The system introduced by Mr. Barrett appeared to merit the attention of both engineers and architects, as there were numerous positions to which it was admirably adapted. He hoped that the subject would be followed by a more comprehensive paper on fire-proof buildings generally.

JENNINGS' SLUICE VALVE.

After the meeting, one of Jennings' Sluice Valves was exhibited in the ante-room. The improvement was stated to consist in simplifying the construction, by casting the "body" and the "faucet" ends in one piece, thus avoiding the use of bolts, nuts, and joints. The slide was first fitted, and made to work properly in the body of the valve; it was then removed, and with two gun-metal faces, was turned, ground, and accurately fitted. The slide, through which a small hole had been previously drilled, was again placed in the valve, the two faces were introduced, and all firmly bolted together. The joints of the faces, which were dovetailed to the body, were then made with lead, or with iron cement; the bolt was removed, the hole plugged, and the valve was completed, at considerable saving of time and cost. These valves were stated to have been extensively used under considerable pressures.

February 1, 1853.

JAMES SIMPSON, Vice-President,
in the Chair.

The following candidates were balloted for, and duly elected :
—Messrs. Benjamin Burleigh, John Evans, David Forbes,
John Jay, Arthur Prentice, and John Trickett, as Associates.

No. 868. "On the Pneumatics of Mines." By JOSHUA
RICHARDSON, M. Inst. C.E.¹

THE necessity for good ventilation in mines is universally acknowledged, but unfortunately, very dissimilar opinions are

¹ The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

entertained, as to the quantity of air required for this purpose, and in consequence, a great diversity in practice prevails throughout Great Britain. In the Southern districts, 2,000 to 20,000 cubic feet of air per minute, and in the North, 50,000 to 170,000 cubic feet per minute, may be taken as the ordinary variations of estimates of the supply. The difference between the districts, and the discrepancy between mines, in the same district, clearly indicate the absence of any fixed principle of determining the quantity really required, and confirm the opinion expressed by the South Shields Committee, that the "ventilation, and consequent safety of the mine, is mere guess-work."¹ The customs and example of the neighbourhood, are usually the only authorities consulted on this important subject; and it is most probably owing to this circumstance, that the ventilation in whole districts presents such few exceptions to a prevailing system of good, or bad practice. There can be no doubt, however, that recourse is had to this mode, chiefly because there are no acknowledged rules to refer to, in order to obtain correct information, and it is hoped that this first attempt to supply an obvious want, will be viewed with the indulgence usually granted in such cases.

The evidence given before the Parliamentary Committees, in 1835 and 1849, and the Reports to the Government, both by able, scientific, and practical men, have elicited much valuable information on the ventilation of mines. In the admirable Report of the South Shields Committee, published in 1843, the employment of scientific instruments to ascertain the state of the mines, is strongly recommended, and amongst these, the "Eudiometer" is mentioned, as necessary "to enable the officer to discover in any part of the workings, at any time, the quantity of oxygen, and also the per-centage of Carburetted Hydrogen, or other gases." (Page 56.) This is clearly an advance in the right direction, but it does not go far enough. Dr. Hutchinson, in his evidence to the Committee of the House of Lords, in 1849, says, in answer to query 1514, "I think, that in a mine of 150 men and 30 horses, and say 180 artificial lights, there should not be less than 2,500 cubic feet of air per minute, for vital-chemical purposes alone." This

¹ Vide "The Report of the South Shields Committee on Accidents in Mines," page 56.

is equal to 16.67 cubic feet per man per minute, which agrees very nearly with the subsequent calculations. This, however, is but a small portion of the air required in a mine, and it is to be regretted that the doctor did not extend his inquiries, as they are obviously based upon true principles. In the Appendix (page 598) to the Report and evidence quoted, a paper is given, by Dr. Arnott, on the warming and ventilating of the York County Hospital, in which it is stated, that 20 cubic feet per minute of ventilating air are allowed for each patient. In the same volume (page 258) Mr. Struvé gives a formula, for determining the quantity of air required in the ventilation of mines, based on the number of men employed and the quantity of coal produced, on the presumption that 80 men work 100 tons of coal per day, giving 100 cubic feet of air per minute per man, in mines with a small amount of fire-damp,—150 cubic feet to a moderately fiery mine, and 300 cubic feet per minute, per man, in a very fiery colliery. If the quantity of the coal produced and the number of the men employed, were always in strict relation to the extent of the works, this mode of computing the quantity of air required, might possibly answer the purpose; but as the same number of men may be employed, and an equal quantity of coal produced, in a colliery of 60 acres, and in another of 600 acres, it is evident, that the ventilation, which would be amply sufficient in the one instance, would be totally inadequate in the other; for as the noxious gases are constantly oozing out of the strata, from all the exposed surfaces of a mine, the ventilation, to be efficient, must be in some relation to the areas excavated, as well as to the number of the men. Rules founded solely on the acreage, are also objectionable, as other considerations than the extent of area, are essentially necessary in arriving at a correct conclusion; Mr. T. J. Taylor¹ says,—“in a mine which yields no fire-damp, with 120, or 130 persons employed in it, I should say, that a current of 20,000 or 30,000 cubic feet per minute, might be a fair quantity; * * * but in a fiery mine, I should require very much more than the quantity named.” This is equal to 166 and 230 cubic feet per minute, per man. In his Report on the Ventilation of Mines, pub-

¹ Vide Evidence Committee of the House of Lords. 1849. Query 6019.

lished in 1850, Professor Phillips says, (page 30,) when speaking of the Newcastle district,—“ I have compared the quantity of air circulating in seven of these collieries,¹ with the number of men (hewers) employed; and find for every man, upon the average, 562 cubic feet of air in one minute.” This far exceeds the estimates before given, and being a practical result, shows their insufficiency as guides on this subject. It is clear, that no sound basis for calculation can be founded on one, or two elements, but that the whole must be taken into consideration; for as the objects sought to be accomplished by ventilation are, chiefly, the maintenance of animal life, and the dilution of dangerous gases, it is evident, that any system which omits to recognise chemical principles, or to estimate the number of men employed,—the size of the areas,—and the length of the galleries,—or any of them, must be erroneous.

Pursuing this mode of investigation, it will be necessary, in the first place, to inquire into the chemical constitution and properties of atmospheric air, its uses in the animal economy, as well as in diluting and rendering harmless the dangerous gases; and then proceed to determine the quantity required, according to the principles adduced, and the circumstances, or conditions of the mine.

Atmospheric air is chiefly composed of oxygen and nitrogen gases, and usually contains about a thousandth part of carbonic-acid gas, with at least one per cent. of aqueous vapour. In every one hundred measures, or volumes of atmospheric air, there are 21 volumes of oxygen, and 79 of nitrogen; or in 100 parts, estimated by weight, there are 23 of the former and 77 of the latter.

Oxygen gas is the principal supporter of animal life, and combustion. It is about 750 times lighter than water, and is rather heavier than air, its specific gravity being 1.1088, that of air being one.

Nitrogen gas, or azote, as the French chemists call it, is

¹ The following are the mines mentioned, and the amount of ventilation in cubic feet per minute of each colliery. Hetton 190,000 C.F.; Wallsend 121,360 C.F.; Haswell 100,917 C.F.; Murton and South Hetton 87,055 C.F.; Willington 66,500 C.F.; Walker 44,800 C.F.; Castle Eden 42,326 C.F.; and Wingate Grange 44,000 C.F.—*Vide* pages 23 and 30.

Professor Phillips averages the ventilation of the above eight collieries at 196 cubic feet of air per minute to one acre.—Page 30.

(negatively) destructive to animal life, and is incapable of supporting combustion. Its specific gravity is 0.9747, and is therefore rather lighter than atmospheric air.

It appears, from careful experiments, that the proportion of these gases in the air, has been found to be the same, at the level of the sea; at an elevation of 22,000 feet; in the most crowded districts, of the most populous towns; at the summit of Mont Blanc; within the polar circle; and at the equator.

Atmospheric air is, however, undergoing constant changes, by being decomposed, and adulterated with deleterious gases. Among other causes, which are constantly operating to deteriorate the air, are the respiration of animals, and the combustion of inflammable bodies. By both these processes, the oxygen is abstracted from the air, and converted into carbonic acid, which with the nitrogen, is returned into the atmosphere. The air thus deprived of its oxygen is unfit for respiration, but in an open and unconfined space, the carbonic acid is absorbed by the vegetable creation, which retains the carbon for its own nutriment, and returns the oxygen into the air, and the nitrogen which is rejected by the lungs, being specifically lighter than air, rises into the upper regions of the atmosphere, to await new combinations; whilst the pure air descends towards the earth, to replace that which has been decomposed. It is obvious, however, that in the caverns of a mine, and even in the rooms of a dwelling-house, those natural laws are more, or less inoperative, and that unless means are employed to compensate such circumstances, disease and death must necessarily ensue among men, or animals so situated.

In order to enable the miner to pursue his avocation in the bowels of the earth with safety to his health and life, it is indispensably necessary to supply him with a sufficient quantity of pure air, not only for the purpose of respiration, but also to displace and carry away the carbonic acid, and nitrogen gases produced by it; a much larger quantity, therefore, being required for these purposes underground, than on the surface of the earth.

An example of an actual case of combustion will give an idea of the quantities entering into the calculation. A dip candle of sixteen to the pound, or one ounce in weight, was found to burn $3\frac{1}{2}$ hours, which gives 125 grains of tallow con-

sumed in an hour. Supposing the tallow to contain 80 per cent of carbon, then $\frac{125 \times 80}{100}$ gives 100 grains of carbon. It requires 16 parts, by weight, of oxygen, perfectly to consume 6 parts of carbon, therefore $\frac{100 \text{ grains of carbon} \times 16}{6}$ gives 266·66 grains of oxygen, as the quantity required to maintain the combustion of the candle for one hour.

This weight must be added to that of the carbon, which makes the weight of the carbonic acid produced 366·66 grains; and as there are 812 grains of this gas in a cubic foot, the volume of it produced in an hour, by burning a candle of this description, is 0·45 cubic foot. This gas requires to be diluted with 50 times its volume of pure air to render it innocuous, therefore $0·45 \times 50$ gives 22·5 cubic feet of air per hour necessary for this purpose. As atmospheric air contains by weight 23 parts of oxygen, and 77 parts of nitrogen, and as a cubic foot of air weighs 527 grains¹ there is $\left(\frac{527 \times 23}{100}\right)$ 121·21 grains of oxygen, and $\left(\frac{527 \times 77}{100}\right)$ 405·79 grains of nitrogen in a cubic foot of atmospheric air; the quantity of air required, therefore, to supply the requisite oxygen is $\left(\frac{266·66}{121·21}\right) = 2·20$ cubic feet; and $2·20 \times 405·79$ gives 892·74 grains, or (divided by 514) 1·73 cubic feet of nitrogen, as the noxious residue of the air, after the oxygen has been abstracted from it; and as it requires 20 times its volume of pure air to be mixed with this gas, to restore its vitality, therefore $(1·73 \times 20) = 34·60$ cubic feet will be needed.

The quantity of atmospheric air required to support the combustion of a candle, one ounce in weight per hour, and to dilute and displace its noxious products in a mine, therefore is, 59·30 cubic feet, viz. :—

	Cu. ft.
For supporting combustion	2·20
For diluting the carbonic acid gas . .	22·50
For diluting the nitrogen gas. . . .	34·60

or very nearly one cubic foot per minute.

¹ The weight of all æriform bodies given in this paper, are on the supposition that the Barometer is at 30 inches, and Fahrenheit's Thermometer at 60 degrees.

The process of respiration is, in many respects, analogous to that of combustion. The food supplies the carbon, and the oxygen is derived from the air by the act of breathing, whilst the products are the same as in combustion. In this process from ten to twelve per cent. of the oxygen in the air combines with the carbon in the blood, and produces carbonic acid, which, with the nitrogen, is expelled from the lungs, at every expiration, into the atmosphere.

Although the quantity of air which enters the lungs, at each inspiration, may be considered as uniform, yet as it is subject to great variations in weight, owing to the difference of its temperature, there is a considerable difference in the quantity of oxygen inspired in dissimilar seasons and climates.

In order to ascertain the amount of carbon taken into the human system, in a given time, and thence to deduce the quantity of oxygen required for respiration, Professor Liebig made observations upon the average daily consumption of about 30 soldiers in barracks, from which it appears, that an adult man taking moderate exercise, consumed 13·9 ounces of carbon in 24 hours, which passed out of the system through the lungs and skin in the form of carbonic acid. The equivalent of oxygen for this quantity of carbon is $\left(\frac{13 \cdot 9 \times 16}{6}\right) = 37$ ounces; but according to Dr. Hutchinson's observations on the respiration of miners,¹ it appears they make, on an average, one-tenth more inhalations than men breathing on the surface, owing partly to the increased pressure of the atmosphere, and partly to the violent exercise they are compelled to make in working; and as the quantity of oxygen inspired is in proportion to the number of respirations in a given time, the temperature being the same, one-tenth, or 3·7 ounces, must be added to the amount given, which makes 40·7 ounces of oxygen, inspired by the miner in 24 hours, or 1·696 ounces, or 742 grains per hour.

It has been ascertained by Lavoisier and other chemists, that only 10 per cent. of the oxygen contained in atmospheric air is absorbed by animals in breathing; the other 90 per cent. being expelled by the lungs, with the carbonic acid, formed by the

¹ Vide "Appendix to the Report of a Committee of the House of Lords on Accidents in Mines, 1849." Page 604.

combination of the carbon, derived from the food, and the oxygen inhaled. One cubic foot of air, therefore, will only supply 52.7 grains of oxygen, and it will require $\left(\frac{742}{52.7}\right) = 14$ cubic feet of air, to supply the oxygen needed for respiration, for one man per hour.

The air expelled from the lungs having become deteriorated, must be freely diluted with pure air, for which purpose a much larger quantity is required than for respiration. Taking the quantity of carbon consumed at 278.25 grains, there is obtained 1.256 cubic feet of carbonic acid, which should be diluted with 50 times its volume of pure air; the quantity required for this purpose is, therefore, 62.8 cubic feet per hour.

The residuary nitrogen, or azote, ought also to be diluted with 20 times its volume of pure air. In the 14 cubic feet of air, required for respiration, there is $\left(14 \times 474.3 = \frac{6640}{514} \text{ grains}\right)$ 12.92 cubic feet residue of expelled air, after deducting the carbonic acid, which $\times$ by 20 gives 258.4 cubic feet of air, required for diluting this gas.

From the careful experiments of Lavoisier and Seguin it appears, that the matter thrown off by a man in perspiration, amounted to 1575 grains, or 1.94 cubic feet per hour. Although this is composed of aqueous, as well as of gaseous substances, it is so contaminating to the atmosphere of a mine, as to require a liberal dilution, and ought to be treated like carbonic acid gas, of which it contains a large proportion; the addition of 50 times its volume ought, therefore, to be allowed, which makes the quantity of pure air required for this use, 97 cubic feet per man per hour.

The quantity of atmospheric air required in a mine, for the respiration of the men, and for diluting and displacing the noxious products, is therefore,—

For breathing	14.0	cu. feet	per man	per hour
For displacing carbonic acid	62.8	"	"	"
For diluting nitrogen or azote,	258.4	"	"	"
For displacing perspiration .	97.0	"	"	"
<hr/>				
Total	432.2	"	"	"

which is equal to 7.2 cubic feet per minute.

Air must also be provided for the horses employed in mines, the number of which is generally taken on an average as one-fifth of the number of men. According to Boussingault, a horse consumes 79·10 ounces of carbon in 24 hours, from which (calculating in the same manner as for men) it is found that the quantity of air required for the support of a horse, in a mine, is as follows :—

For breathing	80·81	cu. ft.	per horse	per hour.
For displacing carbonic acid .	360·50	”	”	”
For diluting nitrogen or azote,	1491·40	”	”	”
For displacing perspiration .	533·87	”	”	”
	<u>2466·58</u>			

To which should be added,				
for one fixed and one	118·60	”	”	”
moveable light ($59·30 \times 2$)				
	<u>2585·18</u>	”	”	”

which is equal to 43 cubic feet per minute.

In some instances steam power is employed instead of horses, in which case a much larger supply of air becomes necessary. If we suppose the coal thus used to contain, on an average, 70 per cent. of carbon, and that 10 lbs. in weight is consumed per hour per horse power, it will require 1086·59 cubic feet of air to supply the requisite oxygen to effect its combustion, whilst 11,050 cubic feet will be needed to displace the carbonic acid, and 17,156 cubic feet to mix with the nitrogen; the whole quantity of air required for this purpose being, therefore, for every horse-power of the engine employed 29,292 cubic feet per hour, or 472·20 cubic feet per minute. As but few steam-engines are employed underground in collieries, the quantity of air required by them is not included in the calculations and table given hereafter.

The total quantity of air required for combustion and respiration for the use of a man during one hour, with his usual accessories, must therefore be taken as follows :—

For a man's respiration, &c.	432·2	cubic feet.
For the combustion of one light, &c. .	59·3	”
For one-fifth of that needed for a horse	517·0	”
	<u>1008·5</u>	”

which is equal to 16·8 cubic feet per minute per man.

This result approximates very nearly to the estimate given by Dr. Hutchinson, which is 16·67 cubic feet per man per minute.¹

The atmospheric air required in mines for the purposes before mentioned is inconsiderable, when compared to the quantity needed for the dilution and displacement of the noxious and dangerous gases, which exude from the strata of the earth, and which next demand attention.

These are known among miners by the names of choke-damp, fire-damp, and after-damp. In some collieries choke-damp only is found; in others, fire-damp; but both are generally present. The after-damp is the produce of explosions.²

The very defective state of the mining statistics of this country occasions considerable difficulty in the investigation of this subject, and in arriving at any satisfactory conclusions, as to the per-centage of these gases in the atmosphere of a mine.

It has been already stated (page 273), that in the valuable report of the South Shields Committee on accidents in mines, the use of the Eudiometer in collieries is strongly recommended. But no description of the Eudiometer, or of the mode of using it, is given in the report; and as those described in chemical works are more adapted for the laboratory than for underground observations, the Author appealed, through the columns of the "Mining Journal," to the scientific world, and was promptly responded to by the late Dr. J. Murray, of Hull, who wrote thus:—

"In my communications on coal mines, I had by no means forgotten the importance of Eudiometers. I cannot conceive anything more simple and easy, in practice, than the employment of a tube graduated into 100 parts, and fitted with a glass stopper at the summit, the lower line to commence say, two inches from the lower orifice.

"The solutions to be employed are those of Chlorine, Green Sulphate of Iron impregnated with Nitrous Gas, and Caustic Potassa, or Baryta.

¹ "I think that, for instance, in a mine of 150 men and 30 horses, and say 180 artificial lights, there should not be less than 2,500 cubic feet of air per minute, for vital-chemical purposes alone."—Evidence to the Committee of the House of Lords, 1849. Question No. 1514.

² The word 'damp' is probably derived from the German 'dampf,'—'vapour, steam, fume.'

“The solution of Chlorine in water, will determine the quantity of Hydro-Carbonate, or Fire-Damp present;—that of Green Sulphate of Iron, impregnated with Nitrous Gas, the relative quantity of Oxygen;—and that of Lime Water (or better, Caustic Potassa, or Baryta), the relative admixture of Carbonic Acid.

“The relative constituents of pure air are 21 per cent. oxygen, and 79 nitrogen. If on using the first test, there be several parts per-centage absorbed, this will be the relative quantity of fire-damp present.—If on using the second test, 21 per cent. is absorbed, the atmosphere may be considered relatively pure, or otherwise, in the ratio of absorption.—The absorption on employing the third test, will indicate the per-centage of choke-damp present. I consider the approximations, obtained by these means, amply sufficient for the practical purposes of the miner.

“The employment of the Eudiometer is simple: remove the stopper, and dip the tube into the solution till the liquid rises to the lower line,—replace the stopper, apply the finger firmly to the lower orifice,—shake the liquid for some time in the tube, then withdrawn from the liquid,—and finally, immerse the lower end into water, when the finger must be withdrawn, and the absorption will be immediately denoted by the rise of the fluid in the tube, and the per-centage read off. These solutions can always be kept ready for use.”¹

Choke-damp, sometimes called “stythe” and “black-damp,” is composed of Carbonic Acid Gas and a greater, or less proportion of Atmospheric Air. It has been usual to consider choke and after-damp as the same thing, and in effect they are the same, both producing instant death when respired; yet, as they are derived from different sources, and recent analysis has proved, that, chemically, they are very differently constituted, it will be better to consider them separately.

Choke-damp is said to be much more prevalent in shallow, than in deep mines; it is generally abundant in old workings, and in some instances oozes out from the strata in such profusion, “that thousands of yards of space are filled with it in a single hour.”² It is usually most prevalent in collieries generally

¹ Vide “The Mining Journal” of the 11th May, 1850.

² Vide “The South Shields Report,” page 11.

free from fire-damp, owing to the sluggish ventilation which too frequently and so lamentably prevails in them. Its presence is indicated by the flame of a candle, or lamp, assuming a dull red colour, burning feebly, and finally going out. Its specific gravity being rather more than one-half greater than that of common air, it is most abundant and in the purest state near the bottom, or floor of the mine, although it is more, or less diffused throughout its whole atmosphere. Men have been known to continue their work in a mine where the atmosphere was so much charged with choke-damp, that a candle would scarcely burn, and who did not leave their work until nearly all the candles were extinguished;¹ so that they must have been in an atmosphere containing from 10 to 12 per cent. of carbonic acid, without any fatal result ensuing; yet such a practice is so replete with danger to the life, and always prejudicial to the health of the miners, as to be deserving of the strongest reprehension. At the meeting of the British Association, held at Birmingham, in 1839, Dr. G. Bird gave the details of many experiments, which he had made, in relation to this subject, whence he had, in some instances, discovered that even 2 or 3 per cent. of Carbonic Acid was fatal to animal life, and that it varied in its effect upon the human constitution, according to the different idiosyncrasies of individuals. It is obvious, therefore, that this gas ought to be diluted with at least 50 times its volume of pure air, which, though a large quantity, is not more than is required to secure the health and safety of the miners.

As the indications of the presence of choke-damp are more equivocal and less apparent than those of fire-damp, its prejudicial influence on the health of the men is probably much greater, whilst it excites less alarm; and even when the atmosphere is in a dangerous condition, it ought not to be allowed to accumulate, but should be dissipated, as quickly as it is produced, by directing and maintaining an efficient ventilation throughout all the works.

Fire-damp, known also as "wild-fire," "sulphur," and in Wales as "uldân" or "tanfa," is the most terrible enemy with

¹ Vide "Reports of the Commissioners on the Employment of Children, 1842. Mines." Part 2nd, page 739.

which the miner has to contend. It exudes from the coal, and its contiguous strata, and when mixed, in certain proportions, with atmospheric air, it acquires, on ignition, an explosive force exceeding that of gunpowder.¹ When it is recollected, that the force, or pressure of gunpowder at the moment of explosion, is, according to Dr. Gregory, about 936 tons on a square foot, the havoc and destruction, which ensues in a coal-mine, on the occurrence of an explosion of fire-damp need not excite surprise.

Fire-damp is generally composed of sub-carburetted hydrogen, and sometimes of olefiant, or sulphuretted hydrogen gases, and becomes highly explosive on being mixed with certain proportions of atmospheric air, a more plentiful addition of which however counteracts the explosive quality. Sir H. Davy, Dr. Clanny, and other chemists, have shown that it will not explode, unless mixed with from 6 to 8 parts of air to one of gas; that it requires 15 parts of air to render the gas non-explosive; and 30 parts of air to one of gas for its thorough dilution, and to deprive the atmosphere, in which it exists, of its dangerous and noxious properties.

It often happens, that fire-damp prevails in a mine to an explosive extent, and even in a still greater proportion, without an accident occurring. This arises from the mixture not being brought into immediate contact with flame, owing to the safety-lamp being used; or it may be attributed to the fire-damp not being mixed with a sufficient quantity of air, to render it explosive; or to the prevalence of carbonic acid gas, one part of which, mixed with seven parts of fire-damp, deprives it of its explosive property. A recent accident in South Wales, is to be attributed to the fire-damp prevailing in a greater proportion than rendered it explosive; the colliery being, however, in a very foul state, on a larger quantity of air than usual being forced into it, without the needful precautions, a disastrous explosion ensued, as an inevitable consequence. It is evident, that there can be no safety, where this dangerous gas is allowed to accumulate; for in such circumstances, an increased ventilation, a slight diminution of carbonic acid, or an accident to a safety-lamp, may at any moment produce the greatest danger.

¹ Vide "South Shields Report," page 8.

It is not unusual to ascribe the occurrence of explosions to the carelessness of the men, in either not using safety-lamps, or imprudently removing the wire-gauze, whilst the fact of the gas being allowed to accumulate so as to render it dangerous, which is the primary cause, is generally overlooked. The absolute necessity for a plentiful supply of air, in all mines, will be readily conceded, when these circumstances and the poisonous nature of the gas, are duly considered; and it may be taken as established, that the health and safety of the miners, can only be secured, by diluting the fire-damp with at least 30 times its volume of pure air, and forcing it out of the mine as quickly as possible.

Sir H. Davy found, that the purest specimens of fire-damp contained $\frac{1}{15}$ th of atmospheric air, and that 100 cubic inches weighed 19·5 grains, whilst the most impure contained $\frac{5}{12}$ ths of atmospheric air. Fire-damp has been more recently analysed by Professor Graham, and the following are the results in two specimens, one from the Gateshead, and the other from the Killingworth Collieries, near Newcastle-upon-Tyne:—

	Gateshead.	Killingworth.	Mean.
Specific gravity	0·5802	0·6306	0·6054
Weight of 100 cubic inches .	17·70 grs.	19·23 grs.	18·46 grs.
Carburetted-hydrogen . . .	94·20	82·50	
Nitrogen or azote	4·50	16·50	
Oxygen	1·30	1·00	
	100·00	100·00	

The following chemical diagram by the late Dr. Clanny, admirably explains the phenomena of an explosion of fire-damp. Dr. Clanny devoted a great portion of his time during forty years, to this subject, and it is to his researches and experiments the miner is in a great degree indebted for the discovery of the safety-lamp; his great services and indomitable perseverance in the cause of practical science and enlightened philanthropy have, however, been but imperfectly appreciated and ill-requited.

Atmospheric Air before Combustion.		After Explosion.	Fire-damp. Elementary Mixture before Combustion.	
Atoms.	Weights.		Weight.	Atoms.
Oxygen 1	Oxygen 8	Carbonic Acid 22	Carbon 6	Carbon 1
Oxygen 1	Oxygen 8			
Oxygen 1	Oxygen 8	Steam 9	Hydrogen 1	Hydrogen 1
Oxygen 1	Oxygen 8	Steam 9		
Nitrogen 8	Nitrogen 112		Hydrogen 1	Hydrogen 1
Mixture before Combustion.				
Atmospheric air . 144		Nitrogen 112		
Carburetted-hydrogen 8		Choke-damp 152	Fire-damp 8	
152				

The third column represents the equivalents of the atmospheric air in a coal mine, and the fifth shows the equivalents of fire-damp.¹

After-damp is the gaseous product of an explosion of fire-damp, and although usually called and treated as choke-damp, is in fact a very different gas, both as regards its origin and its chemical composition,—their only resemblance being in their poisonous properties. Choke-damp is composed of carbonic acid gas and atmospheric air in various proportions; whilst according to Dr. Clanny's diagram after-damp is constituted as follows :—

Nitrogen or azote . . .	73·69	} 100·
Carbonic acid . . .	14·47	
Steam	11·84	

Another important difference between these gases is to be found in their respective weights; 100 cubic inches of carbonic acid weighs 47 grains, whilst the same volume of after-damp weighs

¹ Vide "Evidence to the Committee of the House of Lords on Accidents in Mines." 1849. Page 447.

only 29·32 grains; the former, therefore, is much heavier, whilst the latter is rather lighter than atmospheric air. When choke-damp is abundant in a mine, the greatest safety may be found near the roof, but in an atmosphere of after-damp the most respirable air is found near the floor of the mine; and hence the practice, of the colliers, suggested by a dear-bought experience, of going into a mine immediately after an explosion in a stooping posture, or more generally creeping on their hands and knees.

It is a notorious fact, that in mines, although the gases may be partially diffused, yet they are usually found in a great measure stratified, according to their relative specific gravities; that is, in a mine containing choke and fire-damp, the former, which is the heaviest gas, is found near the floor,—then a stratum of common air succeeds, and the highest space near the roof is occupied by fire-damp.¹ This circumstance may probably be in fact attributed to sluggish ventilation, for if there were a brisk current of air always maintained, the gases would doubtless, be not only more diffused, but would be more speedily forced out of the mine. It is obviously of great importance, that these facts should be known, so as effectually to guard against the dangers to be encountered, as under the circumstances mentioned, it would evidently be unsafe to rely on the received theory of the diffusion of gases; for, if on the faith of it, a man were to hold a candle near the roof, in a fiery mine, an explosion would ensue, or were he to lie down on the floor, where choke-damp prevails, he would be inevitably suffocated. Nor are the consequences less calamitous, if the peculiar properties of after and choke damp are not duly regarded. Both these damps are deadly poisons, when respired; but there is usually a stratum of respirable air above the choke-damp, which enables the experienced collier to enter and work in the

¹ "It will happen at times, that men are unable to get down to work for fear of the foul air, both choke-damp and fire-damp. When examining a coal-pit, careful warning should be given not to hold the candle higher than the breast, and in that case there would be no danger (of an explosion), as the nose would give notice in sufficient time. Advice should also be given not to stoop down in any deep hole which might be seen, without holding the candle forward, in which case, if there was choke-damp, it would go out, which would be a fair warning."—Vide Dr. Mitchell's "Report on the Mines in Shropshire. Appendix to the first Report of the Children's Employment Commission." Part 1st, page 33.

mine, with comparative safety, but the after-damp occupies the whole area of the mine, immediately after an explosion, and being quite devoid of oxygen, produces instant death by suffocation, on being inhaled. On the subsidence of the violent motion of the atmosphere, caused by "the blast" of the explosion, and on the admission of pure air, the safest place is near the floor, where respirable air is soonest found. Many valuable lives have been lost from an ignorance, or a disregard of the precautions necessary to be observed, on entering a mine, after an explosion has occurred; by men attempting to rescue their fellow-workmen, before the deadly after-damp has been sufficiently displaced by ventilation, and their attempting to traverse the galleries in an erect posture.

The after-damp is usually much more destructive to animal life, than the fire and "blast" of an explosion; the number of men that are burnt, contused, and wounded, being usually much smaller than those who are suffocated. To mitigate its dreadful effects, on the occurrence of an explosion, the most strenuous efforts ought first to be directed to the immediate restoration of the means of ventilation, if they have been deranged, prompt measures should be taken to force into the mine a greater quantity of air than ordinary, if the means of doing so has been provided by a wise and judicious foresight; should there unfortunately, be no provision of this kind, then as much air as can be spared from other parts of the mine, ought to be promptly directed to the locality of the explosion. The only efficient remedies for this great evil, are of a preventive nature, viz., a thorough and efficient ventilation, and the judicious use of the safety lamp; the best energies, of all who are interested, ought, therefore, to be directed, with steady perseverance, to perfect, as far as is possible, the systems of ventilation and the other auxiliaries to safety.

The subject which next claims attention, is the quantity of air which is required to pass through a mine in a given period, in order to maintain its atmosphere in a safe and salubrious state.

For this purpose, recourse must be had to such facts, as are easily ascertained and generally known, which may serve as foundations for approximate rules, until absolute certainty be obtained, by the use of the Eudiometer.

It must be borne in mind, that although the quantity of air required is assumed to be in proportion to the amount of damp produced, yet it is necessary to maintain a current of air through subterranean works, independent of that required for the respiration of animals and the support of combustion, for the purpose of displacing the damp and fetid atmosphere, which prevails underground, even supposing that neither choke, nor fire damp are given out from the strata. To meet this contingency, the amount of air required to dilute and disperse the choke-damp, is taken in the following estimates as the minimum amount of ventilation, required in all mines free from fire-damp. It will be necessary, therefore, first to ascertain this quantity, and then to determine that needed in fiery, and very fiery collieries.

It has been shown, that it is necessary to mix choke-damp with 50 times its volume of pure air to restore and maintain the vitality of the atmosphere. By taking the mean of the areas of the galleries and chambers of a mine, and assuming the rate of production of the gas, its volume may be ascertained, so as to approximate very nearly, to a definite rule, sufficient for practical purposes. For instance, supposing the stalls to have an area of 90 feet, the headways of 33 feet, and the air-ways of 16 feet, as in South Wales, the mean area is 46·33 square feet; according to the system of working in the Northern districts, the mean area would be from 45 to 60 feet. For the present purpose 50 square feet are taken as an average area, which may be easily modified, as circumstances may require. To ascertain, in the absence of eudiometry, the quantity of choke-damp present, there is a guide in the fact, that in mines infested with it, in certain states of the weather, candles frequently will not burn, or burn so dimly, that the men are unable to pursue their work. Now as it requires one part of carbonic acid to eight parts of common air, to destroy its power of supporting combustion, this may be taken as a measure of the choke-damp present, which is equal to $12\frac{1}{2}$ per cent. To avoid exaggeration, it will be best to take only 10 per cent. as the basis of a general rule.

Therefore $\frac{10 \text{ per cent.} \times 50 \text{ feet area}}{100} = 5$ cubic feet of choke-damp, which multiplied by 50 times its volume gives 250 cubic feet per second, or 15,000 cubic feet of air per minute. But some regard must be had to the length, as well as to the height and

breadth of the openings in a mine, as although the gases are known to ooze out of the strata most plentifully, during the miner's operations of cutting, or hewing the coal, yet it is equally certain, that it is given out, although less abundantly, in all other parts of the mine. To maintain the atmosphere of the mine in a salubrious state, the quantity of air ought to be doubled every 10 miles it has to travel, as in that distance it would gather up, in its progress, sufficient choke-damp to render it as foul as it was at first; one-tenth of the whole quantity required, ought thus to be added, for every mile the air has to course through the mine.

The air needed for respiratory purposes was estimated on the supposition, that its temperature was at 60° Fahr., which is about 10° below the usual temperature of collieries; when thus heated, the volume is dilated, and therefore contains less oxygen in a given measure, than has been determined, as necessary for the requisite purposes; the quantity must therefore be increased, in proportion to the increase of temperature. But as the barometrical pressure is increased by the depth of the pit, a correction must be made on this account. Supposing 100 men to be employed, in a mine requiring 15,000 cubic feet of air, and adding 1,680 cubic feet for respiration, the increased volume, minus that due to additional pressure, amounts to 330 cubic feet, which is equal to 3·30 cubic feet per man. To avoid complexity in the calculations, and to simplify the rules, this contingency may be provided for, by adding the amount due to expansion (3·30 cubic feet) to that required for respiration (16·80 cubic feet) and taking 20 cubic feet of air per man per minute, as the quantity required for men, horses and lights.

In mines, therefore, free from fire-damp, and whose areas are of a mean of 50 square feet, and in which 100 men are employed, the basis for calculating the quantity of air required is:—

For diluting choke-damp, &c.	15,000	} 17,000 cubic feet per minute.
For respiration and combustion.	2,000	

To this basis must be added one-tenth of its volume, for every mile the air has to course through the mine.

The following table shows the air required in a mine of 50 feet mean areas, employing from 30 to 200 men, and the air coursing different distances as stated.

Number of Men.	CUBIC FEET PER MINUTE.						
	Basis.	1 Mile.	2 Miles.	3 Miles.	4 Miles.	5 Miles.	10 Miles.
30	15,600	17,160	18,720	20,280	21,840	23,300	31,200
40	15,800	17,380	18,960	20,540	22,120	23,700	31,600
50	16,000	17,600	19,200	20,800	22,400	24,000	32,000
60	16,200	17,820	19,440	21,060	22,680	24,300	32,400
70	16,400	18,040	19,680	21,320	22,960	24,600	32,800
80	16,600	18,260	19,920	21,580	23,240	24,900	33,200
90	16,800	18,480	20,160	21,840	23,520	25,200	33,600
100	17,000	18,700	20,400	22,200	23,800	25,500	34,000
120	17,400	19,140	20,880	22,620	24,360	26,100	34,800
130	17,600	19,360	21,120	22,880	24,640	26,400	35,200
140	17,800	19,580	21,360	23,140	24,920	26,700	35,600
150	18,000	19,800	21,600	23,400	25,200	27,000	36,000
160	18,200	20,020	21,840	23,660	25,480	27,300	36,400
170	18,400	20,240	22,080	23,920	25,760	27,600	36,800
180	18,600	20,460	22,320	24,180	26,040	27,900	37,200
190	18,800	20,680	22,560	24,440	26,320	28,200	37,600
200	19,000	20,900	22,800	24,700	26,600	28,500	38,000

The universal applicability of the rule will be readily appreciated, by an inspection of the subjoined table in which the quantities required for different areas, the air coursing the distances mentioned, is shown. The air required for men, horses and lights is omitted to avoid complexity, but when practically applied, must be added to the amounts stated in the "basis" column.

Mean Areas Sq. Feet.	CUBIC FEET PER MINUTE.						
	Basis.	1 Mile.	2 Miles.	3 Miles.	4 Miles.	5 Miles.	10 Miles.
25	7,500	8,250	9,000	9,750	10,500	11,250	15,000
30	9,000	9,900	10,800	11,700	12,600	13,500	18,000
35	10,500	11,550	12,600	13,650	14,700	15,750	21,000
40	12,000	13,200	14,400	15,600	16,800	18,000	24,000
45	13,500	14,850	16,200	17,550	18,900	20,250	27,000
50	15,000	16,500	18,000	19,500	21,000	22,500	30,000
55	16,500	18,150	19,800	21,450	23,100	24,750	33,000
60	18,000	19,800	21,600	23,400	25,200	27,000	36,000
70	21,000	23,100	25,200	27,300	29,400	31,500	42,000
80	24,000	26,400	28,800	31,200	33,600	36,000	48,000
90	27,000	29,700	32,400	35,100	37,800	40,500	54,000
100	30,000	33,000	36,000	39,000	42,000	45,000	60,000

Were the per-centage of gas accurately ascertained by the eudiometer, the air required in mines would be easily and certainly known; but in the absence of such data, it would be imprudent to presume on less than 10 per cent. of gas, and even

when the quantity has been ascertained by the eudiometer to be less, the amount of oxygen in the atmosphere ought also to be tested, and sufficient air ought to be introduced, to establish and maintain the same relative proportion of vital air in the mines, as on the surface of the earth.

Fiery mines are those in which fire-damp exists, but not in large quantities; and very fiery mines, those in which it is found to such an extent, as to render the atmosphere explosive.

In the absence of better data, the measure of fire-damp in fiery mines, may be taken, at a minimum, as equal to that proportion which causes the enlargement, or elongation of the flame of a candle, or lamp, indicating the presence of one part of fire-damp to 15 parts of air, or 6·67 per cent. of fire-damp. It has been shown, that this gas ought to be diluted with 30 times its volume of pure air; then taking, as before, the mean area at 50 square feet, $\frac{50 \text{ feet area} \times 6\cdot67 \text{ per cent.}}{100} = 3\cdot33$ cubic feet

of fire-damp which $\times 30$ volumes gives 100 cubic feet per second, or 6,000 cubic feet per minute, as the quantity of air required to dilute this gas. But as this quantity of air is in addition to that required for dispersing the choke-damp, which is equal to 5 times the mean area, in a fiery mine the area must be multiplied by 7, to give the whole amount of pure air per second, which is required for the dilution and displacement of both these gases. In a fiery mine of 50 feet mean area the basis for calculation is $(50 \times 7 \times 60) = 21,000$ cubic feet per minute, to which must be added, the air required for respiration and combustion, and one-tenth of the whole per mile, for the length of the air-courses.¹

In very fiery mines, in which the safety-lamp is used, the atmosphere may be fairly considered to be in an explosive state, and therefore consisting of 1 part of fire-damp to 8 parts of common air, or as containing $12\frac{1}{2}$ per cent of gas. Therefore $12\cdot5 \text{ per cent.} \times 0\cdot3 = 3\cdot75$ multiplier of the mean area;

$$^1 \frac{10 \text{ per cent} \times 50 \text{ volumes}}{100} = 5$$

$$\frac{6\cdot67 \text{ per cent} \times 30 \text{ volumes}}{100} = 2 + 5 = 7$$

$$\frac{12\cdot5 \text{ per cent} \times 30 \text{ volumes}}{100} = 3\cdot75 + 5 = 8\cdot75$$

but to this, the multiplier for choke-damp, must be added, giving $(3.75 + 5) = 87.5$ as that for very fiery mines; which in a mean area of 50 feet, as before, makes the air necessary for the dilution of gases 26,250 cubic feet as the basis for calculation.

The rules inferred from the premises of this inquiry are therefore as follows:—

In mines quite free from fire-damp, multiply the mean area by 5; in fiery mines, as described, multiply the mean area by 7; in very fiery mines, multiply the mean area by $8\frac{1}{2}$; which will give the quantity of air required for the dilution of choke and fire damp, per second, or multiplied by 60, the amount per minute. To this must be added the air needed for respiration and combustion, at the rate of 20 cubic feet per minute, per man, employed in the mine; the sum of these amounts to be the basis for calculating the increased quantity required for the distance the air has to travel, one-tenth being added for every mile, or the whole quantity doubled in ten miles. By the application of these simple rules, the quantity of air required in a mine, may be always correctly ascertained. To be safe, however, the use of the eudiometer is indispensable; if the per centage of fire-damp be greater than $12\frac{1}{2}$, say for instance 15 per cent., the multiplier must be increased accordingly; for 15×0.3
 $\frac{100}{100} = 4.5$ to which if 5 be added for choke-damp, makes the multiplier of the area $9\frac{1}{2}$ instead of $8\frac{1}{2}$ as before.

The quantity of air shown by these rules to be requisite, may appear large when compared with the practice pursued in some districts, but when contrasted with the ventilation of some of the large and well-conducted mines in the north of England, a near approximation is apparent; for instance, the Hetton Colliery is ventilated with 198,000 cubic feet of air per minute. Taking the mean of its areas as 54 square feet, the distance the air has to travel, 70 miles, and the number of men employed as 1,000, and supposing it to be classed as a fiery mine, 172,760 cubic feet would be required by the rule, or, if it be very fiery, 212,450 cubic feet per minute.

In Haswell colliery there are 94,900 cubic feet per minute; taking the mean area at 50 feet, the air-courses 35 miles, and the number of men at 500;—by the rules, as a fiery mine, it

requires 77,000 cubic feet, and as very fiery, 95,375 cubic feet per minute.

The ventilation of Seghill is said to be 42,708 cubic feet per minute ; as a fiery mine it would require 45,680 ; and, as very fiery, 56,600 cubic feet per minute.

Many other instances might be given, but these, it is presumed, will be deemed sufficient to demonstrate the accuracy and general applicability of the rules proposed.

The following statement of the amount of ventilation in the several collieries named, shows the great diversity of practice which prevails, and the necessity for some certain method of determining the quantity of air really required :—

	Cubic Feet per Minute.		Cubic Feet per Minute.
Derwent Main	2,000	Coxlodge	20,000
Middleton	4,445	Ardsley Main	30,957
Thorpe Hall	5,442	Castle Eden	42,326
Tordoff, Low Moor	5,925	Felling	54,000
Holmside	8,900	Willington	66,500
Emroyd	10,408	Wearmouth	70,500
Mickley	12,856	Seaton Delaval	82,320
Eaglesbush	13,560	Haswell	94,900
West Auckland	14,478	Wallsend	121,360
West Hetton	15,300	Tyne Main	94,810
Gosforth	16,000	Murton and South Hetton .	132,895
Eldon	19,179	Hetton	198,000

Thus, in twenty-four collieries, the ventilation varies from 2,000 to 198,600 cubic feet per minute ; and although it is quite true that one colliery may be better ventilated with 20,000 cubic feet than another with 100,000, yet there can be no doubt, that the great discrepancy observable is more than is warranted by the peculiar circumstances of each mine, and also that it may be attributed to the non-existence of rules, by which the quantity absolutely required might be readily ascertained. The insufficiency of the ventilation, in many instances, is confirmed by an examination of the records of explosions, imperfect though they are, for it appears there have been thirty-one explosions in ten of these collieries, by which six hundred and forty-six men were killed ; if, therefore, a comparison be made between the ventilation herein recommended, and that shown to be adopted in the majority of the mines mentioned, and if it be found that the amount by the proposed rules considerably exceeds that allowed in many instances, it ought not

to prejudice the theory herein advanced, but to excite reasonable doubts as to the sufficiency of the existing scale of ventilation.

It has been alleged, that the fire-damp is produced in such abundance in some collieries, that it is impossible to force a sufficient quantity of air into the mine to dilute it to a state consistent with safety. This allegation is inconsistent with recorded facts and opinions. Mr. Nicholas Wood, (M. Inst. C.E.) of Newcastle-upon-Tyne, in his evidence before the Committee of the House of Lords (1849, Query 1843), says that 1,000 cubic feet of fire-damp per minute exceeds the quantity ordinarily produced in any mine of that district, which is the most fiery in the kingdom ; therefore, the very moderate ventilation of 30,000 cubic feet of air per minute is all that is required to deprive this gas of its dangerous properties. But in addition to the gas ordinarily produced in mines, the colliery is sometimes suddenly inundated by a much larger quantity, in consequence of the workmen incidentally tapping a reservoir, or "bag of fire-damp," when the gas issues in a continuous stream by what is called "a blower," or, on the fall of the roof, it escapes in large volumes. Such casualties are fraught with great danger, and imperiously require consideration in every system of ventilation. Mr. Wood states, that the blower at Wallsend Colliery discharges 120 cubic feet of gas per minute ; and Mr. Mather gives the following as the greatest quantities of fire-damp that are known to have issued from blowers :—

Cubic feet per Minute.

In St. Hilda's Pit, in 1841, for 5 days .	1,799
In Jarrow Pit, 2nd February, 1841 .	4,000
In Percy Main, March, 1840 .	2,618
In Wallsend, from a goaf ¹ of 5 acres .	52

It is obvious that the danger arising from the sudden irruption of such large quantities of gas as even the last amount named, must be very considerably increased, when the ventilation is maintained by allowing ten, or twelve parts of air to one of fire-damp, in which state even an inconsiderable addition of gas renders the atmosphere explosive ; yet this ventilation has been sanctioned by high authorities, and is, in many instances, the maximum attempted. When it is recollected, that one part

¹ This word is evidently derived from the Welsh "Ogof," a cave, or den.

of fire-damp, to eight parts of common air, makes the most explosive atmosphere, the impolicy and danger of such a system must be apparent ; but if, as herein recommended, the fire-damp be mixed with thirty times its volume of air, the danger in most cases would be entirely avoided : but wherever blowers are known to exist, the per centage of gas produced by them ought to be accurately taken, and a liberal addition made to the amount of ventilation in consequence, for the quantity of the air required ought always to be calculated on a maximum scale, so as to be amply sufficient, not only for good ventilation under ordinary circumstances, but also to prevent the occurrence of an explosion by such contingencies, and to preserve the men in full bodily health and vigour.

In conclusion, it may be observed, that the results of this investigation clearly demonstrate the possibility of determining the quantity of air required in mines, by the means here proposed. The rules which have been proposed, have been deduced from the scientific principles advanced, and have been so formed as to suit the varied conditions of all mines, however different their peculiar circumstances. This has been exemplified by comparing the amount of ventilation, as required by the rules, with that maintained in three collieries of different areas and lengths of air-courses, by which it appears that the results of the theory approximate very nearly to the practice pursued in well-conducted mines. The great simplicity and easy applicability of these rules can scarcely fail, it is presumed, to be a strong recommendation for their adoption, and it must be evident, that by the substitution of principles for the mere guess-work now so prevalent, a great improvement may be rationally anticipated in the ventilation of mines, upon which the happiness, or misery, and the life, or death, of so many of the industrial population of this country mainly depend.