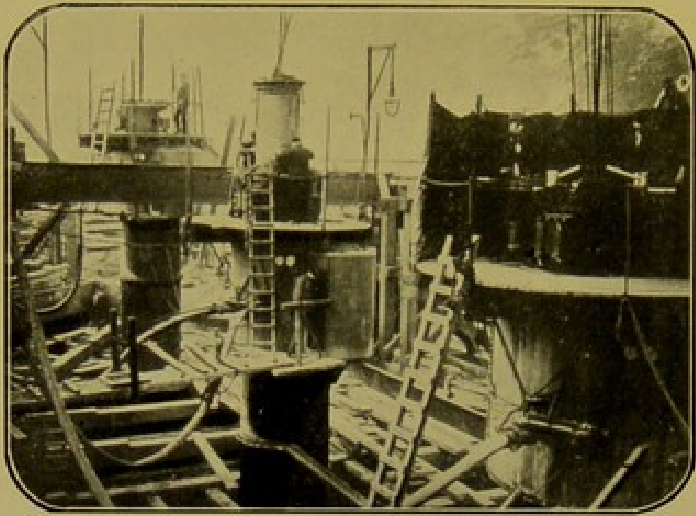

Fig. 7.—Top of Shafts of Caisson. In Middle Shaft Workman observed entering Air-lock. On Platform above is the Material-lock.

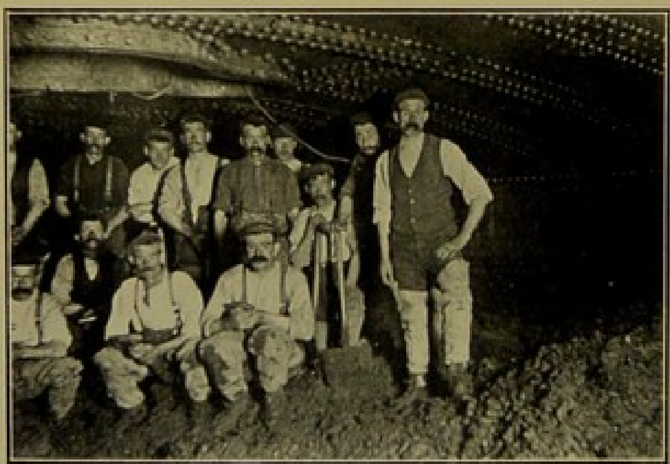

Fig. 8.—Group of Workmen inside Caisson 60 Feet below High-level Water-mark.

[*To face page* 51.

of air from the pumps into the helmet. The "open" suit is not without its risks, since in the event of a diver falling, water might enter the diving-dress and drown him. Diving is now a recognised occupation in the British Navy, and before a man can qualify for the post of diver he must have descended to a depth of 120 feet, and shown himself capable of withstanding a pressure of 52 pounds to the square inch.

In one of the caissons in use at the new high-level bridge on the Tyne thirty-five men worked at a time, and as there were two shifts, seventy sinkers were thus employed daily. It is to the credit of the Cleveland Bridge and Engineering Company, and is a proof of the excellence of the management and of the care taken of the men, that up to the time of preparing this lecture not one fatal case of compressed-air illness has occurred at the works. Several of the men have suffered from caisson disease, a few of them very severely, just escaping with their lives, and at the time of writing one man is extremely ill, ten months after the commencement of his malady; but the fact remains that this huge and difficult engineering undertaking has been accomplished without any loss of life from caisson disease.[1]

When Pol and Watelle published in 1854 their paper on "Compressed-Air Illness," their experience had been gained while in charge of sixty-four men who had worked in caissons on the banks of the Loire at 48 pounds pressure. The men worked on a four-hours shift, and the time spent in decompression was half an hour. Forty-seven of the men stood the work well, twenty-five had to be discharged through illness, and two died. Many of the men suffered from the minor forms of the malady, but the serious cases numbered sixteen. All the accidents occurred after decompression.

In England caissons were first employed at Rochester by Hughes in 1851, during the construction of a bridge over the Medway, and shortly after this by Brunel at Chepstow and Saltash. At Saltash one of the men died soon after coming out of the caisson in which he had been working, at a depth of 87·5 feet and under a pressure of 40 pounds. At the St. Louis Bridge, on the Mississippi, 600 men were employed in sinking the foundations. Of these 600 men, 119 suffered from caisson disease, of whom 14 died. At the Brooklyn

[1] Since the delivery of this lecture this workman has died. In addition to spinal-cord lesions, there were evidences of tubercular disease of the lungs and suppuration of the right kidney. He was the last man to leave the last caisson laid down in the river.

Bridge, New York, there were 110 cases of compressed-air illness, with 3 deaths. Here the pressure varied from 18 to 36 pounds to the square inch above the atmosphere, and the caissons were lighted by gas.

Within recent years no bridge of any importance has been built without caissons. At the Forth Bridge, although there were several minor cases of compressed-air illness, in which epistaxis was a frequent symptom, it is gratifying to know that, under the care of Dr. John Hunter, none of the patients died. Here the pressure was 15 to 34 pounds. The men worked four to six hours at a stretch, but as the caissons sunk and greater depths were reached, it was found necessary to shorten the length of the shifts.

Symptoms of Compressed-Air Illness.

Beyond unpleasant sensations due to pressure upon the membrana tympani, and prevented or relieved by swallowing air and transmitting it by the Eustachian tube into the middle ear, no symptoms arise during the time the men are passing through the air-lock into the caisson or are undergoing what is known as "compression." Nor do the men suffer when working in the caisson; it is usually after the men have finished their work and left the caisson and undergone "decompression" that they become ill. The symptoms may come on immediately they come out of the air-lock or not for some time afterwards. It is an interesting fact that the men who work the internal doors of the material-lock, and who are exposed to the same pressure as the sinkers in the caisson, do not suffer from compressed-air illness. These men have no hard physical work to do: they have only to guide the buckets through the sliding-doors into the material lock. This circumstance of freedom from attacks on the part of these men raises the question as to how far hard work and muscular fatigue may not predispose men to the illness.

In the minor forms of caisson disease the men suffer from pains all over the body, called "bends." These cramp-like pains are often relieved by recompressing the workmen. Occasionally there is epistaxis, and in the worst forms bleeding at the mouth or ears. A workman may have come out of the air-lock, and appeared to be quite well; he is on his way home when he is observed to fall, and is found to have lost the power in his limbs. It is always the lower extremities that are paralyzed, and, as stated, this loss of power may not come on for an hour or two after leaving work.

The number of severe cases of compressed-air illness has usually been greater when the men have been working on the night shift, and yet the length of the night-shift is the same as that of the day. The paralysis is attended by retention of urine, requiring the use of the catheter. In the minor forms of caisson disease the paralysis disappears in a few days or weeks, but in the severer forms it may last ten or twelve months, be accompanied by loss of sensation and by the development of bed-sores on the heels and buttocks, and yet the patient may ultimately recover.

On leaving the air-lock a workman may be seen to reel like a drunken man, and to fall. On being picked up he is found to be unconscious ; his breathing is embarrassed, it may be stertorous ; his pupils are dilated, pulse rapid, and the man is cold. Death may occur without consciousness being regained. Occasionally the men are enfeebled mentally, and for a time are childish and almost imbecile. One man whom I saw was the subject of acute delirium for a few days. A contracted field of vision and blindness have been complained of by some of the men without any ophthalmoscopic changes to explain the loss of vision. Diplopia and loss of hearing, with facial paralysis, have occurred.

The symptoms of caisson disease may be ushered in by vertigo and vomiting or by difficulty of breathing, the men being distinctly cyanosed. Some men seem as if they had received a shock to their nervous system; they become timid and hysterical. It is almost impossible in other instances to say whether the men are not malingering. When the muscular pains or "bends" are severe there is a restlessness of mind and body, and an amount of pain requiring the hypodermic administration of morphia. In the minor forms of compressed-air illness the muscular system is mainly affected ; in the severer forms it is the nervous system that seems to suffer, the spinal cord more frequently than the brain.

What are the Symptoms due to?

Inside the caissons the men are working under abnormal conditions. The atmospheric pressure is high and the work is hard ; the men are dependent for the air they breathe upon what is pumped into the shafts. Since 1 pound of air-pressure is required to displace every 2¼ feet of water, men may be working 70 or 80 feet below high-water-level mark, and under a pressure of 35 pounds to the square inch. It is generally admitted on all hands that the greater the depth the men are working at, and the higher the pressure, also the longer the shift, and the less in quantity, or the greater the impurity, of the air supplied to them the more liable are the workmen to suffer from caisson disease.

On the Tyne the largest number of cases occurred when the men were digging through a layer of soft coal from which gas with an unpleasant odour escaped. At the Forth Bridge Dr. Hunter also noticed that the men suffered most when they were removing the soft silt on the bed of the river. Not only must pure air be pumped into the caisson—there must be an excess of it. The surplus air should escape from underneath the bottom of the caisson, and when a water-tight stratum is reached, the safety-valves in the shaft close to the air-locks ought to act automatically, so as to allow the foul air to escape.

Similar precautions as regards the safety-valves must be observed when the men are filling in the interior of the caisson with concrete. Nothing must be done inside the caisson to poison the air. The men must not defæcate therein: they can easily come out. Electric illumination is superior to that by lamps, since the oxygen of the air is not consumed thereby and no products of combustion are added to the air. Free ventilation and a ready escape for the surplus air not only insure the presence of plenty of oxygen, but favour the removal of carbonic acid, and any other gas that may accidentally find its way into the caisson.

Leonard Hill and J. J. R. Macleod[1] have shown that when animals are exposed to compressed air at a pressure of 4 atmospheres and upwards, the output of carbonic acid is diminished, and the temperature of the body falls. The susceptibility to be thus influenced varies with the idiosyncrasy of the animal. The part played by breathing oxygen at high tension is more important than at first sight appears. Oxygen when breathed under increased pressure becomes a poison. It rapidly produces toxæmia.

Paul Bert found on exposing dogs to high pressures of oxygen and rapidly decompressing them that the animals became convulsed, and on analyzing the gases of the blood during the convulsions he found that the carbon dioxide had fallen to 14·8 and 10·5 per cent. He therefore concluded that excess of oxygen arrested tissue metabolism.

[1] *Journal of Hygiene*, vol. iii., No. 4, 1903.

In a series of experiments which I carried out at the Newcastle College of Medicine with Dr. Parkin of exposing mice to high pressures of oxygen, say 10 atmospheres and upwards, we found that the breathing a few minutes afterwards became rapid and panting, that the animals would suddenly fall on their side in a state of narcosis, that the pupils dilated, and that the mice died in convulsions, even when brought into ordinary atmospheric air. The animals died asphyxiated owing to carbonic acid apparently not being removed.

The hæmoglobin of the red-blood corpuscles is so saturated with oxygen that it is unable to take up CO_2, and thus contribute to the elimination of CO_2 in accordance with the view put forward by Professor Bohr of Copenhagen. But more than this: one of the consequences of breathing oxygen under high pressure is pneumonia. High partial pressure of oxygen causes irritation and congestion of the lungs, and this may be followed by capillary hæmorrhages and by consolidation, so that the lungs present all the appearances of the early stages of pneumonia.

Lorrain Smith has suggested that the inflammation of the lungs may be a cause of caisson disease; but as some of the worst cases of compressed-air illness on the Tyne occurred when the men were working at rather low pressures, and therefore not exposed to high-tension oxygen, and the lesions were on the side of the nervous system, I do not regard the lung condition nor the oxygen tension as playing any part in caisson disease. The oxygen tension under ordinary circumstances is not high enough to do this. On exposing animals to 10 atmospheres or more of oxygen, we found that convulsions occurred, and we regarded them as in all probability the result of the toxic effect of oxygen upon the central nervous system.

Hill maintains that it is not so much the total quantity of oxygen in the blood that produces symptoms as the tension of the oxygen in solution.

Parkin and I found that mice behaved differently in the same pressures of oxygen and compressed air. Exposed to + 10 atmospheres of oxygen, mice in seven or eight minutes became convulsed; but when exposed to even higher atmospheres of compressed air for the same period no convulsions occurred, owing probably to the length of time being too short for intoxication from the oxygen in the air to occur. In our experiments with high pressures—10, 15, and 20 atmospheres, *i.e.*, a maximum of 300 pounds pressure to the square inch—if the length of exposure was not more than fifteen minutes there were no symptoms until decompression having been rapidly induced, the animals then became convulsed, owing probably to the liberation of air in the small bloodvessels.

The results are not identical in the two cases. With high oxygen pressures the convulsions occur during the period the animal is in the compressed chamber, and are therefore toxic in origin; with high pressures of atmospheric air the symptoms do not develop until the animal has been suddenly decompressed. They are therefore due to a different cause—viz., frothing of blood in the small vessels. The fact remains that during the time a man is working in compressed air the circulation of his blood remains, practically speaking, unaltered; if it is quickened at first the blood-flow soon slows. On the other hand, some of the air that he is breathing is pressed into his blood under great pressure, and is held there in solution, the solution of the gases being in proportion to the pressure, and therefore in accordance with Dalton's law.

Now, since nitrogen forms nearly four-fifths of the air we breathe, it is this gas which is found dissolved in the blood in the largest quantity in compressed-air illness. Nitrogen of itself is a harmless gas; it is only injurious to the extent that it keeps out oxygen. Under pressure it is absorbed by the blood according to the law of partial pressures. 100 c.c. of blood under 1 atmosphere of pressure will absorb 1·23 c.c. of nitrogen, and under 4 atmospheres 4·92 c.c. When decompressed from 4 to 1 atmosphere the same blood will give up 3·69 c.c. of nitrogen. It is estimated that the whole of the blood in the body of a man weighing 70 kilogrammes would give up 130 c.c. of nitrogen, but his tissues and fluids would probably yield ten times more.

When by accident or otherwise the atmospheric air in the caisson contains an excess of carbonic acid, there is the danger of a larger amount of carbon dioxide being pressed into the blood than under normal conditions. The effect of the sudden decompression of a man or animal who has been exposed to high atmospheric-air pressures is, practically speaking, similar to what occurs when a soda-water bottle is opened. Effervescence occurs: the blood as it escapes can be seen frothing. In exposing pithed frogs to high oxygen pressure, say 300 pounds or to 20 atmospheres of ordinary air, and watching the circulation through the capillaries of their web, the circulation for the moment is quickened, but by degrees it becomes slower, and no apparent effect is afterwards noticeable either in the rate of the flow or in the calibre of the bloodvessels. On decompression no immediate change occurs in the circulation. Two or three minutes afterwards, however, the blood-stream is observed to become slower, then to oscillate in the vessels—now forwards, now backwards—and there appears a bubble of air inside the capillary. Another bubble of air or two presently appear, and those running together fill the bloodvessel. The circulation ceases, and occasionally small bloodvessels rupture. The gas that is thus set free in the vessels, or which after death can be seen in the frothing blood as it escapes from the heart, is nearly all nitrogen, for the bulk of the oxygen is absorbed by the hæmoglobin of the blood and the tissues.

Leonard Hill[1] tells us that on one occasion when a compressed-air chamber suddenly burst, the dog which was the temporary tenant of it was killed, and that the blood removed from the right side of the heart of the animal yielded on analysis 15·2 per cent. of carbon dioxide, 82·8 of nitrogen, and 2 per cent. of oxygen. Harmful effects must, of course, follow working in compressed air rendered impure by excess of carbon monoxide or sulphuretted hydrogen, but I am not disposed to regard these gases as playing more than a subordinate part in the production of caisson disease, the symptoms of which come on after rather rapid decompression, and are due to the setting free of bubbles of nitrogen gas in the blood, or the production of air emboli in the vessels. The symptoms are the result of mechanical causes; they are not toxic in causation; and yet we cannot but admit that impurities in the air of the caisson somehow or other favour the development of illness, which under the circumstances would be a combination of toxæmia and caisson disease.

Of the various theories brought forward to explain caisson disease, my leaning is towards that which finds the explanation in the frothing of the blood; and yet the respiration of impure air, muscular fatigue, and night-shift work, as already stated, are not without some influence in favouring the incidence of the attacks. The greater the pressure the men are exposed to, and the longer the shift, with its attendant increased muscular fatigue, also the rapidity with which decompression is hurried through—these are to me the most impor-

[1] *Lancet*, July 1, 1905, p. 4.

tant elements in the causation of caisson disease. Pol and Watelle considered the symptoms to be the result of the blood being driven by the compressed air from the peripheral parts of the body into the internal organs, and causing congestion of these organs.

Dr. Andrew Smith, of New York, regards them as the result of a congested state of the capillaries of the nervous system, and of the distended bloodvessels not recovering their elasticity quickly enough when the compression is removed. Corning, basing his opinion upon experience gained during the construction of the tunnel under the Hudson between New York and Jersey, regarded the symptoms as the result of the sudden afflux of blood to the periphery during decompression, and the sudden diminution of the circulation in the central parts of the body.

Some writers maintain that the muscular pains or "bends" the men suffer from are rheumatic in origin, and are a consequence of the combined influence of the cold, moisture, and fatigue the workmen are exposed to. There are two main theories before us: the *hydraulic* or blood-condition theory—viz., congestion of the vessels or its opposite—and the *pneumatic* theory, which is largely the outcome of experimental investigation, and which attributes the accidents to the liberation of gas previously held in solution in the blood. My own experiments and clinical experience leave me in no doubt as to air embolism being the cause of caisson disease, an opinion which is confirmed by post-mortem data.

To Paul Bert we are indebted for having placed the pneumatic theory upon a scientific basis. It is in the small bloodvessels, principally those of the spinal cord, that in serious cases of compressed-air illness those accidents occur after decompression wherein bubbles of air appear, usually commencing on the venous side of the circulation. When decompression is carried out slowly, Nature provides for the gases that have been dissolved in the blood consequent upon compression by their gradual escape, little by little, through the lungs. This gradual escape of gas through the lungs is the saviour of the individual. Taking this view, caisson disease owns entirely a mechanical cause, and ought, therefore, to a large extent to be preventable. It is the result in most instances of too rapid decompression.

Pulmonary respiration is the outward sign of a deeper or internal respiration known as that of the tissues. During in-

Fig 9.—Caisson Worker paralyzed in Both Lower Extremities: Limbs emaciated. Photograph taken Ten Months after Onset of Paralysis. (See p. 13.)

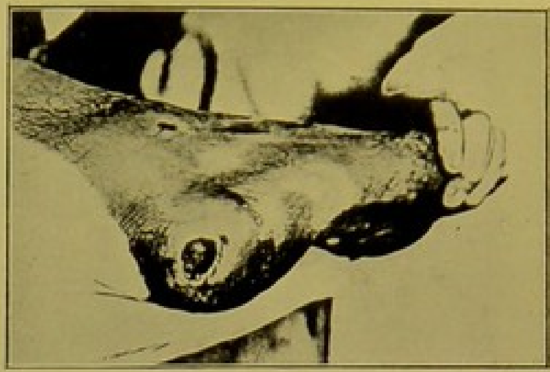

Fig. 10.—Ulcer of Heel in a Caisson Worker suffering from Paraplegia. (See p. 13.)

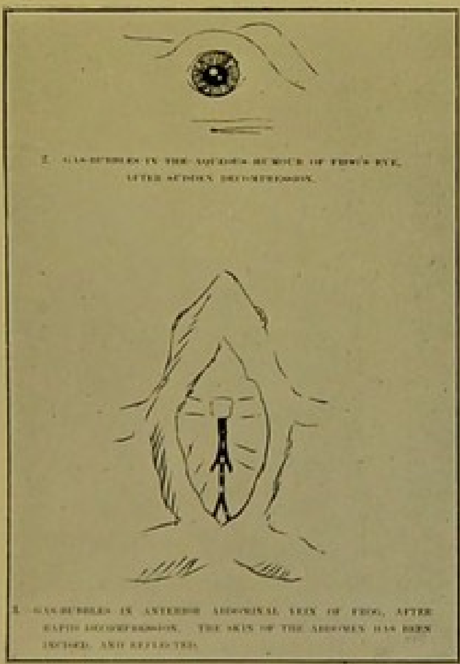

Fig. 11.—Gas-Bubbles in (2) Aqueous Humour of Frog's Eye, (3) Anterior Abdominal Vein of Frog, after Decompression. (Dr. Parkin.)

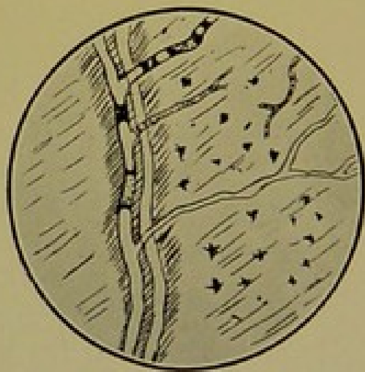

Fig. 12.—Air in Capillaries of Frog's Foot after Rapid Decompression. (Dr. Parkin.)

[*To face page* 58.

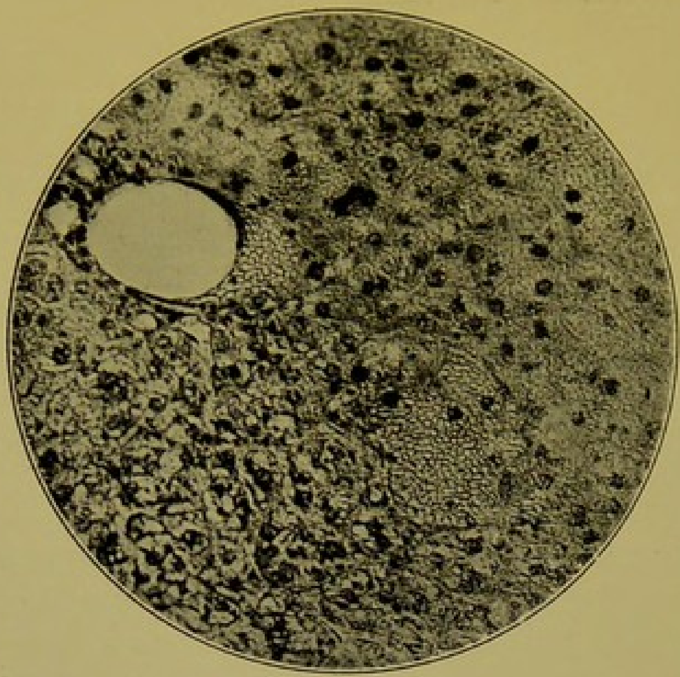

FIG. 13.—LARGE AIR-SPACE AND HÆMORRHAGES IN LIVER OF MOUSE AFTER RAPID DECOMPRESSION. (T. Oliver.)

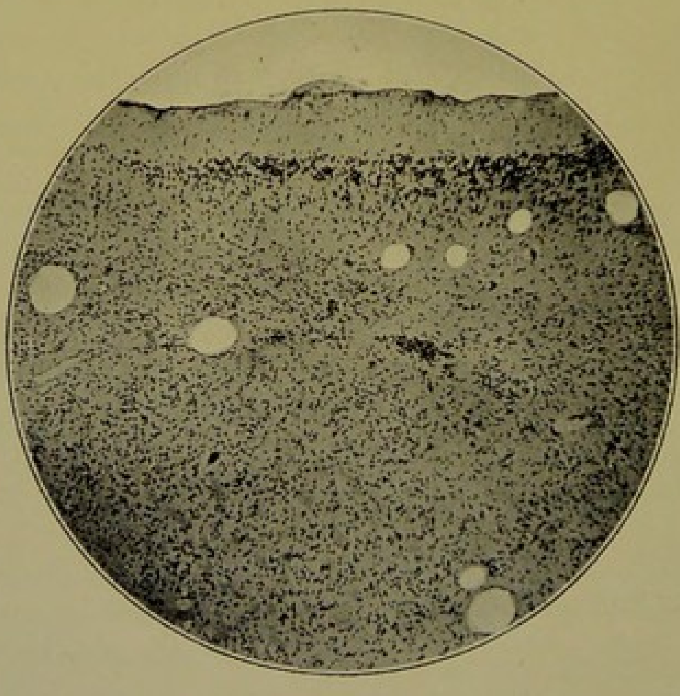

FIG. 14.—AIR-SPACES IN BRAIN OF MOUSE AFTER RAPID DECOMPRESSSPION. (T. Oliver.)

[To face page 59.

ternal respiration oxygen is removed from the hæmoglobin of the red blood-corpuscles by the tissues, and carbon dioxide is given up by the tissues to the blood. Merget, Professor of Physics in Bordeaux, is of the opinion that there is a gaseous atmosphere in our tissues, which is the medium of respiratory interchange in the same manner as the atmospheric medium stands related to pulmonary respiration. He therefore maintains that in compression "the gases in the blood are diffused into these gaseous atmospheres in the tissues until their tension has become equal to the tension of the compressed air." It is upon this equilibrium that freedom from symptoms depends. During rapid decompression this equilibrium is broken, and as these atmospheres of the tissues have still a higher tension than that of the air which was previously compressed, they increase in volume, forcibly separate the tissues that surround them, and cause accidents by tearing the tissues or by leading to the development of intravascular bubbles of air or emboli.

It takes a longer time for the tissues to become saturated with gas than it does the blood; hence it is that short shifts are less dangerous to men working in the caissons, for the shorter the shift the less does the blood become saturated with gas during compression, and the smaller is the amount of gas set free during decompression.

Prevention and Treatment of Caisson Disease.

Since caisson disease is the result of the liberation of gas in the blood and tissues consequent upon too rapid decompression, considerable discussion has centred round the question of the length of time required for decompression to be carried out with safety. The greater the depth the men are working at, the greater is the pressure inside the caisson; the longer the shift, the greater under these circumstances is the saturation of the body fluids with gas, and the longer must be the time spent in decompression. The difficulty is to get workmen who are coming off their shift, and who are eager to get home, to recognise the need for slow decompression. Experienced workmen who know the danger are usually careful enough, but inexperienced men are disposed to run the risk of rapid decompression, so as to get out of the air-lock as quickly as possible. One minute for every 5 pounds of pressure is the time allowed at the new high-level bridge works on the Tyne for decompression. It may be urged that this time is too short when compared with that recommended by Hill and Macleod, viz.:

Atmospheres.	Pounds.	Shift.	Decompression Period.
+2	30	4 hours	30 minutes to 1 hour
+3 to 4	45 to 60	4 hours	1 hour to 2 hours
+5	75	1 hour	,, ,,
+6 to 7	90 to 105	½ hour to 1 hour	2 hours

It would be difficult to restrain workmen this length of time in the air-lock undergoing very gradual decompression, for it is extremely cold therein, and it is not practicable to have the chamber heated. Another difficulty is the comparative small size of the air-lock, which can only accommodate a few men at a time. It would not be easy to have the air-lock larger on account of the necessity of strengthening the apparatus all round.

H. von Schrotter, on grounds that are perfectly correct from a theoretical point of view, has suggested that caisson workers should allow the nitrogen in their blood which has been absorbed under high pressure to be washed out by breathing pure oxygen for five minutes before decompression. C. Ham and Leonard Hill have proved the practicability of the suggestion, and have found it to be efficient in preventing death from air embolism. Rats, although they suffer from convulsions, yet survive rapid decompression after exposure to high pressure of oxygen for a few minutes, whereas rats exposed to similar pressures of atmospheric air are at once killed by rapid decompression. As there is always the risk of animals suffering from inflammation of the lungs after exposure to high pressures of oxygen, it would be unsafe to resort to Schrotter's method of preventing caisson disease above 50 pounds of pressure, and below this slow and gradual decompression keeps the workman within the limits of safety.

No alcoholic subject should be allowed to work in a caisson; also no person with nasal or laryngeal catarrh, or anyone who has a weak heart or diseased lungs. Young men between the ages of twenty and thirty, whose tissues are still elastic, men who are of rather spare than stout build, and who are temperate and of regular habits are the best men for caisson work. Where attention is paid to details as regards choice of men, all of whom should be medically examined before being taken on; good ventilation of the caissons; reasonable length of shifts, and plenty of time spent in decompression, there is no reason why men should not work at greater depths and in higher pressures than has hitherto been done. It is difficult to say what limit of pressure is consistent with safety and effectiveness of work. The higher the pressure the shorter should be the length of time spent in the caisson. The danger of very high pressures is oxygen poisoning. Animals have been exposed to pressures of 8 atmospheres of air for four hours three times a week with safety, but two hours were spent in decompression.

We are scarcely at liberty to compare exposure of animals to very high atmospheric pressures for a short period with exposure of other animals to lower pressures for a longer period. In one of my experiments a mouse was exposed to 20 atmospheres of compressed atmospheric air for ten minutes—*i.e.*, 300 pounds pressure to the square inch. Once or twice during the experiment the pressure had to be momentarily lowered on account of muscular tremors which occurred from time to time. Fifteen minutes were spent in decompression, a short time, no doubt, but it was five minutes longer than the time spent in the compressed air. The animal seemed disinclined to move on being taken out of the chamber, but it gradually recovered and has remained quite well ever since.

Ordinary symptoms of compressed-air illness must be treated as they arise. Since the men, on coming out of the caisson, are perspiring and are in their wet clothes, they often become chilled in passing through the air-lock owing to the rapid fall of temperature. There ought to be, therefore, close at hand a warm mess-room, where the workmen can have hot coffee. When the muscular pains persist, rest in bed and warmth, with hypodermic administration of morphia, will do good.

Recompression.

On coming out of the air-lock or decompressing chamber, the workmen are sometimes seized with severe muscular pains. The muscles do not feel hard or cramped, nor, on the other hand, do they feel emphysematous. The workmen know by experience that if they go back into the air-lock and are again compressed, and then slowly decompressed, the painful symptoms will disappear. Physiological experimentation confirms this fact. At all large works there ought to be a medical lock, where men, on coming out of the caisson and exhibiting symptoms, can be treated. Serious symptoms, possibly a fatal termination, may thus be averted. In one of my experiments, where the animal had been exposed to 20 atmospheres, and had been rapidly decompressed, the respiration, which had ceased, became re-established under the influence of recompression. The medical lock should be large enough to accommodate three or four men, one or two of whom could be in the recumbent position; it ought to be capable of being warmed and ventilated. Attention to these and other details, such as shortening the shift as the depth increases and the pressure rises, also sufficient time spent in decompression, will enable scientific engineers and bridge-builders to undertake and carry to a successful termination operations on even a larger scale than they have hitherto done, and yet be quite consistent with the health and safety of the work-people.

Baillière, Tindall and Cox, 8, Henrietta Street, Covent Garden, London.