THE GASES OF COAL MINES.

BY JOHN J. ATKINSON.

A variety of gases is given off by the coal and other mineral met with in coal mines; a futher supply of gases arise from the breathing of men and animals, and from the burning of candles and lamps, as well as from the explosion of the powder used for blasting the coal and stone in the mines. The whole of these gases are capable of causing the death of men and animals breathing them in their pure and undiluted state, and some of them require to be mixed with many times their own volume of air before the mixture they form with it can be breathed, for any great length of time, with safety.

Some of these gases given off in coal mines, when mixed with certain proportions of air, form violently explosive mixtures. Such a mixture of air and gas, on being ignited by a naked candle or other flame, suddenly explodes and becomes one mass of living flame, scorching and burning everything that may happen to be in contact with it. Such an explosion, in general, also creates a complete hurricane, or tornado, of immense force and violence, tearing mixing with and diluting the gases, render them harmless, and, in that state, carry them off as quickly as they are produced in the mines. It is here proposed, in the first instance, to remark upon the chemical composition of the air we breathe; then upon that of a few of the most important gases met with in coal mines, and afterwards to notice some of the leading principles of ventilation, by taking advantage of which we get rid of the gases as fast as they are given off in mines.

ATMOSPHERIC AIR.

Air is almost entirely a mixture of two gases, oxygen and nitrogen; carbonic acid is also present in limited but variable proportions, forming, on an average, about 1 part to 2,500 parts of our atmosphere. Besides *oxygen*, *nitrogen*, and a trace of *carbonic acid gas* in the atmosphere, there is always more or less of watery vapor diffused through the gases of which it is composed; but this vapor is variable in amount, is not considered as forming a constituent part of the atmosphere, and is, therefore, not embraced in statements as to the chemical composition of air; yet its effects are of the highest importance, both in the general economy of nature, and also in considerations relative to the ventilation of mines. Dry air is chemically composed of

	By Weight.	By Volume.
Nitrogen gas	77 per cent.	79 per cent.
Oxygen gas	23 "	21 "
	100 "	100 "

and driving all before it—knocking down the masonry erected for the guidance of the venilation, as well as the props and timber erected to support the roof of the mine, which falls in great masses, causing bodily injury or death to those it may fall upon, and often enclosing and imprisoning those who, being unhurt by its fall, are left stunned by the concussion, more or less scorched by the flames, and, without lights, shut up to breathe the deleterious atmosphere produced by the explosion. The flames of such an explosion being extinguished, and its violence exhausted, there remains an atmosphere so hot, and so charged with noxious gases and steam, as to cause the death of all who are left alive to inhale or breathe it. The resulting atmosphere is generally termed *after-damp*.

The grand object of the ventilation of mines is to cause such a current of air constantly to circulate through them as shall, by

A cubic foot of air at the temperature of melting ice (32°), and under pressure of 14.7 lbs. per square inch, or 2,116.8 lbs. per square foot, weighs 0.080728 lbs.; so that under the same conditions 1,000 cubic feet weigh 80.758 lbs. avoirdupois.

NITROGEN GAS.

Nitrogen gas is rather lighter than air taken in equal volumes, at the same temperature, and under the same pressure. The specific gravity of air being taken as 1,000, that of nitrogen gas is only 971.37, so that the weight of 1,000 cubic feet of air being 80.728 lbs., that of 1,000 cubic feet of nitrogen is only 78.416 lbs. at the temperature (320) of melting ice, and under the pressure of the atmosphere, taken at 14.7 lbs., per square inch, or 2,116.0 lbs. per square foot. A cubic foot of nitrogen, under the same conditions of temperature and pressure, weighs 0.074.167 lbs., and a cubic foot of air 0.080728 lbs., as heretofore stated.

Nitrogen gas has neither color, taste, nor smell, and so far as it is like air itself. It will not support life, but causes death when breathed. It will not support combustion, but extinguishes lights.

This gas has very little chemical affinity or attraction for other bodies; its chemical properties are rather those of indifference than of activity; its position amongst gases, in general, being almost like that of water amongst liquids, as it serves to render their properties less active. It dilutes the oxygen of the atmosphere, which could not long be breathed without being diluted with nitrogen. Nitrogen is, however, probably the best part of manures for land; and is a component part of nitrous oxide or laughing gas, of ammonia, and of nitric acid, or aquafortis, as well as of many other compounds.

OXYGEN GAS.

Oxygen gas, as has been stated, forms about 21 parts by volume, or 23 parts by weight out of every 100 parts of air, being rather more than one-fifth part. The specific gravity of air being taken as 1,000, that of oxygen gas is 1,105.63; 1,000 cubic feet of air, at 32°, and under a pressure of 14.7 lbs. per square inch, weigh 89.729 lbs.; 1,000 cubic feet of oxygen gas, under the same conditions, weigh 89,255 lbs.; so that this gas is rather heavier than an equal volume of air. Oxygen gas has neither color, taste, nor smell. In our atmosphere it is fitted to sustain life by dilution or mixture with nitrogen gas. Chemical compounds in the gaseous form may contain large proportions of oxygen and yet be unfit for respiration or breathing; to be suited for this purpose, the oxygen must be free and uncombined, and at the same time diluted.

Oxygen is the most abundant substance in nature, and constitutes at least one-third of the solid mass of the earth—23 per cent. of air, and 89 per cent. of water. Oxygen has strong affinities, and combines with all known substances, except *fluorine.* It forms with no other substances, no less than 136 inorganic compounds, and it would be difficult to say how many organic ones. This gas is the great supporter of combustion. Iron wire will burn in oxygen, but not in air; and this is also the case with other metals in finely divided state. When, by breathing, we inhale into our lungs, a part of the oxygen it contains combines with carbon, and we inhale or breathe out, as the result, an equal quantity, by volume, of carbonic acid gas, and consequently liberate about 3 16-21 times as great a volume of free nitrogen gas.

Having glanced at the chemical constitution of the atmosphere, let us next consider the principal gases met with in coal mining.

CARBONIC ACID GAS.

When this gas is met with in coal mines it is often called *stythe*, *choke-damp*, *or black-damp*. It is composed of oxygen and carbon. We have already considered the nature of oxygen as a component part of the atmosphere, but we must not expect to find it show the same properties when chemically combined either with carbon or any other substance whatever. Carbon, the other part of choke-damp, forms the chief ingredient in coal; and coke contains a still larger proportion of this substance; but the diamond is pure carbon, in a crystiline state. The chemical composition of carbonic acid gas is—

	By Atoms.	By Weight.	By Volume.
Oxygen	2	72.73 per cent	1
Carbon	1	27.27 "	1*
	1	100.00	1 condensed.

Now, although this gas contains nearly 3 parts out of 4, by weight, of oxygen (the life-supporting element), yet, because it is combined with another substance (carbon), the result is, in this case, a poisonous gas. It is dangerous to life to breathe air containing 8 per cent., or one-twelfth of this gas. Lights are extinguished in air containing 10 per cent., one-tenth of it. At 32°, under a pressure of 14.7 lbs. per square inch, 1,000 cubic feet of air weigh 80.728 lbs., and 1,000 cubic feet of carbonic acid gas weigh 123.353 lbs., so that it is rather more than 1½ times as heavy as an equal volume of air. The specific gravity of air being 1,000, that of carbonic acid gas is 1,528.01. Before being mixed with air it rests next to the "thrill," or floor, of mines, owing to its great heaviness or density when compared with air. This gas, besides being given off naturally into mines, is always found to result from the breathing of men and animals, the burning of candles and lamps, and mixed with other gases, from the explosion of the powder used in blasting. Near the mouth of an adit or drift, at Butterknowle colliery, in the county of Durham, the writer has seen several small birds lying dead from the effects of this gas. They had come to feed upon crumbs, where the workmen ate their

*Bunsen assumes that the hypothetical of carbon at one-half of that assumed here; but as he gives its density as double the value here given to it, the results are not altered.

meals, close to the mouth of this, an abandoned drift, and the gas coming out of the drift at the level of the ground had overcome them. At the colliery, in several places where the coal has been worked away, the ground has been rent up at the surface, and it is said that birds flying across the rents or pitfalls, in some instances, are so quickly effected by the escaping gas as to drop into the holes and die there. Without disputing the fact of dead birds being found in the holes, the reason assigned as the cause of their coming there seems to be rather doubtful. The effect of the gas is not, perhaps, so instantaneous as to account for it. Unfortunately, birds are not the only sufferers from this gas, for many human beings have met their deaths through breathing it; and in many other cases injurious effects are produced on the health of workmen through the mixture of this gas, in small proportions, with the air of mines.

Limestone consists of carbonic acid and lime, and chalk is of a similar composition; these ingredients, however, being generally mixed with oxide of iron, magnesia, and other substances in less but variable proportions.

PHOTO-CARBURETTED HYDROGEN GAS,

LIGHT CARBURRETTED HYDROGEN GAS, OR, AS IT IS SOMETIMES CALLED, MARSH GAS.

This gas is the fire-damp of mines. It contains one atom of carbon combined with two atoms of hydrogen, or some multiple of these. Taking the atomic volumes of carbon and hydrogen to be the same, it contains one volume of carbon combined with two volumes of hydrogen—in all three volumes—but the three volumes are condensed into one volume of fire-damp. The weight of air at the temperature of melting ice (32°) and 14.7 lbs. per square inch pressure, is, for 1,000 cubic feet, 80.728 lbs., that of 1,000 cubic feet of gas, under the same conditions, is 45.368 lbs., so that the specific gravity of this gas is 562*, that of air being 1,000, it being rather more than half as heavy as an equal volume of air under the same conditions. Owing to the fire-damp of mines being lighter than air, it lodges next the top or roof in mines, until by diffusion it gets quite mixed with the air. This gas would soon cause death if breathed in a pure and undiluted state; but when mixed with twice its own volume of air, it may be breathed for some time

*Professor Bunsen gives the specific gravity of marsh gas at .55314, that of air being 1.

without serious effects. It quickly extinguishes lamps or candles when unmixed with air. Fire-damp, or light carburetted hydrogen, contains nearly 25 per cent., by weight, of hydrogen. Hydrogen is the lightest known gas, being only one-fourteenth part of the weight of air. The hydrogen in fire-damp is, however, condensed into a smaller volume than it occupies in a free state. Light carburetted hydrogen gas is chemically composed of—

	By Atoms.	By Weight.	By Volume.
Hydrogen	2	24.6 per cent	2
Carbon	1	75.4 "	1
	1	100 "	1 condensed.

In the fire-damp of mines, however, we find a small proportion of other gases mixed with it. When 1 part of fire-damp is mixed with 30 parts of air, by volume, its presence can be detected by the appearance of the flame of a candle; and as the quantity of fire-damp is gradually increased from 1 up to 2 parts in 30 of the air, the appearance of the flame is more and more affected by it; but even in the latter proportion the mixture will not explode. The flame of the candle is surmounted by a pale blue halo, called in mining language a "top," or "cap," which partakes more or less of a brown color, according to the quantity of *stythe*, or carbonic acid gas, that may be present along with the fire-damp. The examination of the flame, for the purpose of forming a judgment as to the quantity of fire-damp mixed with the air, in mines, is, in mining dialect, called "*trying the candle*," or "*trying the lamp*." When the fire-damp forms as much as 1 part out of 13 of the air, the mixture becomes explosive, so that, if ignited by an exposed flame, the whole of the mixture is converted into a mass of flame; in this state of the mixture, however, the force of the explosion is comparatively feeble. When there is only 8 to 10 times as much air as fire damp, the explosive force is greatest. If the proportion of gas be greater than 1 part out of 9 to 10 of air, by volume, the force of explosion gradually becomes less and less, until there is only five times* as much air as gas, when the mixture will

* "Even when mixed with three, or nearly four times its bulk of air it burnt quietly in the atmosphere, and extinguished a taper." "When mixed with between 5 and 6 times its volume of air it exploded feebly." "It exploded with most energy when mixed with 7 or 8 times its volume of air, and mixtures of fire-damp, and air retained their explosive power when the proportions were 1 of gas to 14 of air. 1 of carbonic added to 7, or 1 of nitrogen added to 6 parts of explosive mixture rendered them inexplosive."—*From the Collected Works of Sir H. Davey, page 10, Vol. VI., 1840.*

no longer explode, but, on the contrary, will extinguish the flames of candles or lamps that may be brought into it.

The presence of carbonic acid gas, or of free nitrogen gas, in mixtures of fire-damp and air, is found to lessen their explosive force; so that if we add to the most explosive mixture one-seventh part of its volume of carbonic acid gas, it will not explode at all. Air containing one-fourth part of fire-damp, by volume, may be breathed for some time without very serious effects being produced on the animal frame. Common coal gas, as used for lighting, contains a large proportion of light carburetted hydrogen gas—the fire-damp of mines. Besides this, however, it contains a considerable proportion of pure hydrogen, some carbonic oxide, and olefiant gas.

When a mixture of air and fire-damp is exploded, the chemical changes that takes place, and the nature of the resulting mixture, or after-damp are as follows:

MIXTURE BEFORE EXPLOSION.

		By Atoms.			By Measure.		
		No. of Atoms.		Relative volume per Atom.	Uncombined Volume.	Combined Volume.	Volume per cent.
Air	Oxygen	4	x	1	4	18.8	90.385
	Nitrogen	7.4	x	2	14.8		
Fire-damp.	Carbon	1	x	2	2	2	9.615
	Hydrogen	2	x	2	4		
					24.8	20.8	100.000

MIXTURE AFTER EXPLOSION.

		By Atoms.			By Measure.		
		No. of Atoms.		Relative volume per Atom.	Uncombined Volume.	Combined Volume.	Volume per cent.
Free Nitrogen		7.4	x	2	14.8	14.8	71.2
Carbonic Acid Gas	Carbon	1	x	2	2	2	9 6
	Oxygen	2	x	1	2		
Steam	Hydrogen	2	x	2	4	4	19.2
	Oxygen	2	x	1	2		
					24.8	20.8	10.08

Before explosion, there may happen to be present either an excess of air or of fire-damp, beyond what is necessary to cause the explosion; and if so, they will remain mixed with the after-damp, in an unchanged state, after the explosion has taken place. There never can, however, be such an excess of air present as to render the after-damp fit to breathe, or the explosion could not take place; the limits are such that it is impossible. The above proportions of 1 of fire-damp to 9.4 of air form the most explosive mixture, all other proportions forming less explosive mixtures.

From the second table, we perceive that the after-damp contains between seven and eight times as much free nitrogen as carbonic acid gas, or choke-damp. It was at one time a popular mistake to suppose that the injurious part of the after-damp consisted only of carbonic acid gas, or choke-damp—not amongst scientific chemists, but amongst respectable mining authorities—and that, not very long ago. After-damp, it may be seen, by the second table, contains about 71 parts of free nitrogen, 9½ parts of carbonic acid gas, and, at the moment of explosion, 19 parts of steam; so that it may be said, at this stage, that after damp contains in round numbers, seven parts of nitrogen, one part of carbonic acid gas, and two parts of steam, out of a total of 10 parts. Directly after the explosion, a large part of the steam condenses, and leaves, as a residum, about 7½ parts of nitrogen, and one part of carbonic acid gas, out of eight and one-half parts; the whole unfit to breathe, and incapable of supporting either life or combustion. A small excess of air, or of fire-damp, might be left mixed with the after-damp of an explosion, beyond what is noticed in the tables as being chemically changed; but in no case could the air of the after-damp contain less than twice its own volume of deleterious gases, or the explosion could not have taken place; such a mixture, if breathed, would soon cause death. Since explosions can not always be prevented, how important it is, then, to be prepared to mix and dilute the after-damp with fresh air, in as speedy a manner as possible, after their occurrence. If there is more fire-damp present than is chemically changed by an explosion, the force of the explosion itself is lessened, but the after-damp resulting is more deadly than if an excess of air had been present at the time of the explosion.

CARBONIC OXIDE.

This gas is sometimes called white-damp, when met with in the mines. Assuming, as before, that the atomic volume of carbon is twice as great as that of oxygen, its composition is as follows:

	By Atoms.	By Weight.	By Volume.
Oxygen	1	56.69	½
Carbon	1	43.31	1
	1	100	1 condensed.

Its specific gravity is 975.195, that of air being assumed at 1,000; so that 1,000 cubic feet of air at 32°, and under a pressure of 14.7 lbs. per square inch, weighing 80,728 lbs., an equal volume of this gas under the same conditions will weigh 79,426 lbs., and one cubic foot under the same conditions will, therefore, have a weight of .079426 lbs.

Carbonic oxide has a much more deleterious effect on the animal economy than carbonic acid; air which contains only one per cent. of carbonic oxide almost immediately causes the death of warm-blooded animals, as has been shown by the decisive experiments of M. Felix Leblanc. Carbonic oxide is itself an inflammable gas, but does not support the combustion of other bodies. It has no tasse, but has a peculiar odor. Small animals immersed in it die instantly. When inhaled, it produces giddiness and fainting fits, even when mixed with a fourth of its bulk of air. It is easily kindled, and burns with a blue flame, being transformed into carbonic acid by the process. The carbonic acid formed by combustion at the bottom of a coal, coke, or charcoal fire is sometimes converted into carbonic oxide, by being deprived of a part of its oxygen, as it passes upwards through the red-hot embers; and, on coming into contact with the air, at the top of the fire, burns there with a blue flame, and is again converted into carbonic acid gas. This gas is, perhaps, never found in coal mines except as the result of the explosion of gunpowder, or the combustion of coal or wood. Carbonic oxide is obtainable in a state of purity by heating yellow ferro-cyanide of postassium with eight or ten times its weight of oil of vitriol. Bunsen obtained it by slightly heating a mixture of formic and sulphuric acids; and to ensure the perfect purity of the gas, he passed it through a concentrated solution of caustic potash. Such a proportion of this gas might be mixed with air as to form a mixture in which candles or lamps would burn, while life would become extinct; and it is probable that many deaths in mines have resulted from this gas, in situations where the lights have continued to burn.