A PRACTICAL TREATISE

ON THE

GASES MET WITH IN COAL MINES

AND THE

GENERAL PRINCIPLES OF VENTILATION.

BY THE LATE

J. J. ATKINSON,

GOVERNMENT INSPECTOR OF MINES FOR THE COUNTY OF DURHAM.

NEWCASTLE-UPON-TYNE:
ANDREW REID, PRINTING COURT BUILDINGS, AKENSIDE HILL.
LONDON:
LONGMANS, GREEN, LONGMANS, & CO.
1886.

NEWCASTLE-UPON-TYNE:
ANDREW REID, PRINTING COURT BUILDINGS, AKENSIDE HILL.

PREFACE.

THE Manchester Geological Society, before whom this valuable Treatise was read in the session of 1862, having kindly permitted its reprint, to assist the fund now being formed for the family of the late J. J. Atkinson, it is now offered to all who are interested in these, the most important questions of mining science, as the most thorough essay on the subjects of which it treats.

Starting with elementary principles and definitions, and with the aid of the most simple illustrations, the author has worked out the laws which govern the ventilation of our mines in a manner so clear and so convincing as to bring the subjects, hitherto deemed so difficult, within the easy comprehension of every educated miner. It is well known that the late J. J. Atkinson was an authority upon the most complicated questions of ventilation, the larger and more extended knowledge of this subject being due principally to his teaching, and, therefore, no one was better able to undertake such a work.

In commenting on the Treatise, the President of the Manchester Geological Society remarked:—

"I think those of you who were present at the last meeting will remember that Mr. Atkinson, in the opening of his first paper on this subject, said, that it might be useful for young colliery viewers, underlookers, and work-people who might wish to raise themselves; and there is no doubt it will be useful to those; but I think, if his modesty had not been so great, he might have said it would form the most useful book of reference that we have as yet published on the subject of the ventilation of mines. I know of no elementary treatise in which the subjects are so well brought forward, and so many tables given, which will be valuable not only to the beginner but to the viewer as a book of reference."

No further recommendation is needed of the merits of the treatise, but it may add to the success of the generous object which the author had in writing it, if it is known that of his many works for the advancement of the art of mining, this is the only one which can be made available for the benefit of his widow and family, from whom he has so suddenly been removed. The proceeds will go to the augmentation of the "Atkinson Memorial Fund."

ON THE

GASES MET WITH IN COAL MINES,

AND THE

GENERAL PRINCIPLES OF VENTILATION.

THE following remarks were written in the hope that some or other of them might prove of service in conveying to the merely practical miner a general knowledge of the laws and principles of ventilation, as applied to mines, and of the nature and properties, chemical and physical, of our atmosphere, as well as those of some of the gases most frequently encountered in coal mines. They were not intended to have been communicated to this or any similar institution, or they would, in all probability, not only have been put into somewhat different language, but would also have placed some of the matters to which they refer in a more purely scientific point of view. But, after all, such an alteration would, perhaps, have rendered them less useful than it is hoped they may prove to the particular class of persons for whom they were written, such as underviewers, overmen, deputy-overmen, and even workmen who may wish to fit themselves for assuming any of these offices; and, at the request of my colleague, your present President, I venture to submit them to your notice.

A variety of gases is given off by the coal and other minerals met with in coal mines; a further supply of gases arises 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 the 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 and driving all before it—knocking down the masonry erected for the guidance of the ventilation, 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. This 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 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 vapour diffused through the gases of which it is composed; but this vapour 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

A cubic foot of air at the temperature of melting ice (32°), and under pressure of 14·7 lbs. per square inch, or 2116·8 lbs. per square foot, weighs 0·080728 lbs.; so that under the same conditions 1,000 cubic feet weigh 80·728 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 (32°) of melting ice, and under the pressure of the atmosphere, taken at 14·7 lbs. per square inch, or 2116·8 lbs. per square foot. A cubic foot of nitrogen, under the same conditions of temperature and pressure, weighs 0·0784167 lbs., and a cubic foot of air 0·080728 lbs., as before stated.

Nitrogen gas has neither colour, taste, nor smell, and so far 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 it 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 1105·63; 1,000 cubic feet of air at 32°, and under a pressure of 14·7 lbs. per square inch, weigh 80·728 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 colour, taste, nor smell. This gas, in a free and uncombined state, is essential to life; we must breathe it in this state or die; in its undiluted state it is not fit to breathe beyond a very short time. 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 excepting *fluorine*. It forms, with 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. Substances that burn in air burn much more vividly in pure oxygen, showing that the oxygen in the air is the supporter of combustion. Iron wire will burn in oxygen, but not in air; and this is also the case with other metals in a finely divided state. When, by breathing, we inhale air into our lungs, a part of the oxygen it contains combines with carbon, and we exhale or breathe out, as the result, an equal quantity, by volume, of carbonic acid gas, and, consequently, liberate about $3\frac{16}{21}$ times as great a volume of free nitrogen gas.

Having glanced at the chemical constitution of the atmosphere, let us next consider that of 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 crystalline 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

---

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

of this gas. Lights are extinguished in air containing 10 per cent., or 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 $1\frac{1}{2}$ times as heavy as an equal volume of air. The special gravity of air being 1,000, that of carbonic acid gas is 1528·01. Before being mixed with air it rests next to the "thill," or floor of mines, owing to its great heaviness or density when compared with air. This gas, besides being given off naturally in many 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 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 same colliery, in several places where the coal has been worked away, the ground has been rent up to the surface, and it is said that birds flying across these rents or pitfalls, in some instances, are so quickly affected 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 appears 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.

PROTO-CARBURETTED HYDROGEN GAS,

LIGHT CARBURETTED 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 the 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 without serious effects. It quickly extinguishes

---

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

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 colour, 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 9 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 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 some olefiant gas.

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

---

* "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 acid added to 7, or 1 of nitrogen added to 6 parts of explosive mixture, rendered them inexplosive."—*From the Collected Works of Sir H. Davy, page* 10, *Vol. VI.*, 1840.

MIXTURE BEFORE EXPLOSION.

		By Atoms.			By Measure.	
		No. of Atoms.	Relative Volume per Atom.	Uncombined Volume.	Combined Volume.	Volume per cent.
Air	Oxygen ...	4	× 1	= 4	18·8	90·385
	Nitrogen...	7·4	× 2	= 14·8		
Fire-damp...	Carbon ...	1	× 2	= 2	2	9·615
	Hydrogen..	2	× 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	× 2	= 14·8	14·8	71·2
Carbonic Acid Gas	Carbon	1	× 2	= 2	2	9·6
	Oxygen	2	× 1	= 2		
Steam ...	Hydrogen	2	× 2	= 4	4	19·2
	Oxygen	2	× 1	= 2		
				24·8	20·8	100·0

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 this 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 residuum, 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 cannot 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 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 taste, but has a peculiar odour. 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 easy 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 in 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 ferrocyanide of potassium, 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 the gas in situations where the lights have continued to burn.

It appears to be very probable that the deaths of the men and boys in the late accident at Hartley Colliery arose in a great measure from this gas given off by the furnace, after the stoppage of the air-current by the closing of the shaft; inasmuch as the lights used by the workmen engaged in clearing the shaft appeared to be rather increased in brilliancy than otherwise at the time when the worst effects were felt from the escaping gas; and the mine gave off no fire-damp, and very little choke-damp.

At page 120, in the minutes of evidence taken before a select Committee of the House of Commons, on accidents in mines, in 1835, the late George Stephenson, in reply to question 1853, gives an account of an accident at Newbottle Colliery, by which several persons lost their lives by a gas in which the lights burnt well, and which the witness supposed to have been sulphuretted hydrogen gas; but it appears to be more probable that it was a mixture of carbonic oxide, sulphurous acid, and a small quantity of carbonic acid gases, generated by the explosion of gunpowder in the drift, where it was found to prevail;

because sulphuretted hydrogen gas has a particularly offensive smell of which no mention is made in the account of the accident.

The writer is acquainted with several instances where gases have caused deaths, and with others where they have caused severe indisposition, in places where candles continued to burn brightly; in some of these cases the gases were apparently produced by the explosion of gunpowder, and in others by the combustion of coals; and hence it appears to be probable that carbonic oxide was a prominent ingredient in them. In an experiment by M. Leblanc, a large-sized dog was asphyxiated in an atmosphere which contained 4 per cent. of carbonic acid, and only ½ per cent. of carbonic oxide.

HYDRO-SULPHURIC ACID, OR SULPHURETTED HYDROGEN.

This gas is sometimes met with in coal-mines. It is colourless, but distinguishable by its unpleasant smell, which resembles that of rotten eggs. It produces fainting fits and asphyxia, if inhaled, even when present only in very small proportions with atmospheric air. When inhaled in its pure state it acts as a powerful narcotic poison. It does not support combustion, but is itself inflammable, and burns when exposed to a supply of air and ignited; and, when mixed with oxygen gas, the mixture is explosive. It reddens tincture of litmus, but the reddening disappears on exposure to the air.

The composition of sulphuretted hydrogen is as follows:

	By Atoms.	By Weight.	By Volume.
Sulphur	1	94·15	1-6th
Hydrogen	1	5·85	1
	1	100	1

According to Bunsen the specific gravity of this gas is 1174·88; that of air being assumed at 1,000, under the same conditions as to temperature and pressure. Sulphur heated strongly and repeatedly sublimed in fire-damp freed from oxygen by phosphorus, produced a considerable enlargement of its volume, sulphuretted hydrogen was formed, and charcoal precipitated; the volume of sulphuretted hydrogen produced (ascertained by absorbing it by solution of potassa) was exactly double that of the fire-damp decomposed.

Sulphuretted hydrogen gas may be inflamed by charcoal or iron, even at a low red heat. In air it burns with a blue flame, forming water and sulphurous acid, and depositing sulphur. According to some authorities, 1-1500th part of this gas in air is instantly fatal to small birds, 1-1000th killed a middle-sized dog, and a horse died in an atmosphere that contained 1-250th part of its volume. The presence of sulphuretted hydrogen gas in the atmosphere, even in small proportions, can be detected by its action upon moist carbonate of lead, spread upon white paper, which it blackens. M. Parent Duchâtelet observed that workmen breathed with impunity in an atmosphere containing 1 per cent. of sulphuretted hydrogen, and he states that he himself respired air containing as much as 3 per cent. of the gas, without experiencing any serious results. This gas is formed whenever sulphur in a very comminuted form is brought into cantact with hydrogen in the act of being given off, and is probably formed, to some extent, where pyrites is undergoing decomposition in mines. When this gas is present with the air in mines, candles will burn in the mixture, so that if it is not detected by its odour it may prove fatal to life before its presence is detected.

It appears to be probable that this gas is frequently formed in old unventilated workings partly filled with water. There are two instances mentioned by Mr. Nicholas Wood, in his evidence before the Committee of the House of Commons on accidents in mines, in 1853—one at Hartley Colliery, which proved fatal to one person, and another at Tyne Main Colliery, where ill-effects where felt, notwithstanding that the lights burnt well; both of which in all likelihood were due to the generation of this gas from the action of the water upon pyrites in old workings.

A man breathes into his lungs about one-fifth of a cubic foot of air per minute, and converts about seven per cent. (by volume) of this into carbonic acid gas, which, with about three and three-quarter times as much free nitrogen, he exhales, along with about $66\frac{2}{3}$ per cent. of the air he breathes, in an unchanged state. The largest lamp used in mining converts less oxygen into carbonic acid gas than a workman. Both give off watery vapour as well as carbonic acid gas. When coal is on fire it gives off, in burning, carbonic acid, carbonic oxide, and sulphurous acid gases. The explosion of gunpowder gives rise to carbonic acid, nitrogen, carbonic oxide, and steam, besides carburetted and sulphuretted hydrogen in small proportions. In the ordinary course of mining these causes give rise to so small a quantity of gas, in proportion to the air, that they hardly belong to the subject in hand, unless in reference to the state of a confined and unventilated part of a mine, where a shot has been fired, or in the more rare case of coal being on fire in a mine.

Sir Humphrey Davy discovered that the flame of ignited gas would not pass through fine wire gauze containing 28 holes for each inch in length, or 784 holes per square inch, unless the gas is moved with great velocity against the gauze, or the gauze against the gas; and by enclosing the flame of an oil lamp in a cage made of this gauze we are able to carry a light into an explosive mixture of air and gas without setting the gas on fire on the outside of the gauze. By this means an explosion is avoided. If we find ourselves with a safety-lamp in an explosive atmosphere, we should only try to put out the flame by carefully drawing down the wick, and by no means try to blow it out, or we might blow the flame through the gauze and cause an explosion. An explosion might result from drawing the flame of the lamp through the gauze by means of a tobacco pipe; yet workmen are not unfrequently detected in this very daring and dangerous practice in mines. Outside-feeding or oil-tubes used to be attached to safety-lamps, but these are dangerous, as the flame might pass down the wick tube and up the oil tube, and so fire the gas on the outside of the lamp, if the oil plug was out or fitted badly, and the wick was small compared with the tube; but feeding tubes are not used now, at least in many districts. There are several sorts of safety-lamps now more or less used, which give more light than the Davy-lamp; glass being used in lieu of gauze opposite the flame. Glass is brittle and liable to crack from unequal expansion, and many persons do not think glass lamps so safe as the Davy in consequence. The late George Stephenson contrived a safety-lamp, having both glass and gauze around the flame, known as the Geordy, or Stephenson-lamp. The

Davy-lamp is perhaps the best known lamp for detecting the presence of a small mixture of fire-damp in the air of a mine.

Now, since fire-damp, choke-damp, and other gases are met with in more or less abundance in all coal mines, it becomes an important question as to how the bad, and often fatal, effects they are likely to produce if not properly dealt with may best be avoided. To this end it has sometimes been proposed to get them to combine chemically with some substance to be presented to them as they are given off; and only a short time ago, a Mr. Wall had a proposition of this kind before the public. So far; however, the best mode of dealing with them appears to be to dilute them with very large quantities of fresh air, and to sweep them out of the mine by an energetic ventilation as fast as they are given off or generated. After all, however, the natural laws and principles operating in the production of ventilation in mines have been less generally studied in England than on the Continent, and from this cause many mistakes have been made in the practice of ventilation in this country. New arrangements for the ventilation of mines have sometimes been made at great cost, and have not been found to answer when completed. In a few cases lives have been lost from this cause; in others an inferior arrangement and ventilation have been produced, where, by the application of these natural principles, a superior one might have been obtained at the same or even at a smaller cost. Many, if not all the members of this Society, are familiar with the details of the general practice of ventilation as pursued in this country. Instead, therefore, of considering this part of the subject, it is here proposed rather to direct attention to the natural laws and principles affecting the ventilation of mines.

NATURAL LAWS AND PRINCIPLES AFFECTING THE VENTILATION OF MINES.

As an introduction to the general laws and principles affecting the ventilation of mines, let us notice some of the general physical properties of air and gases. The world, on the surface of which we live, is a large globe, about 8,000 miles in diameter, and 25,000 miles in circumference. This great globe is surrounded by, and enclosed in, an atmosphere of air many miles in depth, so that the surface of the earth where we live is the bottom of a deep sea or ocean of air. Air is composed of the two gases, oxygen and nitrogen, in the proportions that have been named. Air and all gases have the following physical properties :—They are *impenetrable.* If any space be filled with air, no other material body can occupy the same space without first displacing the air, because no two material bodies can be in the same place at the same time. Two gases, or a gas and a vapour, may fill the same space (in a certain sense) by being mixed with each other, in the same manner that a sponge will hold water, but each gas or vapour must leave spaces vacant for the other to occupy or fill. Air and gases are possessed of the property called *inertia.* With respect to motion and rest, air, gases, and indeed all kinds of matter, are said to be *inert,* so that they will remain either at rest or in the same state of motion, until acted upon by some force or resistance. This property merely implies what may be termed a negative quality, of such a character as to have the effect of causing matter not to change its state, whether of motion or of rest, without some force or resistance being applied to it to cause it to do so. Owing to the property of *inertia,* a body will remain either at rest or in the same state of motion, both as to speed and direction, in spite of any forces or pressures that may be acting upon it, provided they are equal and opposite forces, so as to counterbalance each other This is the state of the atmosphere in a calm: there is always a pressure in every direction, up, down, sideways, diagonally, and in fact in every direction, in the air of the atmosphere. This pressure arises from the mere weight of the superincumbent air, and amounts generally to nearly one ton on each square foot, or 14 lbs. and upwards per square inch. If the pressure is lessened on one side, the ordinary pressure upon the opposite side drives the air towards the side where the pressure is reduced, and gives rise to a wind. If the pressure is increased on any side, the air is driven away to the opposite side, against the ordinary pressure. Air in motion cannot properly be said to have any more pressure or tension than the still air through which it moves. What would otherwise be extra pressure is really converted into motion in the air. Any excess of pressure really existing is simply that due to the friction which the air encounters in moving. This is a fact not always understood, and not always acknowledged, even in works pretending to treat the subject upon scientific principles. Force may be converted into mere motion without at all increasing the tension or spring of the air to which it applied; if it does increase the pressure on the air, it is only to the extent of the resistance encountered. Air in motion is called "wind;" and owing to its *inertia* it will only lessen its speed by meeting with frictional resistances, or by giving out its force to obstructions, such as the surface of the earth, houses, trees, wind-mills, and other objects; and in every case where power is taken out of the wind, it is done at the expense of lessening its velocity. If, for instance, we should make the wind passing through a mine drive a mill, we would thereby lessen the force and quantity of wind circulating in the mine, in a given time, if the pressure causing ventilation remained constant. Railway trains at high speed, even in a calm, meet with a large share of their resistance from the air—the trains lose force, and the air gains what they lose. Owing to the *inertia* of the air, birds meet with such a resisting medium in it as to give them a fulcrum or resting place for their wings, and enable them to fly. This property of *inertia* belongs alike to all material bodies, and may, in general terms, be called an *unwillingness to move, when at rest, or to change their speed or direction of motion when they are moving*, without a force or resistance being applied to cause them to do so. Air is *compressible.* Air is squeezed and contracted into less and less bulk as we increase the pressure upon it. If we double the pressure (without changing the temperature), the same air only fills one-half of the space; and if we treble the pressure, it only fills one-third of the space; and if we apply four times the pressure, it only fills one fourth of the space, and so on, provided that the heat or temperature of the air remains the same. This is called the law of Mariotte, or Boyle. The air at the surface of the earth is generally pressed by the whole of the air above it, to an extent measured by 29·922 inches of mercury (reckoned at the density due to melting ice, 93°), as shown by our common barometers; a pressure equal to 2116·4 lbs. per square foot. To give this pressure we should require the air of the atmosphere to be 26,216 feet high, if it was all as heavy as the air at the earth's surface. The fact is, however, that the air, as we go up, is pressed by less and less air above it, and owing to its elasticity or spring becomes lighter and lighter; so that instead of 26,216 feet, or nearly five miles high, the atmosphere is immensely higher. It gets so much thinner, rarer, or lighter, that at—

3½	miles above the surface	of the earth it is	2	times rarer.
7	"	"	4	"
14	"	"	16	"
21	"	"	64	"
28	"	"	256	"
35	"	"	1,024	"

And so on. If we carry a barometer up a hill, we have less and less air above us, and its pressure will, therefore, support less and less height of column of mercury, and hence the barometer falls. If we take it down into a mine we get a longer column of air above us, and it supports a longer column of mercury, so that the barometer rises. In ordinary states of the weather mercury is about 10,800 times as heavy as the same volume of air near the surface of the earth, and hence above 900 feet, or 150 fathoms, of ascent or descent, makes a change of one inch of mercury in the height of the barometer. This fact has been applied to measure the height of mountains by means of barometers, and it has sometimes been employed to estimate the friction of air in shafts. The difference between the height of the barometer at the top and the bottom of a pit 150 fathoms, or 300 yards in depth, is about one inch of mercury.

Air is *elastic;* it is a perfect spring, so that whatever force compresses it is an exact measure of the force it will spring out with, if we take away the compressing force.

The air, at the surface of the earth, is pressed at about 14·7 lbs. per square inch, and if we take half this pressure off it will swell out to twice its previous bulk; if we take away three-fourths of this pressure, and only leave one-fourth, the same air will swell out and fill four times the space it previously occupied, and so on. Whatever force or power is expended in compressing air into less bounds, will be given out as force or power by the same air, in swelling out to its former volume, when we take away the pressure so applied.

Air has *weight*, like all other material bodies. The weight of a vessel filled with air is greater than its weight when the air is pumped out of the vessel. A tall column of air, one foot square, and of the full height of the atmosphere, weighs nearly one ton. Another column of the same height, and one inch square, weighs rather more than fourteen pounds. The weight of the atmosphere enables it to support a column of water nearly 34 feet high, or one of mercury nearly thirty inches high; and this pressure acts equally in all directions—up, down, sideways, and in fact in every direction. The body of a man of average size is pressed by nearly thirteen tons weight from this cause.

The direction, speed, and force of the wind, depend upon the amount of the *difference* of pressure that gives rise to it, and in general has little or no connection with the *gross amount* of the pressure acting in the direction of the wind, because a large share of that pressure is counterbalanced by an equal pressure acting in the opposite direction.

In the open air, the velocity of the wind is the same as the velocity that a body would acquire by falling from the top to the bottom of such a column of air of equal density as by its weight would produce the same pressure as that which gives rise to the wind. For instance, if the state of the air as to the temperature and pressure is such that there is a pressure of 2,000 lbs. (which is nearly a ton) on each square foot in one direction, and only 1,999 lbs. per foot, or one pound per foot less, in the opposite direction, when 13 cubic feet of air weigh 1 lb., then the difference of pressure giving rise to the wind is equal to 1 lb. per square foot; and a column of air 1 foot in area and 13 feet high would weigh 1 lb. But a body falling through a height of 13 feet, under the force of gravity, would acquire a velocity of 8·02 times the square root of 13, or 28·9 feet per second; and this is, therefore, the velocity of a wind in the open air, due to a *pressure*, or rather to a *difference of pressure* of 1 lb. per square foot, when the total pressure of the atmosphere is nearly 2,000 lbs. per square foot, and 13 cubic feet of air weigh 1 lb. If we wish to find the velocity of such a wind in the open air as is due to a known difference of pressure on each square foot, we have first to find how many cubic feet of the air is equal in weight to the difference of pressure on a square foot which gives rise to the wind; and eight times the square root of this number is equal to the velocity of the wind in feet per second. In like manner, if we would find the pressure giving rise to a wind when we know its velocity, we must square the velocity in feet per second, and divide the result by sixty-four and one-third, and the quotient will be the height in feet of an air column giving rise to the wind; this height being divided by the number of cubic feet of air weighing one pound will give the difference of pressure in pounds per square foot giving rise to the velocity. This rule is merely the reverse of the former one. A difference of pressure of only one pound to the square foot, under the conditions before stated, gives rise to a wind in the open air, having a velocity of 28·8 feet per second, or more than nineteen miles per hour, which is nearly equal to the highest velocity of the air in the upcast shafts of coal mines.

In practice, in the ventilation of mines, it is found to be necessary to employ a very much higher pressure than one pound to the square foot in order to give rise to this velocity; it is, indeed, in many instances necessary to employ from ten to twenty pounds per square foot to do so, and this pressure is equal to the weight of an air column 130 to 260 feet high, instead of only 13 feet high as in the open air. It has been a very common mistake to consider that this difference shows a discrepancy between theory and practice. It shows no such thing. The true theory of any subject embraces in its grasp all the causes that operate, and can never fail to agree with practice—if it is really the true and complete theory. Theory, indeed, is a collection of general principles, gleaned or generalized from observation of the result of practical trials or experiments; and it is either a false or an incomplete theory that does not embrace the whole of the general principles involved in any phenomenon we may observe. It would be true, and therefore much more becoming, in such cases, to say that we do not understand the true theory, because the hypothesis or supposition we have adopted does not agree with what we notice to occur in practice; and this ought to set us to work to try to find out what is the true theory of the matter, because practice, when not guided by general principles, is mere guess-work or empiricism, so far as regards every case excepting only that in which the observation itself is made.

The reason of from ten to twenty times the amount of force or pressure that is required to generate any velocity in the open atmosphere, often being required to give rise to the same velocity in the air in mines, arises from the friction that air meets with by rubbing against the sides of the air-ways in passing through mines. Every square foot of surface exposed to the air travelling along the galleries of a mine is pressed by the air to the extent of about a ton of force or pressure, and it is therefore no wonder that extra pressure is required to overcome the friction arising from this immense pressure. If, for instance, we find that the last or final velocity of air escaping from a mine by an upcast shaft is such as to require a pressure of one pound per foot, or thirteen feet of air column, to give rise to it, on the supposition that there were no friction; and if, at the same time, we find that the actual pressure employed is ten times as much, or ten pounds per square foot, we learn from this that nine pounds out of the ten pounds per foot are required to overcome the friction of the air in rubbing against the sides of the air-ways, the other one pound per foot, or one-tenth of the whole pressure only, being required to give rise to the velocity; and this is no uncommon case in the practice of the ventilation of coal mines. Friction, then, arising from the air rubbing against the top, bottom, and sides of the air-ways in mines, is really the greatest obstacle to be overcome by the ventilating pressure or power, the force required to put the air into motion, apart from friction, being very small in comparison, at least in a large majority of cases, particularly in coal mines, which generally require a much more energetic ventilation than is necessary for the salubrity of metallic mines.

To show the comparative amounts of pressure expended upon creating velocity in the air, and upon overcoming the frictional resistance it meets with in mines, respectively, the following cases are cited, the pressures due to velocities being those due to the final velocities at the tops of the upcast shafts.

	Pressure in Air Column due to Velocity.	Pressure in Air Column due to Friction.	Total Pressure Employed.	Proportion due to Velocity and Friction respectively.
	Feet.	Feet.	Feet.	
Hetton Colliery, 1st case	10·43	179·88	190·31	1 : 18
Do. Do. 2nd case......	12·37	212·63	225·00	1 : 17
Haswell Colliery	13·84	140·66	154·50	1 : 10
Tyne Main Do.	25·70	177·50	203·20	1 : 7

From this it will be seen that out of a total pressure of nineteen, at Hetton Colliery, no less than eighteen were employed on friction, and only one upon the velocity of the air.

At Haswell Colliery, ten parts out of eleven of the ventilating pressure were spent upon the friction of the air, and only one part out of eleven upon creating its final velocity at the top of the upcast shaft.

At Tyne Main Colliery, seven parts out of eight of the ventilating pressure were spent upon friction, and only one part in eight upon the velocity of the air at the top of the upcast shaft.

From these examples it will be perceived that the amount of ventilation in mines, and, therefore, the safety, health, and comfort of the workmen employed in them, depend almost entirely upon the amount of friction that the air meets with, under any mode of ventilation we may employ; and hence, the great importance of understanding the general laws and principles upon which the friction of air in mines depends, so that we may know how to reduce such friction to its lowest possible amount, and by this means obtain the greatest quantity of air, from any ventilating power we may employ.

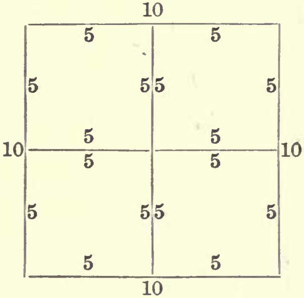
ON THE

FRICTION OF AIR IN MINES.

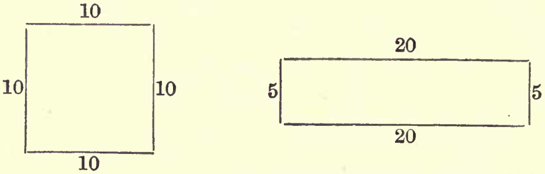
THE amount of friction is reckoned or estimated by the amount of the pressure or force required to overcome it. Numerous experiments have been made to find out the laws that govern the friction of air and gases, both in pipes having an uniform section, and, to a less extent, in the irregular air-ways of mines. By these experiments, the following laws have been found to hold good in practice.

The pressure required to overcome the friction of air increases and decreases in exactly the same proportion that the area or extent of the rubbing surface, exposed to the air, increases or decreases; so that when the velocity of the air, and the sectional area of the air-way, remain the same, the pressure required to overcome the friction is proportional to the area or extent of the rubbing surface exposed to it; and hence, if we double or treble the extent of the rubbing surface, we also double or treble the friction, or, what is the same, the force or pressure required to overcome it. The rubbing surface, of course, depends upon the circumference or perimeter of the air-way, and upon its length. The rubbing surface is found by multiplying the perimeter by the length of the air-way, where it has an uniform section. A circular pipe or air-way offers less rubbing surface, for the same length, than any other form or shape of air-way of equal sectional area; because the circumference of a circle is less, in proportion to its area, than the perimeter of any other figure is to its area. A circle whose area is 1 has a circumference of 3·545, or rather more than $3\frac{1}{2}$;—the perimeter of a square is 4, when its area is 1; so that about 7 yards of square pipe would offer the same resistance as 8 yards of round pipe, having an equal size or area of section, when the same quantity of air passes through them in a given time.

It is true that the friction of air or gas, in passing through the same pipe or air-way, varies in just the same degree that the density of the air or gas may vary; but in air-ways in coal-mines the air has always nearly one and the same density, and it is only in particular calculations that it becomes requisite to notice its changes of density, in reference at least to this part of the general subject, since they are so small in amount. This is the case as regards friction, but the effects of variations in the density of the air circulating in mines are more sensible in producing pressure, operating either in favour of, or against the ventilating pressure, in rise or dip workings; but these effects belong more especially to another part of the subject. In an air-way 5 feet square, the perimeter of the section is $4 \times 5 = 20$ feet; and if it is 1,000 long, the rubbing surface is $20 \times 1{,}000 = 20{,}000$ square feet. In an air-way 10 feet square, the perimeter of the section is $4 \times 10 = 40$ feet; and if it was 1,000 long, the rubbing surface would be $40 \times 1{,}000 = 40{,}000$ feet; so that on comparing the two cases it will be apparent that for four times the area there is only two times the extent of rubbing surface. If such an air-way as that last mentioned (10 feet square, and having a rubbing surface of 40,000 square feet for every 1,000 feet in length)

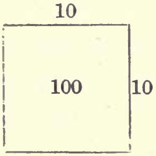


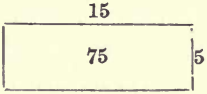
were divided into four equal-sized square air-ways, the rubbing surface exposed to the moving air would be exactly double by the division; and there would be 20 feet of perimeter for each of the four air-ways, or 80 feet on the whole; so that for a length of 1,000 feet, the rubbing surface for the four small air-ways would be 80,000 square feet; or, exactly twice as great as that for the one large air-way, although the united areas of the smaller air-ways would be exactly equal to that of a single large one. In one case there would be a single air-way 100 feet in area; and in the other four smaller air-ways, each 25 feet area; but the rubbing surface, and therefore the friction and the pressure required to overcome it for the same gross quantity of air, would be twice as great in the four small as in the one large air-way having the same area. And from this fact we learn that one large air-way is preferable to a number of smaller ones, even if they together make up the same sectional area or size. In practice it often happens, however, that a number of small air-ways can be made and maintained at a less cost than one large air-way, presenting an equal sectional area; and, in such cases, a few extra air-ways of small area may more than compensate in utility, and make up in cost for the absence of one extra-sized air-way; and hence the futility of insisting upon the sectional area of air-ways in mines being of any particular amount, without specifying their number, beyond requiring that one at least in each split be large enough to admit of persons travelling in it. The same principle may be illustrated by taking two air-ways of equal size or sectional area, but having different forms or shapes of section; supposing one of them to be 10 feet high and 10 feet wide, its size or area of section would be 10 × 10 = 100 feet; and supposing the other air-way to be 20 feet wide, but only 5 feet high, the area would be the same (or 5 × 20) 100 feet.



The air-way 10 feet square would have a perimeter of section 4 × 10 = 40 feet, while the other would have a perimeter of (20 + 20 + 5 + 5) 50 feet, compared with only 40 in the former; so that for equal lengths the friction of the air would only be 40 in the square air-way, compared with 50 in the oblong one; and the friction in 50 yards of length, in the square-shaped air-way, would be no more than that in 40 yards of length in the oblong one for the same quantity of air. Since the air in a mine presses with nearly the same force upon every square foot, it is quite natural that the frictional resistance should be greater or less in amount, to the same extent that the rubbing surface or number of square feet exposed to the air is greater or less; and this is the general law or principle that has just been stated and illustrated by examples.

The pressures employed to ventilate mines are commonly reckoned at so much per square foot of area, and not by the entire pressure employed, which is equal to the number of square feet multiplied by the pressure on each square foot of sectional area in the shaft or air-way. For instance, a ventilating pressure of 10 lbs. to the square foot on an air-way 100 feet in area is equal, on the whole, to 10 × 100 = 1,000 lbs. If the same pressure of 10 lbs. per foot is applied to an air-way of only 50 feet area the total pressure is only 10 × 50 = 500 lbs.; owing to the area being one-half, the total or gross pressure is also only one-half. In order to get the same total pressure, we must make the pressure per foot greater in the same proportion that the area is less, when the rubbing surface and *velocity* of the air are to be the same in two cases. If we reckoned ventilating pressure by its total amount we would not require to notice this law, it is so self-evident; and it is only because we speak and treat of it as so much pressure per *square foot* that we require to consider the number of square feet to which it is applied. If there were two air-ways, one just twice the area of the other, the *velocity of the air* and *the extent of rubbing surface* being the same in each, then we must apply twice the pressure, to each square foot of the small one, that is required by the larger one, to overcome the equal amount of friction in the two air-ways, the quantity of air passing in the smaller one being just one-half of that in the larger. As an example, if we had an air-way 10 feet by 10 feet the area would be 100 feet, and the perimeter of section 40 feet; and another air-way 5 feet high by 15 feet wide, the area would be 75 square feet, or just $\frac{3}{4}$ of the area of the former; the perimeter of section would





be, however, exactly 40 feet in both air-ways. In the larger air-way we would only require to employ 3-4ths of the pressure on each foot of surface (that is to say 3-4ths of the water gauge) that we would require to employ on each foot of the smaller area, so as to make up the same total ventilating pressure—the rubbing surface for an equal length of air-way being the same in the two cases, because the perimeter of their sections are equal, and the velocity of the air being taken as the same in the two cases, the quantities of air per minute would be simply proportional to their respective areas under these circumstances.

This second law relating to the friction of air in mines need not have been noticed at all if we had reckoned ventilating pressure as a whole: but as we generally speak of it as so many pounds per foot, we must also take into account, as has previously been remarked, the number of square feet to which it is applied, that is, the area of the section of the air-way, in the same manner that the area in inches of the cylinder or piston of a steam engine multiplied by the pressure on each square inch gives the total force applied to the piston. An inch of water column, as shown by a water-gauge, represents a pressure of about 5·2 lbs. per square foot.

The third general law relating to the friction of air in mines is, that the pressure required to overcome the friction in the same air-ways, *varies* (that is to say, increases or decreases) in the same proportions that the *square* of the velocity of the air increases or decreases; so that a double velocity of air, in the same air-way, meets with a *double double*, or fourfold resistance; a treble velocity meets with a *treble treble*, or ninefold resistance; and a velocity of four times as great gives rise to a resistance four times four, or sixteen times as great. In the same way a half velocity meets with one-half of a half, or 1-4th of the resistance; 1-3rd of the velocity encounters only a third part of a third, or 1-9th of the friction, and so on.

The third law of friction, at first sight, looks rather complex. Consideration, however, shows it to be quite natural, because, if we double the velocity of the air in the same air-way, we in the first place cause twice the quantity of air to meet the resistance in a given time; and, in addition to this, every part of this double quantity meets every resistance with a double velocity or momentum; the double quantity of air, and the double velocity taken together, may well be supposed to give rise to a *double double*, or fourfold resistance; and this is the true law. Again, if we treble the velocity of the air, we thereby cause three times the number of particles to meet the resistances in each moment of time, and this alone should treble the resistances; but, in addition to this, the treble quantity meets the resistances with three times the speed or momentum, which *trebles the threefold* resistance that arises from the threefold number of particles of air that meets the resistances each moment of time; on the whole, making a ninefold resistance for a threefold quantity of air in a given time.

The laws of ventilation would be very simple, quite as simple, indeed, as they are natural, were it not that, in lieu of the mere quantity of air circulating in a given time, or the mere velocity of the air, we must make use of the square of the quantity, or, what is the same, the square of the velocity in our calculations; and, as a matter of course, in calculations for comparative results, if we employ the squares of the quantities or velocities, we must expect, as results, not the quantities or the velocities simply, but their squares;

and, therefore, it will be necessary to extract the square roots of the results so obtained in order to get at the simple quantities themselves.

It has already been stated, that there is one other principle bearing on the friction of air passing through mines, to the effect that it is greater or less in the same proportion that the density or weight of each cubic foot of air is greater or less; so that if each cubic foot of air had a double weight it would have a double amount of friction; or, if it had only half the weight it would have only half the amount of friction in the same air-way, when the velocity or the number of cubic feet per minute is the same; but the variations in the density of the air in mines are so very small, compared with the whole density, that the effects of this law on the amount of ventilation are very small—so small, indeed, as to be practically unfelt, at any rate as an increase or reduction of friction in the moving air; even in an upright or vertical shaft the density of the air would only be altered on the average by about 1-60th part of its amount, compared with a level air-way, supposing the shaft to be 150 fathoms deep, so far as the pressure of the atmosphere is concerned. The changes of density arising from the heat of upcast shafts, in expanding the air, have a greater effect, so far as such shafts alone are concerned, under furnace ventilation; but this does not affect the friction of the air in the workings of the mine; and, even in these shafts, the lessened density, arising from expansion by heat, has its effects on reducing the shaft friction greatly modified, by the greater velocity due to the increase in the volume of the air; this increased velocity does more than make up, by the accompanying increase of friction, for any reduction in such friction that is due to the lessened density of the air in every case; the friction, in fact, increases or decreases in just the same proportion that the volume of a given weight of air increases or decreases, whether the change of density arises from change of temperature or from change of pressure. Supposing the temperature of the air in a mine to be 60° in winter, and 65° in summer, on the average, such a change would only alter the friction in such mine by about 1-104th of its amount. In summer the friction would be 1-104th greater than in winter for the same weight of air, but it would, at the same time, be about 1-104th part less for the same volume of air, an alteration hardly worth notice for the present purpose. The total friction or the total pressure due to the friction of air rubbing against the top, bottom, and sides of the air-ways of mines is not very well ascertained; all the experiments, at least all that have come under my notice as having been made for the purpose, have been in some respects of a rude character, the necessary particulars not being given in the accounts published to fix with rigid accuracy its amount.

For the best accounts of such trials, it seems probable that for every foot of rubbing surface, and for a velocity in the air of 1,000 feet per minute, the friction is equal to 0·26881 feet of air column of the same density as the flowing air, which is equal to a pressure, with air at 32°, of 0·0217 lbs. per square foot of area of section; calling this the *co-efficient of friction*, we have the following rules with respect to the friction of air in mines:—

Total pressure	$pa = ksv^2$	(1)
Rubbing surface	$s = \frac{pa}{kv^2}$	(2)
Velocity squared	$v^2 = \frac{pa}{ks}$	(3)
Co-efficient of friction	$k = \frac{pa}{sv^2}$	(4)
Pressure per foot	$p = \frac{ksv^2}{a}$	(5)
Area of section	$a = \frac{ksv^2}{p}$	(6)

Where p = pressure per sq. foot.
a = sq. feet of sectional area.
s = the area of rubbing surface exposed to the air.
v = the velocity of the air in thousands of feet per minute—1,000 ft. per minute being taken as the unit of velocity.
k = the co-efficient of friction in the same terms or unit as p is taken in.

Putting these formulæ into words, we have the following set of rules:—

(1.) *To find the total pressure* due to friction.*—Multiply the co-efficient of friction by the extent of the rubbing surface, and the product by the square of the velocity in thousands of feet per minute; that is to say, by the square of the quotient resulting from dividing the velocity in feet per minute by 1,000.

(2.) *To find the rubbing surface.*—Divide the total pressure by the product of the co-efficient of friction, and the square of the velocity in thousands of feet per minute.

(3.) *To find the velocity.*—Divide the total pressure by the product of the co-efficient of friction, and the rubbing surface—this gives the square of the velocity—the square root of which is the velocity itself, in thousands of feet per minute; this multiplied by 1,000 will give the velocity in feet per minute.

(4.) *To find the co-efficient of friction from experiments.*—Divide the total pressure by the rubbing surface, and the

---

* The *total pressure*, in these rules, is found by multiplying the sectional area of the air-way, in feet, by the pressure per square foot.

square of the velocity (in thousands of feet per minute) multiplied together.

(5.) *To find the pressure on each foot of section.*—Multiply the co-efficient of friction, the rubbing surface, and the square of the velocity (in thousands of feet per minute) all into each other, and divide the product by the area of the section.

(6.) *To find the area of the section.*—Multiply the co-efficient of friction, the rubbing surface, and the square of the velocity (in thousands of feet per minute) all into each other, and divide by the pressure on each foot of sectional area.*

The foregoing rules embrace only the pressure due to friction, and not that due to the creation of velocity, so that they may be regarded as being true of long pipes and air-ways, as they are given, but as requiring an allowance for the pressure due to the velocity in short pipes and air-ways. This allowance renders the rules much less simple.

Now these rules, which are found out by practical trials or experiments, lead us to many very important conclusions in reference to the best mode of conducting the ventilation of mines; in proof of which, it would be easy to multiply examples.

These laws of friction may be illustrated by the following examples:—

In an air-way 10 feet square = 100 feet area, and 25,000 feet, or nearly five miles long—if the volocity of the

---

* If it is preferred to employ in these rules the velocity in feet per minute, in lieu of in *thousands* of feet per minute, the co-efficient of friction, in lieu of ·26881 would become ·00000026881; and if the velocity is taken in feet per second it would become ·000967716.

air were 1 foot per second, or 60 feet per minute, the quantity of air would be 6,000 feet per minute—the pressure due to friction (taking the pressure at 14·7 lbs. per square inch, and the temperature at 32°) would be ·7812 lbs. per square foot of sectional area of the air-way, the horse power being ·142.

In another air-way of equal length, but instead of being 10 feet square only five feet square, giving only 25 feet, or 1-4th of the area of the larger air-way, we have the following results:—The rubbing surface in the small air-way would only be one-half of that in the large one; but, on the other hand, the area to which the ventilating pressure would apply would only be 1-4th; and at the same time the velocity of an equal volume of air would be increased fourfold in the lesser air-way, this increase of velocity alone making sixteen times the friction, so that on the whole it would be thirty-two times as great; making the pressure on each square foot 24·998 lbs., being thirty-two times as great as in the large air-way. And, therefore, on the whole the *power* expended would be also thirty-two times as great—in the small as in the large air-way, for the same amount of ventilation per minute: the coals consumed would also be thirty-two times as great. If furnace ventilation were used, and the heat of the upcast shaft and pressure per foot were the same, instead of 6,000 cubic feet per minute, as in the large air-way, we should only have 1,061 feet in the smaller one; but in this case the coals burnt would only be $\frac{1}{\sqrt{32}}$, or between 1-5th and 1-6th of the former quantity, and the power would be less in the same proportion for the lesser quantity of air. This shows in a striking manner the great advantage of large air-ways.

The calculations relative to the two cases, compared with each other for the example just given, stand thus:—

FOR THE LARGE AIR-WAY.

The length is 25,000 feet, and the perimeter of section is 4 × 10 = 40 feet; so that the rubbing surface

$s = 40 \times 25000 = 1000000$ square feet,

the area $a = 10 \times 10 = 100$ square feet,

the velocity $v = \frac{60}{1000} = \cdot06$ in thousands of feet per min.

and $k = \cdot26881$, being the co-efficient of resistance in feet of air-column of the same density as the flowing air.

Now by formula (5) we have

$$p = \frac{ksv^2}{a}$$

giving in this case

$$p = \frac{\cdot26881 \times 1000000 \times (\cdot06 \times \cdot06)}{100} = 9\cdot67716$$

feet of air-column as the pressure required.

Taking the flowing air to have had the density due to a temperature of 32°, and to a pressure of 14·7 lbs. per square inch, a cubic foot of it would weigh ·080728 lbs., and, therefore, such a column would represent a pressure

$9\cdot67716 \times \cdot080728 = \cdot7812$ lbs. per square foot;

and hence the horse power due to the friction of 6,000 cubic feet of air per minute, in passing through such an air-way would be

$$\frac{6000 \times \cdot7812}{33000} = \cdot142, \text{ or about 1-7th of a horse power.}$$

FOR THE SMALL AIR-WAY.

Proceeding as in the former case, we have

$$\frac{\cdot26881 \times (20 \times 25000) \times (\cdot24 \times \cdot24)}{25} = 309\cdot66912$$

feet of air-column, as the pressure required for putting the same quantity of air, 6000 cubic feet per minute, into circulation; being equal to a pressure of

$309{\cdot}66912 \times {\cdot}080728 = 24{\cdot}9989$ lbs. per sq. ft.; giving

$$\frac{6000 \times 24{\cdot}9989}{33000} = 4{\cdot}545 \text{ horse power.}$$

If the *pressure per square foot* was the same in the small as in the large air-way, or ·7812 lbs. per square foot, the air-column would be $\frac{{\cdot}7812}{{\cdot}080728} = 9{\cdot}67716$ feet high; and the square of the velocity (in thousands of feet per minute) would by formula (3) be

$$v^2 = \frac{9{\cdot}67716 \times 25}{{\cdot}26881 \times (20 \times 25000)} = {\cdot}0018$$

and hence the simple velocity, in thousands of feet per minute, would be

$$v = \sqrt{{\cdot}0018} = {\cdot}042426$$

and the velocity in feet per minute would therefore be

$${\cdot}042426 \times 1000 = 42{\cdot}426\,;$$

and this gives for the quantity of air that would be put into circulation in the small air-way, by the same pressure per foot that is required to circulate 6,000 cubic feet per minute in the large one, $42{\cdot}426 \times 25 = 1{,}061$ cubic feet per minute, as has been stated.

To circulate 1,061 cubic feet of air per minute in the small air-way would, however, only involve the application of

$$\frac{1061 \times {\cdot}7812}{33000} = {\cdot}0251 \text{ horse power.}$$

which, under the conditions of the small air-way, and the assumed pressure, represents the entire power due to the friction of the quantity of air that would circulate in it.

Air, in being heated under a constant pressure, expands 1-459th part of its volume at the temperature of zero of Fahrenheit's thermometer for each degree of temperature imparted to it; 459 cubic feet of air at 0° become 469 at 10°, 479 at 20°, 489 at 30°, and so on. 1,000 cubic feet of air at 32°, the temperature of melting ice, expand to 1,366½ cubic feet at 212°, the temperature of boiling water. To find the relative volumes occupied by equal weights of air, under equal pressures, but at different temperatures, we have simply to add the constant number 459 to the temperatures, and the sums give the relative volumes. The ordinary pressure of the atmosphere is equal to that of a column of water about 34 feet or 400 inches in height; we, however, seldom employ a difference of more than 2 or 3 inches of water column, as ventilating pressure in mines. The pressure of the air is about 2,116 lbs. per square foot, but we seldom employ more than 10 to 17 lbs. extra as ventilating pressure. Owing to the ventilating pressures being so small, the changes of density in the air of mines (as it circulates), arising from changes of temperature, the mixture of watery vapour or steam, the gases given off, and one or two other causes, give rise to small local pressures in the various splits of air in a mine. In rise splits these local pressures usually operate against the general ventilating pressure, and lessen the quantity of air that would otherwise circulate. In dip splits these small local pressures commonly act in the same direction as the general ventilating pressures, and so add to the amount of their ventilation. This arises from the return air of any split being generally less dense than the intake air.

The laws of ventilation lead us to conclude that if we increase or decrease the total ventilating pressure, and total quantity of air circulating in a given time, where the seam of coal is perfectly level, each way or split will get a *fixed share* of the whole of the air entering the mine, no matter how long or short may be the different splits, and no matter how great or small may be the quantity of air. This is contrary to an old notion, that a short split gets an increasing, and a long one a decreasing share of any lessened amount of ventilation, apart from considerations as to the rise or dip of the seam. Not long ago this point was severely tested, by numerous experiments, at several collieries; the results showed that the old idea was a mistaken one, and that the only changes that took place in the *proportion or share* of air going to different splits, with a reduced ventilation, arose from their relative rise or dip, together with the relative densities of the intakes and returns, and had no connection with the mere lengths of the splits. In ordinary cases, where the air of the returns is less dense than that of the intakes, if we have a short level split regulated so that, with the full ventilating pressure, it gets the same amount of air as a long dip split; and if we then halve the total quantity of air circulating, we find that the short level split no longer gets its share, but only a quantity less than that which goes into the long dip split; the very reverse of this is the case where the long split is a rise one; and these results are perfectly agreeable to the laws of ventilation that have been stated. In practice, and with the ordinary splits of air used in mines, except in extreme conditions as to the amount of rise and dip, and changes of density in the air, and in the amount of ventilation, the *share or proportion* of air going into the different splits of a mine is nearly maintained, whether we increase or lessen the total amount of ventilation; and any deviation from this depends upon the rise or dip of the splits, and not at all upon their relative lengths. In practice, then, when any reduction of ventilation has been brought about, we should generally find that the rise splits have been more affected than dip ones, if even the rise splits are shorter than the dip ones, and we should therefore expect to find accumulation of gas in the short rise splits rather than in the long dip splits of the mine. The greater the rise the greater is the danger of this, quite apart from the mere length of the splits, supposing them to be equally well ventilated to begin with.

So far as experiments have gone, they show that if we had a series of equal sized and similarly shaped air-ways, made of different substances, the friction of air in passing through them would differ according to the nature of the substances.

Taking the friction in earthenware pipes at	100
In the air-ways of mines it would also be	100
In sheet-iron pipes, new and clean	39
In do. rusty inside	10
In cast-iron pipes, sooty inside	20
In do. tarred inside	18
In tin pipes the friction would only be	10

So that 1-10th of the pressure would send the same quantity of air through a tin pipe that would be required to force that quantity of air through an earthenware pipe of the same size in the same time. (*See* Table annexed.)

From these laws we learn, that the quantity of air that will pass through any mine is greater or less as the ventilating pressure is greater or less, but not in the same proportion. When the air-ways are the same, the quantity of air only alters in the proportion of the square root of the pressure; so that a fourfold pressure only gives a double quantity of air, and a ninefold pressure only gives a treble quantity of air. But, on the other hand, one-fourth of the pressure still gives one-half of the air, and one-ninth of the pressure gives one-third of the air. The changes in the quantity of air, then are sluggish as compared with the changes in the ventilating *pressure*, only varying as its square root. The quantity of air, however, is more sluggish still in reference to the *power* employed to cause it to circulate. The quantity of air only varies

TABLE.

Showing the values of the co-efficient of friction, represented by the letter *k*, in the formulæ given at page 39, being the height in feet of air column of the same density as the flowing air, required to overcome the frictional resistance encountered by 1,000 cubic feet of air per minute in passing through a passage having one foot of sectional area, and presenting one square foot of rubbing surface to the air in motion.

Nature of the material composing the pipe or air-way.	State of the internal or rubbing surface exposed to the wind.	Observers' names	General Temperature of the air or gas.	Head of column of the same density as the moving air or gas required to overcome the friction, being the co-efficient of friction = K.
Burnt earth	Clean	Péclet	Hot	0·26881
Galleries of a coal-mine	Ordinary state	G. C. Greenwell	Cool	0·25436
Sheet iron	New and clean	Péclet	Hot	From 0·10583 to 0·06773
Cast iron ?	Ordinary ?	Mons. Rudler	Hot	0·08466
Cast iron	Sooty	Péclet	Hot	0·05292
Cast iron	Old, Tarred	Girard	Cool	0·04844
Gas in pipes—cast iron	Ordinary	Mr. Hawkesley	Cool	0·03014
Water in pipes do.	Ordinary	Eytelwein	Cool	0·03028
Sheet iron	Old and rusty	Girard	Cool	0·02752
Tinned iron	?	D'Aubuisson	Cool	0·02540

REMARKS.—In applying these values of *k* to the formulæ at page 39 since they are calculated for velocities of which the unit is 1,000 feet per minute, the real velocities in feet per minute must be divided by 1,000, to give the value of v in the formulæ; and v in the formulæ must be multiplied by 1,000 to give the velocity in feet per minute.

as the cube root of the power, and of the quantity of coals burnt to produce it; so that eight times the coals only double, and twenty-seven times the coals only treble the quantity of air circulating in a mine, whether the ventilation is produced by furnace-action, ventilating machines, or otherwise, so long as the air-ways remain in the same unaltered state. From this we learn, that we must not expect any great general improvement in the ventilation of mines from a mere increase of power; any increase in the quantity of air in the same air-ways is slow, small, and costly, compared with the necessary increase of power required to produce it.

In the same manner these general laws show us, that the quantity of air increases as we decrease or lessen the extent of the frictional rubbing surface; but again, not in the same proportion, but only as the square root of the extent of the rubbing surface. If we could do away with three-parts out of four of the rubbing surface, so as to reduce it to one-fourth, other things being the same, we should only double the quantity of air in the mine; if the rubbing surface were reduced to even one-ninth, the quantity of air circulating per minute would only be increased to three times its previous amount. On the other hand, if the extent of workings and rubbing surface were increased to four times, or nine times their previous amount, while the area of the air-ways and the ventilating pressure remained unaltered, the air would only be lessened to one-half or one-third of its previous amounts respectively by such extensions, if we suppose the size of the air-ways and the number of splits of of air to remain the same, as well as the ventilating pressure, in each case.

From these laws, then, we learn, that either to increase the ventilating pressure, or to lessen the extent of rubbing surface exposed to the air circulating in mines, is a very slow and very costly mode of proceeding to increase the amount of ventilation, as the quantity of air circulating in a given time alters so slowly with any alteration that may be made in the ventilating power or pressure, or in the mere extent of rubbing surfaces that may be presented to it. For general improvements we must, therefore, look chiefly in some other direction, owing to these being slow and costly modes of increasing the ventilation of a mine.

The same general laws of resistance show us that if we could reduce the velocity of the air, consistently with increasing the quantity circulating in a minute, we should greatly lessen the friction in comparison with the quantity of air circulating, and so obtain an increased quantity for the same amount of friction, or by the same ventilating pressure. This object is accomplished by splitting the air, so that instead of allowing the whole of the air to traverse the whole of the workings, a separate portion is taken into each different district of workings, and also brought out in a separate channel to a point near the upcast shaft, after it has done its work. The air, as a whole, thus has as many ways to go in, and as many to come out by, as there are separate splits in the mine; the extent of the rubbing surface is not lessened by this, on the whole, but the area offered to the air is greatly multiplied; and although the velocity of each current may be reduced, still, on the whole, the quantity of air in all the splits is very much greater than if there were only one single current in the mine, even when the ventilating pressure is the same. Splitting the air does not necessarily enlarge the area offered to the air in the shafts, and the increased resistance arising from the increased quantity and velocity of air in them sets a limit to the benefits resulting from splitting the air in a mine. Owing to the resistance offered by the shafts, we dare not have more than a limited number of splits in a mine, because although every split adds to the total quantity of air circulating, still in each separate split the quantity ultimately becomes less and less, and if the number be too great, the current of each becomes too feeble and slow to sweep into the holes, corners, and places driven in advance of the actual current; and besides this, powder smoke is a long time in being carried away from the workmen. Still it is a fact that an additional quantity of air, on the whole, is obtained from every new split that is made.

The following general rules should be observed in splitting the air in mines :—

Every principal split of air should commence as near as possible to the bottom of the downcast shaft, and should have a distinct air-way to return in, as nearly as may be, to the furnace or the bottom of the upcast shaft, except in cases where it is necessary to mix different currents, lest some one or more of them may be dangerously charged with gas. Splits of air only commencing far into the workings of a mine have comparatively little effect in increasing the quantity of air.

Where the air-ways are nearly of the same area in all parts of a mine, and the gases given off, and the workmen employed are pretty evenly distributed, the length of the runs of the different splits should be as nearly equal to each other as circumstances may permit. The observance of this rule has a tendency to render regulators and other obstructions comparatively needless, and so to increase the amount of ventilation.

If we have a number of splits of air in a mine, each with an equal amount of air, then it is necessary so to obstruct each of the shorter splits as to cause their frictional resistances, when they have their proper share of air, to be as great as that of the very longest split, when it also has its due share; otherwise they would get too much air, and the longer ones too little. These obstructions, of course, lessen the total quantity of air circulating.

The increased quantity of air obtained by splitting depends greatly upon the relative depths and areas of the shafts, as compared with the lengths and areas of the air-ways forming the workings of the mine. Supposing a mine to have such shafts and air-ways, that when there are five equal splits of air, the shaft resistances amount to one-half of the resistances offered by the mine—and this is no uncommon case—then, if before splitting the air at all, we had a ventilation of 10,000 cubic feet of air per minute, the following are the quantities of air that would circulate by increasing the number of equal splits, while the entire extent of the workings, and the upcast shaft, and the ventilating pressure all remained the same :—

No. of Currents.	Quantities of Air on the whole.	Quantities in each split.
1	10000	10000
2	27892	13946
3	49449	16480
4	71527	17882
5	90789	18158
6	107800	17966
10	141710	14171

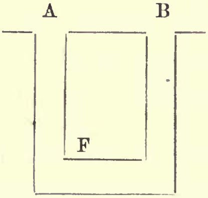
In this case, the coals burnt, whether in a furnace or by an engine driving a ventilating machine, would increase in the same proportion that the quantity of air increased, because the power would increase in that ratio. If the coals burnt, and the power remained unaltered, the results would only be as below:—

No. of Currents.	Total Quantities of Air per minute.	Quantities of Air per minute in each split.
1	10000	10000
2	19813	9906
3	29022	9674
4	37121	9280
5	43736	8747
6	48797	8133
10	58556	5856

Enlarging the sectional area or size of air-ways has a great effect in increasing the ventilation, but it is attended with great cost, and in general terms may be said to be much less effectual than judiciously splitting the air into a series of different currents. The beneficial effects of splitting air are, I believe, more fully appreciated, and the practice is more extensively followed in the Newcastle coal-field than in any other mining district; but, even there it too often happens that the splits are made too far from the bottom of the downcast shaft, and are again brought into the same return too soon after they leave the face of the workings. This often arises from pillars being worked away near the shafts, without proper places being left to make additional air-ways leading to and from the more distant parts of the mine. This is a very common oversight, and often entails either danger or a serious outlay, which might be avoided by care and forethought.

ON THE MEANS OF APPLYING POWER OR PRESSURE TO PRODUCE VENTILATION.

We have seen that *pressure* is required to put air into motion, and, more particularly, to overcome the friction it meets with in rubbing against the top, bottom, and sides of the galleries in mines. We have next to consider the means employed to give rise to this ventilating pressure. There is constantly a pressure of nearly a ton to the square foot in every direction in the air near the surface of the earth, owing to the weight of the air above it; and we must either increase or lessen the amount of this pressure, in order to put the air into motion; and it is only the amount of this increase or decrease, and not the entire pressure, that puts the air into motion and overcomes the friction in mines.



Take the case of two pits or shafts, of equal depth, and having their tops and bottoms on the same level, and filled with stagnant air, which likewise occupies an opening, extending from the bottom of one shaft to the bottom of the other; and suppose that, in the first place, the weight of the air in one shaft is the same as that in the other, the temperature and other conditions being the same in each, and that the shafts are of the same sectional area or size: in this state the two columns of air exactly counterbalance and support each other, so that there is no motion in the air, and therefore no ventilation is produced; nay, further, if one shaft be ever so much larger than the other, the air it contains can only press upon that in the smaller one over the area of the smaller section; the air contained in the extra size of the larger shaft resting or pressing upon the sides of the shaft or air-way at the place where the area is lessened, and not upon the air in the smaller shaft; so that whatever may be the relative sizes of the shafts, the air in the one will balance that in the other if the density of the air is the same in each; this may be termed the pneumatic paradox. If, however, by means of a furnace, at F in the diagram, the air in one shaft is heated and expanded, it becomes lighter, bulk for bulk, than the cool air in the other, and no longer balances it; the pressure of the heavier air then overcomes that of the lighter air, and pushes it up the shaft before it, while the cool air from the cool shaft takes its place, but not in a cool state, as it gets heated in its turn in passing over the furnace, so that there is a continual current of cool air going down one shaft which pushes before it a constant current of hot air up the other shaft.

In mines the air, instead of being allowed to go direct from the bottom of one shaft to the furnace and up the other, is guided by means of stoppings and doors into and along the various passages forming the workings of the mine, before it is brought upon the furnace or into the upcast shaft, and, by this means, a continual stream of air is made to sweep through the workings and mix with and carry off the gases as they are given off, and this is called the ventilation of the mine.

In some cases, men, boys, and horses require to travel in directions that the air is not wanted to go, and in such cases we cannot build up the way by a stopping, but have to place doors to stop the passage of the air; in many cases, the opening of a door to allow a person or horse to pass would have a bad effect by allowing the air to pass through it even for so short a time, and to avoid this evil two doors are employed, so that one may always be closed when the other is open. The use of doors in the principal roads of mines is objectionable where it can be avoided, and is much less common, at least in some districts, than formerly; in other districts of the kingdom the number of ventilating doors is very great, notwithstanding the danger and cost attending their use. The neglect of keeping doors shut has, no doubt, often led to serious explosions of gas in mines. In some cases it is necessary that the route of one split or current of air should intersect and cross that of another, and in such cases one current is carried over or under the other by means of drifts or masonry to prevent their coming into contact with each other; this arrangement is called an air-crossing or bridge. When an explosion occurs, the force of the concussion often destroys air-crossings, and thereby interrupts the ventilation; so that they should be avoided as far as possible, and made very strong where they are used in fiery mines.

It has already been stated that, where there are several splits of air in a mine, of different lengths, and offering different resistances, we sometimes find that too little air goes into the longer splits, compared with the quantity going into the shorter ones; and, in order to correct this evil, we put regulators or contractors into the shorter ones so as to increase the natural resistance they offer, and cause more air to go into the long splits. Regulators, although useful where they are unavoidable, are not desirable, as they contract the air-ways, and so lessen the total quantity of air circulating in the mine in a given time. As far as may be, the routes of the air should be so proportioned that each split may obtain its proper share of air without using any artificial regulators. Doors, air-crossings, and regulators should be avoided in all cases where the circumstances of the mine admit of it.

In order to find the amount of ventilating pressure, and the power arising from the use of a ventilating furnace, we require to know the weight of a cubic foot of air at different temperatures and under different pressures. Careful experiments show that 459 cubic feet of air at 0°, or zero of Fahrenheit, the common thermometer, weigh 39·76 lbs., when the pressure is 30 inches of mercury of the density due to 32°—a pressure equal to nearly $14\frac{3}{4}$ lbs. per square inch, which is the ordinary pressure of the atmosphere—but it only weighs 1-30th of this, or 1·3253 lbs. when the pressure is only 1 inch of mercury; and since 450 feet of air at 0° expand exactly a cubic foot for each degree of heat added, we get the following *rule* to find the weight of a cubic foot of air, at any temperature, and under any pressure :—

$$W = \frac{1·3253 \times I}{459 + t}$$

Where $I =$ the height in inches indicated by the barometer, and $t =$ the temperature by Fahrenheit's thermometer. At 38°, under a pressure of 30 inches of mercury, 100 cubic feet of air weighs just 8 lbs.; a box 5 feet every way would just contain 10 lbs. of such air.

On one occasion, at Hetton Colliery, when 225,176 cubic feet of air per minute were circulating, the average temperature of the air in the downcast shaft was $43\frac{1}{2}$°, and that of the air in the upcast shaft was 211°. Now, by the rule given (if we take the barometer half-way down the shaft to have shown a pressure of $30\frac{1}{2}$ inches of mercury), the weight of a cubic foot of air, taking the average, in the downcast shaft, would be ·08044 lbs.; and the pit being 900 feet deep, this air would produce a pressure of $·08044 \times 900 = 72·396$ lbs. on each square foot by its mere weight. The air in the upcast shaft, owing to its being hotter, would be lighter, and only produce a pressure on each foot = 54·297 lbs; and hence the difference of pressure on each square foot of area, between the two columns of air, would be = 18·099 lbs. Now, in order to find the horse power producing ventilation, we require to multiply this difference of pressure of 18·099 lbs. on the square foot, by the number of cubic feet of air circulating per minute, and then to divide the result by 33,000, the number of lbs. raised one foot high per minute by a horse power. In this case, then, we find the ventilating power at Hetton Colliery must have been

$$\frac{\overset{\text{lbs.}}{18{\cdot}099} \times \overset{\text{c. ft. pr. min.}}{225{,}176}}{33{,}000} = 123\tfrac{1}{2} \text{ horse power};$$

225,176 cubic feet of air per minute being in circulation at the time. Some part of the extra heat of the air in the upcast over that in the downcast shaft, would have arisen from the heat of the mine, and would have caused what is called a natural ventilation, even if furnaces had not been used. But natural ventilation is generally very small in amount, and cannot be depended upon, as, in hot weather, the downcast column of air is little or no cooler or denser than the air in the upcast, and, by making the weight or pressure of the two air columns equal there is a liability to stop all ventilation.

Where furnaces are used to produce ventilation, the deeper the upcast shaft the better; because this gives rise to a longer upright column of hot air, and so causes a greater ventilating pressure, and consequently a brisker ventilation. Furnaces are not well suited for causing ventilation in shallow pits for this reason; and sometimes machines are fixed at the top of the pit to pump the air through the mine. These machines, for the most part, exhaust air out of the upcast shaft, and the pressure of the denser air in the other, or downcast shaft, causes the current. Such a ventilating machine, like a furnace, acts by rendering the upcast column of air lighter, bulk for bulk, than the air in the downcast shaft; the same effect is sometimes produced by large fans, the machines mostly being worked by steam engines. A few of these ventilating machines are used in the south of England and in Wales, and a great number are used on the Continent. Ventilating machines of the best construction consume less coals (to produce the same quantity of ventilation) than furnaces, except in very deep and dry shafts. But coals are plentiful at collieries, and the liability of ventilation being suspended by the breakage of the machinery, and the inconveniences attending the stopping of the ventilating machine for repairs to itself or the engine, together with the difficulty of applying ventilating machines to working shafts, render them, in the opinion of many persons, less to be depended upon than furnaces in general. Taking the average of eleven different collieries in the Newcastle district, each pound of coal puts 13,000 feet of air into circulation by the action of furnaces. In some collieries two or three times as much air is circulated, by each pound of coal, as in others, depending on the depth of shaft, and its state as to dryness or wetness, and on the friction of the air in the shafts and in the mine itself. There are in Wales some seven or eight ventilating machines at work, producing ventilations varying from 16,000 to 75,000 cubic feet of air per minute. The largest machine is one recently erected at Deep Duffryn Colliery, which, with air-ways of sufficient area, is capable of producing a ventilation of double the latter quantity.

Jets of steam were proposed to produce the circulation of air in mines a few years ago, but by an elaborate series of experiments their effects were found to be far below that of furnaces, and the cost to be very great; the idea of their utility for ventilating mines was therefore abandoned. The useful work contained in a jet of steam, probably varies as the cube of the velocity of the steam, so that if the same quantity of water was converted into steam, in a given time, the power contained in it would depend upon the smallness of the jet orifice it had to escape through; by halving the area of the jets we should obtain eight times the power, and should therefore get a double quantity of air through the same mine; by reducing the area of the jets to one-third, we should obtain a treble quantity of air, by the same quantity of steam, in a given time. At least these are the results given by calculations, made upon the principles of mechanics, which are found to be true for streams of water and air. I have not taken pains to compare them with the results of the experiments on steam jets as applied to ventilation, because the results seemed to hold out no hope of steam jets ever been made available for ordinary ventilation. There are, no doubt, temporary and peculiar circumstances under which steam jets may be useful in the production of ventilation, such as cases where it is either unsafe or impracticable to use ordinary furnace action.

Falls of water are sometimes employed in downcast shafts to cause a current of air to descend; but, as the water has, for the most part, to be raised again from the mine, and as the effects they produce are small, in proportion to the power employed, this mode of ventilation is seldom used, except where furnace action or other means are necessarily excluded.

ON THE INSTRUMENTS USED IN CONNECTION WITH THE VENTILATION OF MINES.

Barometer.—The pressure of the atmosphere, in different states of the weather, varies from 28½ to 31 inches of mercurial column, being from 2,016 to 2,192 lbs. per square foot; and it is found that the natural discharge of gas in mines becomes greater as this pressure becomes less, so that the reduced atmospheric pressure as shown by a barometer, is a warning that an increased quantity of gas may be expected to be given off in mines, and, therefore, calls for increased care and vigilance to keep the ventilation at its greatest point, and for taking precautions against the enemy. The air pent up in goaves, and abandoned excavations, also expands in volume from the reduction of pressures which causes the fall of the barometer; the increased volume being given out into the air-ways, and often being mixed with gases necessitating careful attention, as the barometrical pressure of the atmosphere is lessened; the more suddenly the pressure falls the more observable are these results. A very *sudden* fall of the mercury is accompanied by a worse effect on mines than a greater fall, provided it takes place less rapidly. An increase or decrease of the pressure of the atmosphere has little or no effect in altering the *volume* of air passing through a mine in a given time, although it alters the *density* and *weight* of such air often to a considerable extent.

A good portable barometer may be used to ascertain the friction of air in passing along air-ways, because the loss of pressure, by friction, as the air circulates, is always taken off the pressure of the air itself; so that in level air-ways the air is less and less compressed as we proceed in the direction followed by the air, and the reduction of pressure is an exact measure, in such air-ways, of the pressure spent on friction. When the air-way rises or dips, allowances for this have to be made in finding the amount of friction from the pressure of air in this manner. Aneroid barometers appear to be better suited for use in mines than the common barometer or weather glass, as they are more portable, less liable to derangements, and almost equally reliable, at least for comparative indications, which are just as useful as absolute ones in mines.

Thermometer.—The thermometer is used to measure the heat of air in mines; when the fresh air, going down a downcast shaft, is heated, it expands and becomes lighter, and is, therefore, less able to force the air before it through the the mine; in other words, by being heated, the weight of the column of air in the downcast shaft is reduced till it is more nearly equal to that in the upcast shaft, and, consequently, the ventilating pressure is lessened, and, therefore, the quantity of air circulating is also reduced in amount. By the use of this instrument we find the difference of temperature between the air in the downcast and that in the upcast shaft, and so are able to calculate the ventilating pressure due to the action of a furnace.

Water Gauge.—The water gauge is merely a glass tube, bent into the form of the letter U with a scale of inches and parts, by which we can measure the difference between the height of the water in one tube and that in the other. It has already been stated that the air loses the pressure that is spent on the friction as it progresses along an air-way. Now, when an air-way happens to turn so as to come nearly parallel to itself, there is often a door or stopping separating the two adjacent parts of the same air-way, and this instrument enables us, in a direct way, to measure the amount of pressure that is spent on friction between the two adjoining parts of the air-way so situated. The air has less pressure on the outcome or return side of the separation than the air on the intake side, which has not yet met with the friction of the intervening distance of air-way. If the water in one leg of the tube is exposed to the pressure of the intake air, while that in the other is exposed to the lesser pressure of the return air, the greater pressure on the intake leg of the water gauge sinks or depresses the surface of the water in that leg, and raises it in the other leg; the difference of level, which represents the ventilating pressure spent on the air-ways lying beyond the place where it is taken, is seldom so much as three inches, and often only one inch in well-ventilated mines. The amount of water gauge can be increased, either by increasing the ventilating pressure, and, consequently, also the quantity of air circulating in a given time, while the air-ways are in the same state, or it can be increased by falls of material, or other obstructions in the air-ways, even while they lessen the quantity of air circulating; because such obstructions increase the frictional resistance of the air, and the gauge is a measure of that resistance. A water gauge does not show the shaft resistance when used in a mine; the pressure shown by the water gauge is equal to the general shaft ventilating pressure, *less* or *minus* the friction due to the air in the shafts and in the air-ways extending from the shafts to where the gauge is tried. It is also a measure of the resistances the air meets with in the workings lying beyond it, *less* or *minus* any local force, arising from the air in the returns being lighter than that in the intakes, in dip-ways; or it is equal to such friction added to any such pressure that may operate against ventilation from the same cause in the rise-ways or splits of air in the mine; and in cases where the air of the returns is more dense than that of the intakes, the effects arising from the dip or rise of the workings will, of course, operate in the reverse manner upon the indications of the gauge. When the air-ways remain in the same state, the amount of water gauge increases as the ventilation increases, and falls as it decreases; but the proportion of variation of the gauge-pressure is much greater than that of the quantity of air circulating; the *square* of the quantity of air, except in so far as local pressure may interfere, is proportional to the pressure indicated by the gauge, because the friction varies as the square of the quantity of air.

The *Anemometer* is an instrument used to measure the rate at which the air flies in mines. That invented by the late Mr. Biram is the one mostly used in English mines; it is not a very easy matter to find how much each of these instruments requires to be allowed for its own working friction; no perfect rule has yet been established for this purpose, although one is much needed. An approximate rule requires that a constant quantity should be added to the number of revolutions in a minute, no matter what may be the speed of the wind or of the instrument; and that the sum so obtained should be multiplied by another constant quantity, to give the velocity of the air in any terms in which we wish to find it. Coombes' anemometer can be put into or out of gear by pulling strings attached to it; this instrument is said to give very correct results, and is greatly used on the Continent; it is, however, more troublesome to use than Biram's anemometer, and is seldom seen in our mines. There are a few other kinds of anemometers; but a good and simple instrument, or mode for finding the velocity of air in motion, has probably yet to be contrived.

The Hygrometer.—In fine experiments, the hygrometer is used to ascertain the proportion of moisture in the atmosphere of mines, from whence its density and also its capacity for heat are found. Mason's wet and dry bulb hygrometer is better adapted for use in mines than the more delicate one of Daniel. The return air in nearly all mines is found to be saturated with vapour of water; that is to say, it contains the greatest quantity of vapour that can exist in it at its temperature; and a portion of vapour is condensed by the least degree of cooling that takes place in the air. An atmosphere saturated with vapour is lighter, bulk for bulk, than another at the same pressure and temperature, but containing less vapour.

In the discussion which followed—

Mr. Atkinson said: Supposing you have a long split and a short one in the same mine, and you regulate or contract the short one by an artificial obstruction until the quantity going into each is equal; then supposing, from some cause or other, the general ventilating pressure is gradually reduced, what would be the result? Would the short split get half the remaining total quantity of air, or would it get less or more? That question would have been answered in my younger days by saying that the short split would ultimately take the whole of the air, and none would go to the long one. Now, however, it is a fact, which I have proved over and over again, that if the air-ways are level, and you reduce the ventilating pressure, each split will take its original *proportion;* but if the long one is a dip-way and the short-way is a level one, on reducing the gross quantity of ventilation the long-way gets more than its original *share* of the reduced quantity, and so takes the lead of the short split. If, on the other hand, the long split is a rise and the short a level, on reducing the gross quantity the long split gets less and the short one gets more than its *share.* Supposing one split gets 60 per cent. and the other 40 per cent. of the total to begin with, if the air-ways are level, each will get the same percentage when the gross amount is lessened. Just the reverse results take place if you take the proportions from any standard amount of ventilation, and then *increase* the gross quantity, where there are rise and dip splits, supposing the air in the returns to be hotter and less dense than in the intakes in each case. If, however, the returns were so mixed with carbonic acid gas, and so cool as to be more dense than the air in the intakes, then the reverse results would ensue on increasing or reducing the ventilating pressure where the splits are not level. We had a long discussion about this at the North of England Institute of Mining Engineers. Some one suggested, after the Lundhill accident, that instead of having air kept so much in one current, if they had taken it up each bank on separate splits, they would have got a much better ventilation; but the objection was raised that in the event of the furnaces being low and the general ventilation being reduced, the far-off places would get no air; it would all run through the "short cuts;" and it was to correct that idea that the matter was made the subject of investigation by careful experiments. Further, the benefit of splitting air depends in a great measure upon the proportion of resistance that occurs in the shafts as compared with that which occurs in the workings. The total pressure applied may be divided into two separate items, one of which is employed to overcome the shaft friction, and the other to overcome the resistance in the workings. Generally speaking, you can subdivide the workings till you reduce the friction very materially; but the friction in the shaft is, of course, always the same for a given quantity of air, and it is only from reducing the friction in the workings that the beneficial results of splitting the air are derived. As to dumb drifts in some collieries, where discharges of gas occur, it might be expedient to use them; but he would rather have a sweeping ventilation, as a rule, and a mixing of the return air from the place where the gas was given off with that from the other ways, so as to render it safe before reaching the furnace. If you supply the furnace with fresh air, you never get with the same furnace the same amount of air into the workings, and our object is to cut down the amount of friction in the downcast and upcast shafts. There is one rare case where that does not hold, and that is if your returns were so charged with carbonic acid gas, so fearfully charged with it, that they would not let the furnace burn, you would have nothing else for it but to use fresh air, but you would use it at the expense of not getting the same amount of ventilation as you would get with ordinary air.