C A R B O N I C O X I D E P O I S O N I N G

I N M I N E S

WITH SPECIAL REFERENCE

----- to the -----

TYLORSTOWN EXPLOSION.

Ashfield House,

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CARBONIC OXIDE POISONING in MINES

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The occurrence of an explosion at the Tylorstown collieries (of which I am the medical officer) on January 27 1896, drew my special attention to this subject.

The explosion occurred about 5.30.a.m. and was propagated through the three pits by coal dust. Fortunately, it occurred when most of the night shift had finished, and before the day-men had gone down, or there would have been a much greater loss of life. As it happened, only 90 men were in the pits at the time, of these, 57 were killed, and 33 were brought out alive. Three of the latter were suffering from the effects of burns, and afterdamp. But before entering into an analysis of the cause of death, as shown by an examination of the bodies, some description should be given of the composition and action of the air found in mines, before, and after an explosion.

<u>The Air of Mines:-</u> The air of mines, whether coal, lead or whatever mine it may be is extremely liable to be vitiated, and the amount of vitiation produced, is of considerable importance in relation to the health and safety of those working in the mine. The different impurities that are met with are called by miners under such names as, Black-damp, Fire-damp, White-damp, Gob-stink, After-damp.

To ventilate all mines a current of air is produced and this is guided into every part of the mine, and is managed by means of one shaft which is known as the downcast, which serves for the supply of fresh air, which is distributed to the different working places by means of "intake" roads. The more or less impure air then passes along a system of "return" roads to the upcast shaft, by which it passes out. In the South Wales coalfield, where the ventilation has to be done on a large scale, the current is maintained by means of a centrifugal fan placed at the upcast shaft. So that if the composition of the air in a mine is required, we can obtain it by analysing the air coming through the up-cast shaft, while, if we test the air at different parts of the mine, we find the change in the air due to local conditions.

Black-damp. This impurity is met with in all mines to a greater or lesser degree. It is recognised by the fact that it extinguishes a candle or lamp. When present in small quantities, it causes a lamp or candle to burn dimly, without producing any noticeable effect on men; in larger amounts it extinguishes a candle, or lamp, and in still larger amounts, it causes death by suffocation. It is never explosive when present by itself, and is almost always heavier than air, unless, as very frequently occurs in coal mines it is found mixed with fire-damp.

Black-damp was until lately believed to issue from coal and other strata, and was commonly supposed to be Carbonic Acid. Investigations by Dr. Haldane and Mr. W. N. Atkinson* have shown that this is a mistake and

* Transactions of the Institute of Mining Engineers Vol. viii p.549, Vol xi, p.265.

that black-damp is nothing else but the residual gas produced by the action of air on oxidisable material present in coal and other materials.

Pure black-damp is a mixture containing about 87 % of nitrogen and 13 % of Carbon dioxide. The black-damp met with in coal mines is formed from the oxidation of Iron Pyrites (FeS_2) which is present in coal, as a result of this oxidation process, Sulphate of Iron and Sulphuric Acid, are formed, and this coming into contact with Carbonate of Lime which is also present in coal, evolves Carbonic Acid. You may represent the whole process by the following equation.

$$4\ Fe\ S_2 + 15\ O_2 + 8\ Ca\ CO_3 = 8\ CO_2 + 8\ CaSO_4 + 2Fe_2O_3$$

The red oxide of iron resulting from this reaction can be frequently seen on pieces of coal which have been exposed for some time to air and moisture. Crystals of Sulphate of iron will be found on other pieces where there is no Carbonate of Lime, in the position previously occupied by Iron pyrites, while the coal itself will be unchanged. The oxygen of the air left in contact with coal gradually disappears; so that any part of the mine, such as old workings and spaces of every kind, which have been left unventilated soon become filled with black-damp. Should the barometer show a fall in pressure, the black-damp from these spaces issues out. The return air of coal mines always contains black-damp about 2 % being commonly present in the air of the upcast shaft. As the air current passing through a coal-mine is enormous, there is a considerable amount of black-damp formed in a pit, usually amounting to over 2000 cubic feet per minute in a large pit.

Black-damp is ordinarily recognised by its action in extinguishing a candle or lamp. The amount required to extinguish a tallow candle has been carefully determined by Dr. Haldane.+ He found that a candle held vertically will not continue to burn if more than 15.8 % of black-damp is present (corresponding to an oxygen percentage of 17.6 %) that 17.7 % of black-damp extinguished an ordinary safety lamp, and that 18.6 % extinguished a candle held horizontally. The extinction is due practically speaking to the reduction in the oxygen percentage of the air and not to the presence of

+ Hygiene of Occupations edited by Prof Oliver.

Carbonic Acid, although dilution of air with Carbonic Acid extinguishes a light somewhat sooner than dilution with Nitrogen. A light will still burn in a mixture of 75 % of Carbonic Acid and 25 % of Oxygen. The presence of black-damp affects the light given by a candle some time before the point of extinction is reached. The flame becomes smaller and the rate of combustion is diminished. Angus Smith[*] found that when a candle was allowed to burn in air increasingly vitiated by its own combustion and by respirations, the light diminished to 22 % of its original value when the oxygen percentage falls to 18.5 (corresponding to 8.9 % of black-damp)

The effects of black-damp on men are due partly to the Carbonic Acid and partly to the diminished Oxygen percentage accompanying the admixture of black-damp with air. It is therefore necessary to describe the influence of excess of Carbonic Acid and of the deficiency of Oxygen separately. Until 3 % of Carbonic Acid is added to air no noticeable effect is produced,[+] then the breathing begins to be distinctly

[*] Air and rain p.167

[+] Haldane & Lorrain Smith. Journal of Pathology Vol.i, p.168.

deeper and slightly more frequent, even after a long exposure no other unpleasant effects are produced and the health of animals kept in air containing 3 % of Carbonic Acid is not affected. The breathing becomes more and more affected as the percentage of Carbonic Acid increases, until at about 6 or 7 % there is severe panting, the pulse being also more frequent and vigorous, and the sensation experienced is similar to that accompanying hard muscular work. A long stay in air of this composition is followed by frontal headache; with 10 % of Carbonic Acid the respiratory distress is very great, but with a still higher percentage a narcotic effect is produced, and the mind becomes confused. Animals sometimes die from long exposure to air containing about 25 % of Carbonic Acid, but even 50 % may not prove fatal for some time. Diminution in the oxygen percentage of air causes usually no noticeable effect until the percentage falls to about 12, when the respiration becomes slightly deeper and the lips become slightly bluish. At 8 % the lips and face become a leaden-blue colour, and usually the breathing is deeper and more frequent, but in some cases no change is felt by the person breathing the vitiated air, although to a bystander his face appears alarming. At 5 or 6 % there is clouding of the senses and loss of power over the limbs and after, complete loss of consciousness which, judging from experiments on animals, would probably soon end in death either from gradual failure of the respiratory centre, or from stoppage of the heart. These symptoms are those observed when the breathing of the vitiated air is not accompanied by muscular exertion, when any muscular exertion is made, such as climbing or even walking, the point of danger is reached much sooner. When there is 15 % of Oxygen, dizziness on exertion, and shortness of breath are often felt, and fainting is very apt to occur if there is a much further fall of Oxygen percentage, and this is probably the cause of many accidents where men are fatally injured by falling off ladders in vitiated air. When the percentage of oxygen falls below 8 or 10, death may occur as a result of muscular exertion. In the case of air which is vitiated simply by the diminution of the percentage of oxygen present there is a great deal of danger, because there are hardly any warning symptoms before there is danger to life, and if it was not that a light is generally carried in such air, accidents would be much more frequent, but the extinction of the light which occurs in air with about 17 % of oxygen gives timely warning.

If the composition of black-damp is noticed the effects produced by it are seen to be due, at least, in most cases both to the Carbonic Acid as well as to the diminished amount of oxygen. When a candle is just put out by the amount of black-damp present, there is, as a rule no noticeable effect, since it then contains 17 % of oxygen and about 2 % of Carbonic Acid, but when the amount of black-damp present is increased, panting will become more noticeable, due to the increased Carbonic Acid. Thus with 50 % of black-damp, there is usually about 6 % of Carbonic Acid and 10 % of Oxygen, so that the panting due to Carbonic Acid will therefore be very considerable. When the percentage of black-damp is greatly increased, the symptoms from want of Oxygen will show more and more, so that life cannot be supported when there is 75 %, that is 5 % of Oxygen. Death is not due to the poisonous action of Carbonic Acid, but to the want of Oxygen, in fact the danger is diminished by the presence of Carbonic Acid as its presence produces panting and so gives warning, and besides more oxygen is supplied to the lungs on account of the panting and thus the effects of the deficiency of oxygen are warded off for a time.

Fire-damp. This gas is known to miners by the fact that it forms explosive mixtures with air, and from experiments made in different collieries in South Wales, it is always practically pure Methane (CH_4) The miners detect its presence by the production when it is present of a pale, non-luminous "cap" over the ordinary flame of a lamp. It appears similar to the non-luminous flame of a Bunsen burner though much paler unless the air is nearly explosive. To test for it the flame should be lowered until only a small blue flame is left; the percentage of fire-damp present can be nearly determined from the size, and distinctness of this "cap". With very careful observations about 1 % of fire-damp in the air can be detected. With a hydrogen flame, as in the Clowes lamp, it is possible to detect as little as 0.2 %[#] and as the percentage amount of fire-damp increases, the "cap" becomes more distinct and longer, and when the air is very nearly explosive it passes right up the chimney. Air containing between 5 and 13 % of fire-damp is explosive.

Fire-damp is contained in coal in a high state of compression. Some seams give off more fire-damp than others. Those which give a large amount are called "fiery" as for example, the Albion colliery at Pontypridd, where an explosion occurred in June 1894. According as the parts above the coal are gas-tight, the amount of fire-damp in the coal increases but if there is a way in which it can escape upwards, it escapes from the coal. The fire-damp met with in mines is often mixed with a large proportion of black-damp so that the fire-damp is not suspected to be present unless it is carefully looked for, as the lamp is put out before a clear "cap" is visible, though still capable of forming an explosive mixture. Fire-damp as such, has no action on men, it acts by diluting the oxygen of the air, so

[#] Clowes detection of Inflammable gas 1896.

that as long as there is a sufficiency of oxygen present, fire-damp is neutral in its effects, for example, animals may be kept for long periods in a mixture of 79 % of fire-damp and 21 % of Oxygen. So long as a lamp burns in air containing fire-damp no harm results from breathing the air, as fire-damp is lighter than air, a man who has been affected by it falls down and so gets into better air; if it were not for this there would be more frequent cases of suffocation from fire-damp. Much caution is required in going into air containing fire-damp especially in ascending an incline, as the percentage of fire-damp is apt to increase very rapidly up an incline, and before he falls a man may be in an atmosphere of fire-damp which does not even contain on the floor of the incline enough Oxygen to support life. This can be avoided by going slowly and with a companion a few feet behind. Sometimes fire-damp is mixed with traces of Sulphuretted Hydrogen; this is easily recognised by its smell and if there is smarting of the eyes and catching of the breath, these are signs of great danger from this gas. I have often heard the miners relate incidents of fellow-workmen putting their heads through a hole in a fall to see the effects of the fall and seeing them long in withdrawing their heads, have been obliged to pull them away by their legs, just in time to prevent their being poisoned by fire-damp. If the fire-damp contains little or no air, loss of consciousness occurs suddenly and without previous warning.

White-damp and Gob-stink. By these miners mean the poisonous gas given off from coal which has heated by spontaneous ignition.

"Gob-stink" is so called from the fact that the heating occurs in the waste coal of a gob (that is the waste coal which has been left after all the workable coal has been removed) These gases have the same property as after-damp and the poison is Carbonic Oxide, and the other gases evolved would be Carbonic Acid and Hydrocarbons of the paraffin series, especially the latter, when it is the shales of the seam that have been heated.

After-damp:- The gas which is left in a mine after an explosion is known to miners by the name of after-damp and this is dreaded by the miners on account of its poisonous properties. The constituent which has the most dileterious action in this is Carbonic Oxide (CO) and this Carbonic Oxide is practically the cause of all the deaths in explosions, at least in the South Wales Coalfield, as will be seen later on when the examination of the different bodies recovered is described.

Carbonic Oxide or Carbon Monoxide(CO) is a compound of one atom of Carbon with one atom of Oxygen. It is found along with Carbonic Acid (CO_2) wherever combustion occurs in the presence of an amount of Oxygen insufficient to consume the whole of the Carbon and Hydrogen, which are actually undergoing combustion, where sufficient Oxygen is present only Carbon Dioxide is formed. It has only a very slight odour which is not perceptible when the gas is much diluted. Its specific gravity is nearly the same as that of air. When inhaled it produces symptoms identical in character with those produced by want of Oxygen. The phenomena observed vary considerably however, according to the percentage inhaled, and the period during which the inhalation is continued. It differs from other poisonous gases in its specially slow and insidious action, and the reason is this. The natural process is for the blood to take up the oxygen from the air in the lungs forming a loose chemical combination with the haemoglobin of the corpuscles, and so by means of the circulation it is carried to the tissues where it is used up, but haemoglobin has a greater affinity for Carbonic Oxide and forms with it a much more stable compound, and it has been shown by Claude Bernard that haemoglobin which is saturated with Carbonic Oxide cannot take up Oxygen so that in a living animal whose blood has been saturated with Carbonic Oxide, the haemoglobin cannot convey the oxygen from the lungs to the tissues and death therefore must occur from want of oxygen. Carbonic Oxide has no other effect than that caused by interference with the oxygen supply to the tissues.* Apart from its

* Haldane in Journal of Physiology Vol.xviii (1895) pp.200, 430, 463.

property of combining with the haemoglobin, it is a physiologically indifferent gas, like nitrogen; and it has no action on lower animals which do not possess haemoglobin. This can easily be demonstrated by putting a cockroach into a jar containing 20 volumes of Oxygen and 80 of Carbonic Oxide, and putting another cockroach in a jar containing 20 volumes of Oxygen and 80 of Carbonic Acid. In the Carbonic Oxide mixture the animal is not sensibly affected even after a week. In the Carbonic Acid mixture on the other hand, the cockroach almost instantly exhibits convulsive movements, and becomes quite motionless at the end of from 20 to 30 seconds. It appears to be dead, but nevertheless recovers after a time if taken out before too long. This experiment shows clearly the contrast between an indifferent gas, Carbonic Oxide, and the poisonous gas, Carbonic Acid. The symptoms produced by Carbonic Oxide are practically the same as those due to deficiency of Oxygen in the air breathed. No noticeable symptoms are produced until the haemoglobin is about a third saturated with Carbonic Oxide and death does not usually occur until about 70 or 80 % saturation has been reached.

It might be supposed that the presence of any proportion however small, of Carbonic Oxide in air might ultimately prove fatal from gradual absorption of the gas by the blood. Actually however, there is a maximum limit to absorption with any given percentage of Carbonic Oxide in air; for although the affinity of haemoglobin for Carbonic Oxide is much greater than for Oxygen, yet, if both gases are present, the haemoglobin is shared between them in proportion not only to the relative strengths of their affinities for haemoglobin but also to the relative percentages present of the two gases since although the affinity of Carbonic Oxide for haemoglobin is so much greater than that of Oxygen, yet, if the percentage of Carbonic Oxide is very minute as compared with the percentage of Oxygen, only a little of the haemoglobin will combine with the Carbonic Oxide and consequently no symptoms of poisoning will be produced, however long the exposure may be. Thus with less than about .03 % of Carbonic Oxide in the air, the blood will never absorb enough of the gas to produce distinct symptoms, and with less than .2 % life will hardly be endangered although very severe symptoms may be produced.

In recovery from Carbonic Oxide poisoning, the gas is driven out from the blood through the lungs, in consequence of the greatly increased influence of the Oxygen of the air, and in the course of several hours the blood will be again practically free from Carbonic Oxide. An hour of breathing fresh air will usually suffice to remove any dangerous excess of Carbonic Oxide, but if, as it often happens in persons who have been rendered unconscious, the breathing is shallow, a much longer time may be needed unless artificial respiration has been employed. Carbonic Oxide is not oxidised within the body so that the only way in which it can be got rid of, is through the lungs.* The blood from which the Carbonic Oxide has been expelled is in no way injured. The expulsion of Carbonic Oxide during recovery from poisoning can be greatly hastened by the inhalation of pure

* The supposed oxidation of Carbonic Oxide in the living body .By Dr.Haldane in Journal of Physiology Vol.xxv,No.3 Feb.1900.

Oxygen, since its influence in driving out Carbonic Oxide from the blood is about five times as great as that of air, which only contains 20.9 % of Oxygen.

There are two facts which explain the peculiarly insidious action of Carbonic Oxide.

(1) Carbonic Oxide has a very strong affinity for haemoglobin so that when it is present in air only in a very small percentage absorption by the blood may go on steadily, though slowly until in the end the haemoglobin's power of carrying the Oxygen is reduced to a dangerous extent.

(2) The symptoms produced by deficiency in the Oxygen supply to the tissues are very slight up to the point at which there is loss of power over the limbs. When the limbs completely fail, it is impossible for a man to get out of the poisonous atmosphere. Carbonic Oxide has 250 times as great an affinity for haemoglobin as Oxygen, that is, if air containing 0.1 % of Carbonic Oxide is breathed, the haemoglobin of the blood will become finally about equally saturated with Carbonic Oxide and Oxygen. If this blood was now brought into

vontact with a steady current of pure air, the Carbonic Oxide would in time be driven out. So that with less than 0.1 [*] % of the gas in the air, the blood becomes saturated not more than 50 %; so that complete helplessness does not occur even after a long exposure. With 0.2 % that is about 67 % saturation, complete helplessness with loss of consciousness would occur and this percentage would most likely cause death finally.

It is useful to have an idea of the time required for dangerous symptoms to develop in atmospheres containing Carbonic Oxide, as it is sometimes necessary to enter into such atmospheres for rescue or other purposes. The time required may be roughly calculated as follows. The blood of a man will take up about two pints of Carbonic Oxide, or Oxygen. Hence about 1 pint of Carbonic Oxide must be absorbed to produce half saturation of the blood. Now a man at rest breathes about 10 or 12 pints of air per minute and experiment shows that of the Carbonic Oxide inhaled about 60 % is absorb-

[*] Journal of Physiology Vol.xviii p.430 &c.

ed. Suppose, therefore, that the air contained 0. 1 % of Carbonic Oxide, he would absorb about 7/1000ths of a pint per minute. It would thus take him about 2¼ hours to absorb a whole pint. A man who is walking however breathes about 3 times as much air as a man at rest. Hence he might absorb a pint in an hour. With 0.2 % the time would be half as long and with 0.3 % a third as long. For a man who had already been in the poisonous atmosphere and whose blood had not recovered, the interval of safety would be less than in the case of a perfectly fresh man. Hence in any case where it is necessary to work in an atmosphere suspected to contain Carbonic Acid, men should as far as possible be kept in reserve in fresh air. It was by adopting this precaution that the lives of the Manager and his fellow rescuers were not lost at the Tylorstown explosion. Had the whole party advanced together none might have escaped. It has practically no smell or irritating properties, by which its presence might be easily recognised and its action is peculiarly slow and insidious. The first sympton of Carbonic Oxide poisoning is usually dizziness, and shortness of breath, and palpitation, following any unusual exertion, such as lifting a heavy weight, running or climbing. Sometimes there is drowsines and also unusual excitement, similar to that produced by alcohol. As the saturation of the blood increases the symptoms become more marked until the limbs are so weak that any effort to walk causes them to give way entirely. Some of these symptoms were produced in rescuers at Tylorstown. The general manager who was the first to go down the pit after the explosion accompanied by a fireman, to explore the pit in search of men still living told me that after getting some distance along one of the main roads, he began to feel weak and was unable to walk steadily. He also felt drowsy, had frequently to stop and sit down and had much difficulty in climbing over the falls. His lamp was not extinguished by the after-damp. The manager of one of the other pits who had gone down with a party, experienced still more serious symptoms. The manager and another man who were leading this party were rendered unconscious for a short time, and were themselves rescued with difficulty. They had penetrated nearly as far as the place, where, afterwards, a number of men were found dead with their lamps burning. Feeling affected, they went back into the fresh air behind the doors separating the two pits, and after a short time made another attempt to penetrate along a road leading towards the shaft. After walking some distance they began to feel weak and endeavoured to return to the doors, but before they reached them, first one and then another of the party, dropped and became unconscious. Fortunately the precaution had been taken of leaving several men behind in the fresh air, and they at once came to the rescue and succeeded though with great difficulty in dragging the disabled men out. The manager told me that even when the air was most poisonous, his lamp burnt perfectly and he was under the impression just before he fell that he was getting into fresher air. On getting into the after-damp he had felt smarting of the eyes, but the first definite symptom was loss of power over the legs. He and his companions were brought back to the shaft lying unconscious on trucks. On recovering consciousness, those affected had severe headache, and nausea or vomiting, accompanied by shivering. The only gas, which could have caused such symptoms as described above, is Carbonic Oxide. The same symptoms are produced by great deficiency of Oxygen in the air, but from the fact that the lamps still burned fairly well, there must have been at least 18 % of Oxygen in the air and with that percentage there could be no symptoms due to deficiency of Oxygen. The symptoms caused by excess of Carbonic Acid gas are quite different in character, as also are those caused by Sulphurous Acid, Sulphurretted Hydrogen or any other gas which might possibly be present. The only symptom not due to Carbonic Oxide is the smarting of the eyes and slight irritation of the air passages. These symptoms as shown further on were probably due to the presence of a very small amount of Sulphurous Acid. Men who have been unconscious for some time from Carbonic Oxide poisoning, but have been rescued, may suffer for many days or even weeks from after symptoms of a serious character. Two men who were saved at Tylorstown complained of headache for some weeks subsequently though both informed me that they never practically had a headache before the explosion. A man who has been only partially disabled by Carbonic Oxide or who has been only unconscious for a short time will usually recover completely in a few hours, but recovery is accompanied by very severe headache and often by nausea and vomiting, which are more severe according to the length of the exposure.

Dr Haldane*, in experiments made on himself, found that an exposure of several hours to as little as .07 % of Carbonic Oxide will cause not merely dizziness and shortness of breath on exertion at the time, but a headache afterwards lasting for about 12 hours, also he calculated that about 6 hours are required for the Carbonic Oxide to disappear entirely from the blood in severe cases of poisoning. In the case of one of the men rescued at Tylorstown, we examined the blood about 24 hours after his removal from the pit whilst still absolutely helpless and almost unconscious. No Carbonic Oxide could be detected with the spectroscope. He was found still alive beside the bodies of four other men who had died of Carbonic Oxide poisoning. The mistake may be made of attributing

* Journal of Physiology Vol. xvii Nos. 5.&.6. 1895.

what are really the after effects to the continued presence of Carbonic Oxide in the blood. Whenthe cases are more severe, recovery is very slow and uncertain and is accompanied by symptoms showing serious damage to the nervous system sustained during the deprivation of Oxygen and in one of the men recovered at Tylorstown about 12 hours from the time of the explosion after being in the pit all day, the breathing was shallow and irregular and he was unconscious for two days; the pulse was almost imperceptible. He had increased reflex excitability of the trunk and limbs and the least attempt to move the arms or legs gave rise to violent contraction of the muscles, so that it was almost impossible to carry on artificial respiration; but these symptoms are not peculiar to Carbonic Oxide poisoning as the same symptoms show themselves in poisoning by Sulphuretted Hydrogen and other gases.

It is of great practical importance that the presence of Carbonic Oxide in the air of mines should be capable of being recognised, as, undoubtedly, many lives have been lost on account of the fact that miners have trusted to their lamps (as they do in other gases) to indicate the presence of Carbonic Oxide, but with regard to this gas, the lamps which they use give no direct indication of the presence of Carbonic Oxide. It shows a "cap" on an ordinary flame if present in a higher proportion than 1 % like other explosive gases, but in after-damp it occurs in combination with such an excess of Nitrogen, that the lamp is extinguished before it can show a "cap". When more than 16 % of after-damp or about 0.5 % of Carbonic Oxide is present, it extinguishes a lamp; so that this will prevent a man going into an atmosphere which is rapidly poisonous from Carbonic Oxide, but a better test than this is required.

Carbonic Oxide is usually ascertained by reducing the blood and then examining it by the spectroscope in the following way. The blood is diluted with water in a test-tube until the two absorption bands (of Oxy- or Carboxy-haemoglobin) are most clearly visible. A drop or two of Ammonium Sulphide are now added and the solution slightly warmed. If the two bands are not now replaced in the usual way by the single band of reduced haemoglobin, Carbonic Oxide is present. This test is not a very delicate one for two reasons,

(1) The two bands of Carboxy-haemoglobin although they occupy nearly the same position as those of Oxy-haemoglobin are not nearly so well defined.

(2) The bands are in such a position that the luminous space between them becomes filled by the single absorption band of reduced haemoglobin when the latter is present, so that when the blood is less than about 40 % saturated with Carbonic Oxide, the test becomes useless since the double bands are no longer even dimly visible in the reduced blood. But there is a more direct and more delicate method of testing its presence, namely, by simply observing the colour of the diluted blood. Undiluted blood when saturated with Carbonic Oxide and examined in bulk cannot be distinguished by its colour alone, from blood saturated with air, after diluting it sufficiently, however, there is a striking difference The normal blood gives a yellow, and the Carbonic Oxide blood a pink colour. But Dr. Haldane has made use of this difference in tint to determine the relative satur-

The coloured strips are a representation of the tints actually observed.

A is a solution of normal blood; B of blood from body of No.12; C of normal blood saturated with Carbonic Oxide.

A.

B.

C

To be looked at by daylight.

ations of the haemoglobin with Carbonic Oxide in different specimens of blood, by determining the relative amount of their differences in tint from the tint of normal blood.

Dr. Haldane describes the process in a paper written on "The Action of Carbonic Oxide on Man."* as follows:-

"By mixing dilute carmine solution with dilute Oxy-haemoglobin solution it is possible to reproduce exactly the tint of dilute Carboxy-haemoglobin. Hence carmine solution may be employed for estimating the percentage saturation of blood with Carbonic Oxide If blood be diluted a hundred times and a portion of the solution be saturated with Carbonic Oxide, it requires somewhat more than an equal volume of carmine solution of about .01 % strength to bring the unsaturated portion to the same tint and intensity of colour as the saturated portion. The exact relation of the carmine solution to the blood solution requires of course to be determined by

* Journal of Physiology Vol. xviii.

trial and if necessary adjusted.

In applying this method to human blood, I employed narrow test-tubes similar to those of Gower's haemoglobinometer and each holding about 5 or 6 c.c. They were made from a piece of glass tubing of even bore and of about 3/16ths inch internal diameter. 2.0 c.c. of water having been measured from a narrow burette into one of the tubes, .02 c.c. of blood obtained by pricking the finger, was measured off in the pipette of a Gower's haemoglobinometer, and mixed with the water in the tube. A similar diluted solution of the blood was well shaken with Carbonic Oxide or more conveniently with coal gas and placed in another (shorter) tube, which was filled quite full and corked. This latter solution was prepared in a larger test-tube or small bottle, which was filled with coal gas through a tube, and quickly closed with the thumb, before the gas had time to escape.

Standard carmine was now added from a narrow burette to the blood under examination until the tint was the same as that of the saturated blood solution. When the tints became nearly equal, the carmine was added in quantities of not more than .2 c.c. at a time and the points were noted at which there was just appreciably too little, and just appreciably too much carmine, the mean between these points being taken as the correct result. The calculation of the percentage saturation is illustrated by the following example.

2.1 c.c. of carmine required to be added to every 2.0 c.c. of diluted normal blood to reproduce the saturation tint, with a specimen of partially saturated blood only 1.6 c.c. of carmine were required. In the latter specimen $\frac{2.1 - 1.6}{2.1} = \frac{.5}{2.1} = 24\ \%$ of the haemoglobin was combined with Carbonic Oxide."

In some of the samples of blood examined at the Tylorstown explosion, we noticed that the blood had to a certain extent lost its power of changing colour when saturated with Carbonic Oxide. The saturated solution had a slight yellowish tinge as compared with that of normal blood solution saturated in the same way. It was manifest that the haemoglobin had to a certain extent decomposed, forming a yellowish coloured derivative. This decomposition might be due to one of two things,

/e (1) Putrefactive changes, or

(2) The inhalation of Sulphurous Acid present in the after-damp.

So we examined the blood a couple of days afterwards when putrifaction was still further advanced, but the result was exactly the same so that it was most likely due to the presence of Sulphurous Acid.

The foregoing test is not, however, applicable on the spot, in the pit, on account of the bad light; there is however, another method by which the presence of Carbonic Oxide can be detected, and this method depends on the difference in the rate of exchange between air and blood in the lungs in various warm-blooded animals. Take for example a mouse and a man. The exchange between air and blood in the lungs of a mouse is 20 times as fast as in a man. Therefore it would be expected that a mouse would absorb a proportional amount of Carbonic Oxide about 20 times as rapidly as a man.

If a mouse is taken into an atmosphere of Carbonic Oxide, it will show symptoms of Carbonic Oxide poisoning and the mouse will be affected in about a twentieth of the time required to affect a man; so that the symptoms of the animal may be watched with safety for a few minutes.

The mouse may be carried in a small cage or a lamp chimney closed at the ends with wire gauze. When dangerous percentages of Carbonic Oxide are encountered, the mouse will begin to pant, and show signs of weakness in the legs. Should the mouse suddenly become unconscious, danger is imminent. This action of Carbonic Oxide on mice was shown to be of value in examining the different levels of the Snaefell Lead Mine, Isle of Man where an underground fire* took place in May 1897. When Dr. Le Neve Foster the inspector of mines having been wired for, brought a supply of mice with the object of employing them as indicators of the poison in case it should still be present, a mouse was put into an improvised receptacle and this was attached to the winding rope, whilst lighted candles were placed inside the kibble.

* Report on the Snaefell Lead Mine after an underground fire by C. Le Neve Foster, Esq., D.Sc., F.R.S. 1897.

By means of this, they found without any danger to themselves that the air was not bad as far as the 115 fathoms level and that it became poisonous at the 130 fathoms level. The mice showed precisely the same symptoms as human beings; for if not completely dead on arriving at the surface, they had lost all power in their legs, whilst pinkness in the snout recalled the pink lips of the dead bodies of the miners.

Death from Carbonic Oxide poisoning may be recognised from the fact that the colour of the blood after death is more or less red instead of blue. The bodies thus often present a very life-like appearance. The lips and tongue are pink and the skin has a life-like reddish appearance. These are the appearances that are always present in the case of men killed by an explosion in the South Wales Coalfield. I have myself been present at the examination of the bodies of men recovered after seven explosions and they invariably present the above appearances to a lesser or greater degree, and from inquiries I have made of other medical men who practise in this coalfield they all agree with the description I have given of their appearance.

With regard to the treatment of Carbonic Oxide poisoning, there is no doubt that if it can be used immediately, Oxygen is of great benefit in rapidly clearing the blood of the gas, but Oxygen is not usually at hand in the case of an explosion in a pit, and by the time a man has been brought to the surface Oxygen will be probably of little use. If the air contains afterdamp the men should be removed out of it at once. If the breathing is at all shallow, and irregular, artificial respiration should be employed until it becomes regular. In one case at Tylorstown artificial respiration was persisted in for over two hours, for as soon as it was stopped, the breathing became again shallow and irregular. If the pulse is weak stimulants should be given. I used hypodermic injections of ether to those cases I came across in going round the pit after the explosion and I found it to be of great benefit. The first effect of cool fresh air seems for some reason to be somewhat dangerous. We noticed this in some of the rescued men at the Albion colliery explosion at Pontypridd which occurred in 1894. For some of the men seemed to lose consciousness on being brought to the fresh air. Profiting by our experience at the Albion we had plenty of blankets and water bottles warmed at the colliery office, and these seemed to be of great service. The explanation of the bad effects of the current of cool air is not altogether clear. It may be that the cold in some way diminished the blood supply to the brain, or perhaps, there is impairment of the heat producing, or heat regulating function, and thus a reduction in the temperature of the body takes place.

It is very difficult to treat the men brought out alive from the pit after an explosion, in their own houses on account of the absence of skilful nursing. It is very important to watch the temperature as death from pneumonia is common. Burns and injuries should be specially looked after in order to promote rest.

<u>Sulphurous Acid.</u> This gas is sometimes present in after-damp and causes irritation of the eyes and air passages. According to Lehmann[#] as little as .001 %

[#] Archiv. fur Hygiene Vol.xviii (1893) p.180.

produces slight irritation of the respiratory passages. With .003 per cent the symptoms of irritation are very marked. Sulphurous Acid is thus an exceedingly poisonous gas, but the symptoms of irritation caused by it seem to occur long before there could be any danger to life. Its presence in after-damp therefore, affords a very valuable indication of danger. When Sulphurous Acid is breathed in poisonous proportion, it causes decomposition of the haemoglobin so that the two absorption bands shown by the spectroscope in dilute blood become finally much less visible than usual. As there might have been a possibility of poisonous proportions of Sulphurous Acid being present in the after-damp at Tylorstown, we carefully examined the blood for evidence of decomposition of the haemoglobin. Although the haemoglobin seems to have been slightly decomposed, it could not have contributed in any material way towards death.

<u>Carbon Dioxide and Nitrogen</u>:- The other two gases present in after-damp are Carbon Dioxide (Carbonic Acid) and Nitrogen.

Carbon Dioxide when present in great excess is a distinctly poisonous gas. It is sometimes stated that it only acts by merely diluting the Oxygen present, but this is a mistake. If Carbon Dioxide is mixed with air to the extent of 50 %, it causes rapid death whilst air mixed with an equal proportion of Nitrogen has very little effect, but there is never this proportion of Carbonic Acid gas in the atmosphere after an explosion, the proportion is always under 12 %. In breathing air containing increasing proportions of Carbon Dioxide, the first distinct effects are felt with about 3 or 4 %. The respirations become slightly deeper but nothing further is experienced. The respirations increase with the percentage, both in frequency and depth, until with about 5 % there is distinct panting. At the same time slight frontal headache may be felt which often increases for a short time when fresh air is again breathed. At 7 or 8 % the panting is very distressing, especially at first; and with 10 or 11 % the respiratory distress is extreme. With a little higher percentage consciousness is benumbed or entirely lost, although life may not be endangered, at least, not for many hours, judging from experiments on animals. The action of Carbon Dioxide on lights depends entirely on the reduction of the Oxygen percentage which accompanies the dilution of the air with Carbon Dioxide.

<u>Nitrogen</u>:- This gas has no specific action on men or animals. When added to air it acts indirectly by diminishing the Oxygen percentage. When Nitrogen is added to air so that the Oxygen percentage is reduced, very little may be felt before the senses become impaired, and loss of power over the limbs occurs. If the reduction takes place gradually, and if you watch carefully the symptoms, it will be noticed that at 12 % of Oxygen the respirations become faintly deeper. At 10 % the respirations are distinctly deeper and more frequent and the lips become slightly bluish. At 8 % the face begins to assume a leaden colour, though the distress is still not great. With 5 or 6 % there is distinct panting and it is accompanied by loss of power over the limbs and clouding of the senses which would probably end in death. Loss of consciousness is quickly succeeded by convulsions which are followed by cessation of the respiration. The heart still continues to beat, in the case

of cats and dogs, for from two to eight minutes; in man this period is probably longer for it seems to be a general rule that the larger an animal is, the longer it will resist asphyxiation. So long as the heart is beating, however feebly, animation may be restored by artificial respiration. This may be required to be continued for a considerable period, as the after effects of being deprived of Oxygen are very serious, and the respiratory centre may not recover for some time, After breathing has been established consciousness may not return for many hours, and careful treatment may be required to prevent death occurring at a later stage.

Smoke:- Some of the most disastrous accidents in mines have been due to the poisonous action of smoke from underground fires. Fires may occur from the spontaneous combustion of coal, iron pyrites, cotton waste &c., from the careless use of lights, from engines underground or as a result of gas explosion setting fire to brattice cloths, igniting blowers of gas; whatever be the cause the presence of an underground fire is extremely dangerous especially when it ignites the timbering. If the fire occurs on or spreads to an "intake" road, the ventilation current will carry the smoke over the mine, killing all who are unable to escape from it. If smoke has travelled some distance in a mine it appears to lose its pungent odour and deposit the suspended particles which ordinarily render it visible. This greatly increases the danger as there is then nothing to give warning of its presence. This occurred at the Snaefell accident in 1897, when a number of men descended into the shaft without their suspicions being in any way aroused until they had gone too far to be able to return.

The poisonous constituent of smoke is Carbonic Oxide This was clearly established in the case of the Snaefell accident, where the timbering had caught fire.⁜ A sample of the poisonous air was collected and examined and was found to contain 1.1 % of Carbonic Oxide, besides, the symptoms of the rescuers and the result of the examination of the bodies were the same as those noted at Tylorstown.

⁜ Report of the Snaefell Fire by Dr.C.Le Neve Foster.

Examination of the Bodies of the men killed at the Tylorstown Explosion:-

The bodies may be divided into two classes:-

(1) Those who had been killed by after-damp,

(2) Those who had been killed instantaneously by violence.

The first class comprises 52 cases (i.e. 91 % of the whole)

(1) Men killed by after-damp:- The external appearance of the men killed by after-damp varied very much. In 35 % of the cases there were no marks of burning or violence. In a number of the remaining cases, the face, hand, and other exposed parts of the skin, were more or less covered by a thin layer of adherent coal dust, so that in extreme cases, they appeared as if they had been charred. There was, however, no real charring of any part of the bodies, for when we rubbed off the coal dust, it was found that the skin was practically intact, except, that the outer layer of the epidermis was loosened and that there was congestion of the underlying dermis in many parts. This appearance of charring was evidently produced by a layer of coal-dust which had covered the

skin and had adhered firmly to it, during or immediately after the explosion. In some of the bodies this had been washed or rubbed off after death, when it could be seen that the marks of burning or scalding associated with the layer of dust were often distributed in blotches almost as if some hot liquid had been thrown in drops against the skin, and in many cases we noticed that the adherent coal-dust was only present on one side of the face or body and it is most probable that this side was the one which had been exposed to the blast of the explosion. The adherent dust taken from one of the bodies (No.48)* was microscopically examined and was found to consist of both rounded and angular particles, the latter greatly predominating. The outer layer of epidermis covering the backs of the hands in many cases was completely loosened, so that it could be peeled off in the same way as when a poultice has been applied for some time. We noticed that when pieces of the loosened epidermis were removed that the underlying skin on

* These numbers correspond to the numbers and descriptions at the end.

the back of the hands and fingers was as a rule quite white and free from congestion. It was only on the palms of the hands where the blood supply is normally more abundant, that a red colour could be seen. The most constant sign of burning was singeing of the hair, and whiskers. In some cases most of the hair was singed off. There was no lymph beneath the loosened epidermis, showing that it had not been separated by ordinary blistering. The superficial burning or scalding in some cases, seemed to be sufficient from its extent to have finally caused death, apart from the effects of the after-damp. Besides that associated with coal-dust, there was in some cases burning which had been caused by flame or heated air alone. This was indicated by singeing of the hair, congestion of the skin, and sometimes loosening of the epidermis in parts which had been most probably facing a blast of heated air or after-damp. We frequently saw that a layer of coal-dust covered the inside surface of the mouth and nose. So that it might be possible that some of the men might have been killed by suffocation from mechanical obstruction of the air passages, by dust. In no case, however, was death due to this cause. If that had been the case, the blood could not have had time to become highly saturated with Carbonic Oxide as was always the case when much dust was found in the mouth. We noticed no definite signs of scalding inside the mouth. Some of those who died from after-damp had received injuries, such as, bruises, fracture of the limbs or jaw, or skull, and dislocation. In one or two of the cases the fracture of the skull was evident and in others it was probable from the existence of oozing of blood from the ears. In two cases injuries of this kind would undoubtedly have caused death even if the men had survived the after-damp. In nearly every case of death from after-damp, the parts of the skin or mucous membrane through which the colour of the blood could be observed, had a red or pink colour, instead of being blue or pale, as is the case from any other cause. So that often this reddening seen in the face and hands gave the bodies an extraordinary appearance of life. In some cases the face was pale, so that the red colouring was not very evident. The pink or carmine colour was usually well marked on the lips, though they were sometimes also pale. It was often necessary to rub away the coal-dust from the inside of the lips in order to see the colour. It was often present, in irregular patches on the neck, chest, and shoulders and one or two red coloured veins could also sometimes be distinguished. The nails were pink, but where the epidermis could be peeled off the hands, we could distinguish best of all the characteristic colour. In these cases the skin of the back parts of the hands and fingers was usually pale, but on the palmar surface, the bright carmine red colour of the blood was very striking. A glance at this part was sufficient to determine the cause of death.

There seemed to be only one cause which could account for the carmine red colour of the blood, namely, Carbonic Oxide. To make sure, we examined the blood on the spot, with the spectroscope, in the first two houses which we visited. One of the bodies from which blood was taken, was singed, and much blackened by dust, whilst the other showed no signs of burning and had been found beside a lighted lamp. The blood was obtained by opening the external jugular vein, and was of a dark carmine-red colour. A drop was diluted with water until the two absorption bands came out sharply on examining the solution in a test tube. Ammonium Sulphide solution was then added to absorb the Oxygen present and the solution slightly warmed. The bands remained almost as sharp as before, which indicated not only that Carbonic Oxide was present, but that the haemoglobin was nearly saturated with it. We then determined the percentage saturation of the haemoglobin with Carbonic Oxide. The method employed was the colorimetric one, which has been described earlier. The haemoglobin was in both cases 79 % saturated. This result is of special interest as showing I believe for the first time, the percentage saturation of the blood at the moment of death from Carbonic Oxide poisoning.

It might be suspected that in some cases the red colour of the exposed surfaces, was produced after death by absorption of the Carbonic Oxide through the skin, or mucous membrane, and that death was due to other causes such as, burning or shock. The blood which we examined was taken from the jugular vein; this could not have been affected by post-mortem absorption of Carbonic Oxide and the colour was quite as marked in less exposed parts, such as the inside of the lips or the thickened epidermis on the front of the hands, as in more exposed parts, such as the skin of the face. One of the men had a bruise on the face which he received during the blast of the explosion, and there was a small swelling containing blood beneath the mucous membrane of the lips. This blood which had evidently been effused at once was dark blue, while the rest of the lip, through which the blood had circulated freely until death was carmine red. Had it been possible for Carbonic Oxide to diffuse itself through the skin or mucous membrane and been capable of reddening the underlying blood, the effused blood would have been red like that of the rest of the lip. Further evidence on this point was presented by the appearance of the bodies of men who had evidently been killed at once. In these cases the colour of the blood in the bodies was blue, whenever it could be distinguished (i.e. Nos.2,20, 56) as these bodies,all of which were burnt, more or less, must have lain in the very midst of the after-damp, it seems clear that there was no considerable absorption of Carbonic Oxide through the skin after death.

In two cases of suffocation (Nos. 19, 21) the appearances differed from what has just been described. The face and lips were of a reddish blue colour instead of bright red or pink. The veins on the front of the face, neck and upper part of the chest were distended and visible, a network of blue veins was particularly prominent on the upper part of the chest. The face was greatly congested. Death was probably due in these cases to acute suffocation brought about by complete or nearly complete absence of Oxygen in the air, combined with the presence of Carbonic Oxide or it may be, by the presence of such a large percentage of Carbonic Oxide that death occurred before the venous blood had time to become more than partially saturated with Carbonic Oxide.

In two cases (Nos. 38 & 42) there was no reddening of the blood. We examined a sample of the blood of one of the bodies (No.42) and there was no trace of Carbonic Oxide bands with the spectroscope. Nor was there any trace found on analysis. There were no marks of burns or violence which were sufficient to cause immediate death so that it seems probable that these men had died in fresh air some hours after the explosion without recovering consciousness, from the after effects of poisoning by Carbonic Oxide and that there had elapsed a sufficient time before death, for the blood to free itself from Carbonic Oxide. The body of one of these (No.38) was found about 10 hours after the explosion, close to a man who was still alive and who recovered under our treatment. Decomposition was far advanced in most of the bodies even within 48 hours of death. Decomposition seemed to have been greatly hastened by the fact of the bodies having lain for a day in the warm air of the pit.

(2) Men killed by violence:- In the five cases where death was instantaneous, the injuries inflicted gave evidence of great violence. In one case (No.2) there was dislocation of the spinal column, and one shoulder, and fracture of the skull and one arm. In No.20. there was fracture of both arms, dislocation of one hip joint, and fracture of the skull. In No.25 most of the skull and brain were smashed away. In No. 47, the head, legs and arms were torn from the body. In No.56, the mutilation was nearly as great.

From what has been written the question might be asked could not death have occurred from deficiency of Oxygen and not from the presence of Carbonic Oxide. At the Tylorstown explosion undoubtedly the cause of death was in nearly every case due to Carbonic Oxide and not want of Oxygen. When death occurs from absence of Oxygen in the air the appearances met with are marked blueness of the face, lips, tongue &c. with distention of the veins of the neck and part of the chest. If Carbonic Oxide is also present the blue colour is nevertheless not replaced by a distinct red. Death occurs before the venous blood has time to become saturated with Carbonic Oxide. Except Nos. 19 and 21, none of the bodies of men killed by after-damp at the Tylorstown explosion showed the appearances just mentioned. Hence it follows that Oxygen sufficient to support life must have been left in the airways all along the track of the explosion. One would have thought that as Carbonic Oxide was present in the after-damp all the Oxygen of the air must certainly have been used up and that men in the track of the explosion must be killed by the absence of Oxygen if not by other means. But there were other proofs that Oxygen was present immediately after the passage of the flame, for a small fire was discovered near the "face" in a part of the pit traversed by the explosion. This fire was caused by a small blower at the face being ignited by the explosion. At other places there was evidence of timber and brattice cloths having been burnt for a time after the explosion, and in one place a man's cap was found burnt.

THE SAVING OF LIFE AFTER A COLLIERY EXPLOSION.

First of all, with regard to the men imprisoned in the mine, at the face, or beyond the track of the explosion. The rush of air and coal dust driven towards them often extinguishes their lamps, they then try to make at once for the shaft along the ordinary "intake" haulage roads. The men soon meet the after-damp on the roads and drop. The best plan for those imprisoned would be to remain where they are, and if possible to put up curtains or anything convenient between themselves and the main roads in order to keep back the after-damp, and the best position for these curtains would be at a point beyond a door opened towards a return airway, so that when the ventilation was restored, the after-damp carried before it, should have a free passage into the return air-ways and not be driven in upon the men. Any attempt to get out should be done with caution and should after-damp be met, the only safe course is to retire before it, and, when a number of persons are endeavouring to get out, one man only should go on before the others, so that if he should fall the rest may bring him back into safety. It is often easier to reach the shaft by the return air-ways, than by the haulage roads. What may be done by being cool and collected was shown in the case of a fireman named Rodrick Williams who was alone in one of the districts of the Tylorstown colliery at the time of the explosion. He told me, that finding the ordinary road to the shaft blocked by after-damp, he returned before it and went round by the return air-way. Again meeting after-damp before reaching the shaft, he retired into some old workings, and waited for a couple of hours, after which he found that the after-damp had cleared sufficiently to enable him to pass through the doors into the main roadway, where he met the rescuers on their way in and helped them to explore the rest of the pit. He had escaped in two explosions before, in the same way.

The first thing that is thought of by those on the surface is getting the air into the pit. If the fan has been damaged or thrown out of action by injuries at the top of the upcast shaft, fresh air will at first pass down the upcast shaft freely in consequence of the suction produced by the heating of the sides and contained air in the downcast shaft, so that rescuers might possibly descend by the upcast shaft and even penetrate a considerable distance inwards, so that the work of restoring the doors &c. could be started upon at once, but this work would be greatly facilitated by using mice as indicators of the presence of after-damp, as much time might otherwise be consumed in helping disabled comrades or from uncertainty as to where the after-damp is situated.

For the revival of disabled men whether they have been burnt, and injured as well as poisoned, or not, the use of Oxygen cylinders would be of great service. Although in severe cases, it will not restore consciousness, the Oxygen will in a few minutes drive out most of the Carbonic Oxide from the blood and thus give a man the best chance of coming round.

It has bean proposed that airtight refuge chambers should be constructed with narrow and strong double doors At the face they might be of great service, 100 cubic feet of air would keep a man alive for 10 hours. A chamber 20 ft sq. by 6 ft high might thus preserve the lives of 24 men for 10 hours. It would be probably difficult in practice to make such refuge chambers even approximately airtight, and the trouble and expense would be great. What would even be better would be to provide at the working places, some apparatus for maintaining life in irrespirable atmpsphere and if electric lamps were also placed there for lighting parties of men on their way out. It would require about 4 cubic feet of Oxygen to keep a man alive for two hours while making his escape to the shaft, or for 6 hours, while remaining at rest. This volume of Oxygen can be compressed into a steel cylinder of the capacity of 1¾ pints. Then some apparatus would be required to economically breath this Oxygen. Compressed air would not be nearly so available as pure Oxygen since at least 10 times as much of it would be required. No respirator would be of any use against after-damp, as there is no known absorbent which could be practically applied to arrest Carbonic Oxide.

POST MORTEM APPEARANCES AND CAUSES OF DEATH OF THOSE KILLED AT TYLORSTOWN EXPLOSION.

No.	Description	Cause of Death.
1.	Engine driver, Body & hands burnt, Hair and Whiskers singed - - - - - - - - - - - -	Carbonic Oxide poisoning.
2.	Ostler. Back of head and right side of face covered with coal dust and singed. Lips and nails bluish,(not pink). Extensive scalp wound behind and probable fracture of skull, spinal column dislocated in dorsal region. Fracture of left humerus, and disloca- tion of right shoulder, (Found in stable beside a number of living horses, and a compan-	Violence.

No.	Description	Cause of Death
	ion who escaped. Injuries probably due to violent contact with the timbering of the stalls and to the kicking of the horses.)	
3.	Collier. Body pale, Lips, tongue, and nails pink. No burns or injuries.	Carbonic Oxide poisoning.
4.	Ostler. No injuries or burns Skin pale, Lips, tongue and nails pink.	Carbonic Oxide poisoning
5.	Collier, No burns or injuries. Nails pink. Lips &c. pale pink.	Carbonic Oxide poisoning.
6.	Collier. No burns or injuries. Skin pale. Lips, tongue and nails pale pink.	Carbonic Oxide poisoning.
7.	Collier. No burns or injuries Skin pale, Lips pale pink, tongue and nails pink	Carbonic Oxide poisoning.
8.	Collier. No burns or injuries Some patches of pink on chest. Lips carmine-red. Nails pink.	Carbonic Oxide poisoning
9.	Labourer, No burns or injuries Pink flush on chest and neck. Lips pink.	Carbonic Oxide poisoning.
10.	Collier. No burns or injuries. Skin pale. Lips tongue and nails pale pink.	Carbonic Oxide poisoning
11.	Labourer. No burns or injuries. Tongue and lips pink.	Carbonic Oxide poisoning
12.	Collier. No burns or injuries. Skin pale. Lips and tongue pink. Haemoglobin of blood	Carbonic Oxide poisoning

No.	Description	Cause of Death.
	from left external jugular vein found to be 79 % saturated with Carbonic Oxide.	
13.	Collier. No burns or injuries. Skin pale Lips, tongue and nails pink.	Carbonic Oxide poisoning.
14.	Labourer. No burns or injuries. Tongue, lips and nails pink.	Carbonic Oxide poisoning.
15.	Collier. Body covered with a layer of adherent coal dust, and scorched superficially Lower jaw fractured. Lips bright red.	Carbonic Oxide poisoning.
16.	Collier. Body covered with adherent coal dust and superficially scorched. Tongue and lips coated with coal dust Lips red beneath the dust.	Carbonic Oxide poisoning
17.	Fireman. Marks of superficial burns on face, forearm and hands. Superficial layer of epidermis on hand loosened. Under loosened epidermis carmine red colour seen very distinctly.	Carbonic Oxide poisoning.
18.	Ostler. Hair singed. Scalp wound Lips and nails pink.	Carbonic Oxide poisoning.
19.	Haulier. No burns or injuries. Face and neck much congested Lips reddish blue. Tongue protruded and bluish. A network	Carbonic Oxide poisoning, and deficiency of Oxygen.

Nos. 3, 11, 12, 13 & 14 found lying dead together with two lamps burning beside them.

No.	Description	Cause of Death.
	of distended reddish-blue veins prominent on upper part of chest (No.21, who was found in the same stable also presented these appearances, which might be caused either by poisoning with a higher percentage of Carbonic Oxide than was usually present or by asphyxiation from deficiency of Oxygen along with Carbonic Oxide poisoning.)	
20.	Labourer. Fracture of humerus in both arms. Dislocation of right hip joint. Bleeding from ear, and probably fracture of base of the skull. Hair and eyebrows singed. Nails &c. blue (not pink).	Violence
21.	Ostler. No burns or injuries. Marked cyanosis of face and chest. Face dusky red. Nails bluish pink. Network of distended reddish-blue veins on the upper part of the chest.	Carbonic Oxide poisoning, and want of Oxygen.
22.	Ostler. Face and hands somewhat scorched. No injury. Face pink all over.	Carbonic Oxide poisoning.
23.	Collier. Slight singeing of face, hair and whiskers. Lips pale pink.	Carbonic Oxide poisoning.
24.	Collier No injuries or burns. Face red. Nails pink.	Carbonic Oxide poisoning.
25.	Labourer. Brain and abdominal cavity exposed. Both legs and arms smashed. Body scorched, and clothes torn off.	Violence.

No.	Description	Cause of Death.
26.	Master Haulier. Face and hands scorched superficially. Face very pink. Pink colour also very marked under loosened epidermis of front of fingers.	Carbonic Oxide poisoning.
27.	Fireman. Hair singed. Superficial burn of face, which is brick red. Epidermis loosened over hands, and bright red colour visible under epidermis of front of fingers.	Carbonic Oxide poisoning
28.	Collier. Superficial burns of face, hands, chest and back. Pink inside lips, and where epidermis peeled off on front of fingers.	Carbonic Oxide poisoning.
29.	Haulier. Skin superficially scorched on exposed parts. Red colour visible beneath denuded epidermis. No injuries.	Carbonic Oxide poisoning.
30.	Collier. Hands and face superficially scorched,Hair and whiskers singed. Ecchymosis of blue colour of lower lip. Lips otherwise red. Bleeding from ear, and probably fracture of base of the skull.	Carbonic Oxide poisoning
31.	Collier. Hair singed. Epidermis of hands loosened. Lips pink Red flush on chest under epidermis on front of hands carmine red.	Carbonic Oxide poisoning.
32.	Collier. Superficial burns of face, forearms and hands. Hair	Carbonic Oxide poisoning.

No.	Description	Cause of Death.
	and eyebrows singed. Carmine red colour on lips and under epidermis on front of fingers.	
\# 33.	Labourer. Face pink, Lips pale. Teeth closed on tongue. Nails pink. No burns or injuries.	Carbonic Oxide poisoning.
34.	Labourer. No burns or injuries Skin pale, Lips and nails pale pink.	Carbonic Oxide poisoning.
35.	Collier. No burns or injuries. Pink flush on skin. Face life-like. Lips pink.	Carbonic Oxide poisoning.
36.	Haulier. Superficially scorched all over above legs. No injuries.	Carbonic Oxide poisoning.
37.	Fitter. Body superficially scorched above legs.	Carbonic Oxide poisoning.
38.	Haulier. Skin pale. Hardly any pink tinge visible anywhere. Blood seems only partially saturated with Carbonic Oxide, and had probably been partially freed by the action of fresh air before death.	Carbonic Oxide poisoning.
39.	Master Haulier. Face covered with caked coal-dust. Epidermis peeled off in parts. Parts of skin have colour of red sealing wax. Lips bright red. Teeth closed on tongue.	Carbonic Oxide poisoning.

\# Nos. 33, 34, 35 & 38 were found lying together about ten hours after the explosion along with a man who was still alive, and who recovered under treatment.

No.	Description	Cause of Death.
40.	Haulier. Superficial scorching of hand and face. Hair singed Face vermilion-red. Lips pink.	Carbonic Oxide poisoning.
41.	Labourer. Hands, face, body and legs superficially scorched. Hair singed. Face carmine-red colour.	Carbonic Oxide poisoning.
42.	Labourer. Scorched a good deal on right side of chest, face, and hands. Hair and eyebrows singed. No pink or red colour visible. No Carbonic Oxide found in sample of blood taken from external jugular vein. May probably have died in fresh air after blood had been freed of Carbonic Oxide.	Carbonic Oxide poisoning.
43.	Collier. Face and body covered with caked dust. Unrecognisable Found with no clothes and only one shoe on. Dislocation of left shoulder. Lips bright pink beneath the coal dust.	Carbonic Oxide poisoning.
44.	Haulier. Scorched all over superficially. Inside of mouth coated with coal dust. Hair and moustache singed. Red coloured vein visible on shoulder where protected from burning Face carmine red. Lips and tongue very pink beneath the dust. Nails pink. Haemoglobin of blood from external jugular vein found to be 79 per cent saturated. No injuries.	Carbonic Oxide poisoning

No.	Description	Cause of Death.
45.	Labourer. Scorched all over body and hands. Hair singed. Under loosened epidermis of front of fingers carmine red colour.	Carbonic Oxide poisoning.
46.	Collier. Superficially scorched over exposed partw. Hair singed. Epidermis of hands loosened, and on stripping off, carmine red colour visible on front of fingers. Face very red. Lips pink.	Carbonic Oxide poisoning.
47.	Rider. Upper part of skull and brain nearly all removed. Face and hands burned. Both arms fractured.	Violence.
48.	Ostler. Slight general scorching of exposed skin and hair. Pink patches on body. Lips and tongue pink.	Carbonic Oxide poisoning.
49.	Haulier. Hair singed and face superficially scorched, and bright sealing wax red colour in patches. Coal dust had been washed off. No injury.	Carbonic Oxide poisoning.
50.	Haulier. Skull fractured. Generally scorched on exposed parts. Hair singed. Lips red	Carbonic Oxide poisoning.
51.	Collier. Exposed parts of skin scorched. Hair and eyebrows singed. Inside of lips pink, also under epidermis of front of hands.	Carbonic Oxide poisoning.

No.	Description	Cause of Death.
52.	Collier. Face, hands and arms badly scorched on surface. Epidermis covered with coal dust Carmine red colour visible on front of fingers on peeling off epidermis.	Carbonic Oxide poisoning.
53.	Fireman. Superficially scorched over exposed parts. Pink inside lips, and under loosened epidermis on front of fingers	Carbonic Oxide poisoning.
54.	Collier. Skull fractured. Body scorched on exposed parts. Inside of mouth coated with coal dust. Wound of finger. Lips red beneath the dust.	Carbonic Oxide poisoning.
55.	Fireman. Covered with caked dust, and generally scorched. Inside of mouth bright red beneath the dust.	Carbonic Oxide poisoning.
56.	Fireman. Body much mutilated. Neck severed, chest covered with caked coal dust. Right leg fractured and twisted. Left leg torn off below the knee. Right shoulder torn away, also half of left arm. No red colour visible.	Violence.
57.	Fireman. Neck fractured. Severe injury of nose. Hair, chest and arms scorched. Lips bright pink Under epidermis of hands also bright pink. Body was found under a fall, and the fracture of neck &c. evidently occurred after death.	Carbonic Oxide poisoning.