SOME PHASES OF THE COAL-DUST QUESTION.[1]

UP to the year 1875 all great colliery explosions in this country were attributed to the accidental ignition of a large volume of firedamp that had either previously existed in an abandoned empty space, or goaf (like that which admittedly caused the Whitehaven explosion in May 1910), or was supposed to have burst suddenly into the workings and filled them with inflammable gas. In the absence of a goaf, and when, for some reason or other, the occurrence of an "outburst of gas" was not assumed, the cause of the explosion was described as a mystery.

In 1845 Faraday and Lyell directed attention to the presence of crusts of coked coal-dust and to the evidences of intense heat which they had observed in the workings of Haswell Colliery after an explosion, which they, no doubt correctly, assumed had been caused by the accidental ignition of a large quantity of firedamp in the goaf. Following up that assumption, they remarked that "there was every reason to believe that much coal-gas was made from this dust in the very air itself of the mine by the flame of the firedamp, which raised and swept it along."

These words indicate clearly, I think, what was in their minds, namely, that the participation of the coal-dust was an important, but by no means an essential, incident in the firedamp explosion.

During the fifteen years preceding 1875 some French engineers expressed the opinion that coal-dust must have greatly lengthened the flame of certain small explosions of firedamp and blasting shots, and aggravated the consequences to a corresponding extent; and one of them, M. Verpilleux (whom, however, none of his contemporaries seemed disposed to follow), went so far as to compare, in relative importance, the initial flame with that of the priming, and the coal-dust flame with that of the discharge, of a gun.

I had been seeking for a rational explanation of great explosions for some years before I came to South Wales as assistant inspector on mines. Before that time I had had much experience in investigating the causes of small firedamp explosions in damp and wet mines in Scotland, but of no explosions of any kind in dry and dusty mines. Accordingly, when I found that all the great explosions in this district had occurred in mines of the latter, and none of those of the former class, I began to associate them with the presence of coal-dust. Acting under this impression, I made experiments in the summer (July 3) of 1875 with a mixture of coal-dust and air, which was made to flow through the small wooden apparatus described in my first paper on coal-dust referred to hereafter. I found that when a small proportion of firedamp, less than that contained in the return airways of practically every fiery mine, was added, the resulting mixture could be ignited by means of a naked light, and continued to burn with a dark yellow, smoky flame so long as coal-dust and firedamp were supplied to the current. This discovery proved to my entire satisfaction that coal-dust, although consisting of solid particles, played exactly the same part as a combustible gas when disseminated in the air—could, in fact, be substituted for firedamp, and did not require the extraneous heat of a firedamp flame, as imagined by Faraday and Lyell, "to distil coal-gas from it." So far as I was personally concerned, the question was solved then and there; that is to say, I had no longer a shadow of doubt that coal-dust played the principal, and firedamp only a subordinate, part in all great explosions; or, again, that coal-dust played the part that had been assigned to "outbursts of gas" by the colliery explosion experts and inspectors of mines of that day and of many previous years.

In December of the same year, when an explosion, by which seventeen men lost their lives, occurred in a dry and dusty district in Llan Colliery, near Cardiff, I made a careful study of all the circumstances, attended the inquest, and gave evidence[2] to the effect that in my opinion coal-dust had been the paramount factor in the explosion; that the coal-dust had been swept up from the floor, mixed with the air, and ignited by the explosion and flame, respectively, of a comparatively small volume of firedamp, and that this gas had itself been accidentally ignited by a naked light.

At the same time I made some further experiments with coal-dust, as well as another series to determine the height of the firedamp cap corresponding to various mixtures of air and firedamp containing carefully measured proportions of each (a subject that had not been previously investigated). I then prepared a paper entitled "On the Influence of Coal-dust in Colliery Explosions," and through the late Dr. Frankland presented it to the Royal Society, by whom it was published in the following March (Proc. Roy. Soc., vol. xxiv., p. 354).

Early in 1876 Mr. (now Sir Henry) Hall carried out his celebrated experiment with a blasting shot, and published an account of it in June of the same year; two years later Prof. Marrecco and Mr. Morison, and four years later Sir Frederic Abel, made experiments with coal-dust, and in 1886 the two inspectors of mines Messrs. W. N. (now Dr.) and J. B. Atkinson published a book describing explosions in certain mines in their respective districts, which they attributed to coal-dust.

Owing chiefly, as can now be fully appreciated, to the small proportions of volatile matter contained in the two kinds of coal-dust with which my experiments were made (about 16·5 per cent. and 18·5 per cent. respectively), and partly, no doubt, also to the swiftness of the air-current necessary to sustain it in suspension in the apparatus, I had not up to this point proved that a mixture of air and coal-dust, at ordinary pressure and temperature, could be ignited by means of a naked light. On the other hand, I had proved that, when less than 1 per cent. of firedamp was added to such a mixture, it could be so ignited, and continued to burn like a large jet of inflammable gas. Again, at p. 369 of my first paper I stated the opinion that "if coal-dust could be made fine enough, and were thoroughly mixed with dry air in the proportion of about one pound to 160 cubic feet of air, the mixture might at least be so nearly inflammable" (at ordinary pressure and temperature) "that an explosion begun in it in a confined space," like the workings of a mine, "might be propagated through it"; and, further, on September 7, 1878, I said, in *Iron*:—

"It must not for a moment be supposed by anyone who has perused the foregoing pages that because I have only spoken of mixtures of air and coal-dust, or of air, coal-dust, and firedamp, as forming feebly explosive mixtures, I mean to imply that they cannot produce any, or all, of the results observed in the most destructive explosions that have ever been witnessed. I have constantly made use of the qualifying expression "*at ordinary pressure temperature*," thereby signifying that their behaviour at extraordinary pressure and temperature, such as are brought into play when an explosion is begun in a confined space, like the interior of a mine, may be, and probably is, very different." "That they do behave very differently has long been my settled conviction. . . ."

I entertained no doubt in my own mind as to what result would follow the initial stage, but in laying the question before the Royal Society and others I could not go beyond proved facts, and hence the necessity of approaching it hypothetically in my first paper, as follows (*loc. cit.*, p. 354):—

"If it could be shown . . . that a mixture of air and coal-dust is inflammable at ordinary pressure and temperature there would be no difficulty in accounting for the extent and violence of many explosions which have occurred in mines in which no large accumulations of firedamp were known to exist; for it is only necessary to suppose that a sudden gust of wind (originated, for example, by the explosion of a small accumulation of firedamp) had swept through the adjoining galleries, raising a cloud of dust into the air, and then all the other phenomena would follow in regular order. The flame of the originally inflammable mixture would pass directly into the newly formed one, expanding its volume; the disturbance would be propagated over an ever-widening area until that area might possibly become co-extensive with the workings themselves; and the consequences would be the same as if the whole space had

[1] Abridged from the Presidential Address delivered to the South Wales Institute of Engineers on January 18 by Prof. W. Galloway.

[2] Published *verbatim* in the *South Wales Daily News* of December 22, and *Western Mail* of December 23, 1875.

been filled with an inflammable mixture before the disturbance began."

It was demonstrated a few years later (Proc. Roy. Soc., No. 219, p. 437), by means of a larger apparatus built at Llwynpia Colliery with funds provided by the Lords of Committee of Council on Education, at the instance of the Royal Society, that a mixture of air and coal-dust from the same sources and of the same quality as that which had been used in my first experiments was inflammable at ordinary pressure and temperature. The cloud of coal-dust thrown out of that apparatus into the open air, in some instances from 30 to 50 feet long by from 10 to 15 feet in diameter at its widest part, was permeated with rolling flames in identically the same manner as, although on a smaller scale than, the corresponding clouds ejected from the larger apparatus at Altofts and Liévin.

It might have been expected that this final proof would have settled the question definitely; but, as its subsequent history shows, the number of those who began to discuss it has been so great, and their opinions so diverse, that but little progress has been made during the thirty years that have since elapsed.

The object of my experiments was to elucidate the causes of great colliery explosions. They were a means to that end, and nothing more. For it appeared to me that if once the causes were known a means of prevention would be easily discovered, but that, so long as explosions continued to be attributed to outbursts of gas, which could neither be foreseen nor prevented, the safety lamp would be looked upon as the miners' only shield against a constantly threatening danger.

Proneness to attribute all explosions to firedamp was the real stumbling-block to progress. It held the French engineers and many others in bondage for thirty-one years after 1875, and was only finally and effectually removed by the occurrence of the Courrières explosion and the sensational phenomena subsequently revealed in the experiments at Altofts and Liévin.

After arriving at the conclusions narrated above, I sketched out in another article, which was published in *Iron* in 1878, what appeared to me to be two necessary additions to the Coal Mines' Regulation Act, as follows:—

(1) "No shot must, on any pretence whatever, be fired in a dry mine until the floor and sides of the working place, or gallery, in which it is situated have been drenched with water, and rendered artificially damp, to a distance of at least 15 yards from the shot-hole."

(2) "In every naturally dry mine water shall from time to time be sprinkled on the roadways, and in the neighbourhood of the working places, in sufficient quantities to render them damp at all times, both by night and day."

In 1886 the first of these two rules was adopted in the Coal Mines' Regulation Act, 1886–7, but 20 yards was specified instead of 15; the second was voluntarily adopted almost immediately in many mines in South Wales and elsewhere, and was made compulsory by the Prussian Government in 1899–1900, but is not insisted on by the law of this country.

I can still conceive of no better safeguard against the dangers of shot-firing than that of rendering the dust harmless with water in the manner now specified in the Coal Mines' Regulation Act, provided it be properly carried out. As regards the second precaution, I am now of opinion that universal watering might be safely dispensed with if a zone of wet ground of adequate breadth were created round about every accumulation of explosive gas or every point at which such an accumulation is liable to occur in open spaces near the working places or accessible to the workmen.

Although French engineers had taken a prominent part in the assigning of a certain *rôle* to coal-dust thirty or forty years ago, they rejected the coal-dust theory from the first, and continued to oppose it until within the last few years, concentrating the whole of their attention, as M. Taffanel tells us, upon discovering the best means of dealing with firedamp. As an indication of their attitude, I may quote the words of M. H. Le Chatelier, who, writing in 1890 regarding the three supposed special causes of explosions, viz. barometric variations, coal-dust, and outbursts of gas, expressed himself as follows:—

"The first is purely imaginary, the second is insignificant in the absence of explosive mixtures of firedamp and air, the third alone is really serious, but happily it occurs only under very exceptional circumstances."[3]

It is remarkable, therefore, that the sudden blow which eventually shattered this opposition and brought the coal-dust question into world-wide prominence, namely, the great disaster at Courrières Colliery in 1906, in which more than 1100 men perished, should have fallen upon France herself. The effect was immediate; commissions and committees were hastily called together or revived, thousands of pounds were forthcoming for experiments, apparatus on a comparatively gigantic scale was erected in England, France, and the United States, and experiments were resumed in an artificial gallery in Austria that had been disused for several years.

In the midst of this great awakening in the coal-mining world, the Mines Department of the Prussian Government, which formulates and promulgates the laws governing the safety of the Westphalian coal mines, remained apparently unmoved.

In 1884 the Prussian Firedamp Commission made experiments with coal-dust on a fairly large scale in an artificial gallery at Königsgrube, Saarbrücken, some of which were seen by Lord Merthyr and myself on October 24 of that year. The dust employed in these experiments was collected from the floors of various collieries producing coal of different qualities, and as it was submitted to the test without having been sifted to remove the coarser particles and reduce it to a uniform degree of fineness, the different kinds naturally gave different results. As a consequence, the commission reported that although some kinds of dust produced explosive phenomena, and were therefore highly dangerous, others did not do so under the same conditions, and might, therefore, be considered safe. Acting under this impression, they recommended, first, a system of watering in a general way in dangerous mines; secondly, the use of brisant and short-flaming explosives in place of gunpowder in all dusty mines; and, thirdly, the thorough damping of the dust for a distance of at least 10 metres in front of every blasting shot.[4]

Soon after the completion of the experiments water-mains were laid in the Saarbrücken mines, which belong to the Prussian State,[5] and later some of the large Westphalian mines began to follow their example; but very little was done in this direction until after the occurrence of a disastrous explosion at Carolinenglück Colliery on February 17, 1898, by which 116 men were killed.

Experiments with shots charged with gunpowder on the one hand, and with brisant explosives on the other, in the presence of inflammable gas and coal-dust, were begun more or less simultaneously in Germany, France, and other Continental countries, and in England both with brisant explosives and water-cartridges, early in the nineteenth decade of last century. I had the honour of conducting those carried out in this country during a period of several years, with the collaboration of Lord Merthyr, who was a member of the Royal Commission on Accidents in Mines, under the auspices of which they were made.

As the result partly of the voluntary, partly of the legislative, action taken in this country, it will be seen from the following table that there has been a marked diminution in the number of deaths from explosions during the last thirty years, notwithstanding the increase of more than 50 per cent. in the number of men employed and in the output of coal:—

Year, or Average of Period Named.

Period		Output	Men employed underground	Number of deaths
1 year	1851	—	—	321
1 ,,	1852	—	—	264
10 years ending	1862	—	—	216
,, ,, ,,	1872	128,680,321	403,281	238
,, ,, ,,	1882	168,921,705	461,024	263
,, ,, ,,	1892	203,322,840	588,446	147
,, ,, ,,	1902	250,940,800	747,509	104
9 ,, ,,	1911	—	—	134

[3] Le Grisou et ses Accidents, Extrait de la Revue Générale des Sciences pures et appliquées. No. 20, du 30 Octobre, 1890, p. 19.

[4] Hauptbericht der Preussischen Schlagwetter Commission, p. 221 (1887.)

[5] Die Entwickelung des Niederrheinisch-Westfälischen Steinkohlen-Bergbaues, vol. ii., p. 6 (1904).

The high average of the last period of nine years is due to the occurrence of two great explosions, admittedly of coal-dust, in which 480 men were killed. To my personal knowledge these two explosions might have been avoided had ordinary precautions been taken of the kind referred to above. But for these two explosions the average of the last nine years would have been 80 instead of 134, or the lowest on record for sixty years.

In the United States, the greatest coal-producing country in the world, the coal-dust question attracted scant attention until 1907, when the total death-roll from coal-dust explosions, so-called "windy shots," and gunpowder explosions reached the appalling figure of 1148.

In 1908 Congress was induced to vote a sum of money for the investigation of mine explosions; the Geological Survey was entrusted with the work, and on December 3 of the same year a testing station that had been built at Pittsburg during the interval was formally opened.

The recent experiments have corroborated the announcement made many years ago that an explosion capable of propagating itself through the workings of a mine cannot be initiated unless the cloud of dust and air is both large dense, and is ignited by a flame preceded by an air-wave.

The quantity of dust ordinarily in the air, or raised by the passage of a train of mine waggons, however rapidly they may be moving, is far too tenuous to be in the slightest degree inflammable.

M. Taffanel states[6] that the minimum quantity of the very highly inflammable coal-dust employed in his experiments that must be suspended in still air before the mixture can be ignited by a large flame like that of a comet lamp is 1 lb. to 80 cubic feet; that the probability of a dust-cloud of that density being formed in any mine working under normal conditions is extremely feeble; and that even "in working places called *very dusty* or *smoking* the density does not exceed more than a few grams per cubic metre" (say, one-third of an ounce in 80 cubic feet, or about one-fiftieth of that required to render the mixture inflammable).

I mention these facts in order, if possible, to counteract the exaggerated notions that have sometimes of late been expressed regarding the dangerous nature of coal-dust even in a state of quiescence, some persons seeming to credit it with qualities akin to those of gunpowder.

The relative fineness of the dust, proportion of volatile matter contained in it, and quantity present per unit of length in the experimental gallery determine the velocity of the flame and the pressure attained by the explosion at any point. When all three conditions are favourable the velocity and pressure increase rapidly with the distance traversed, and if the distance is sufficiently great the pressure is liable to burst the gallery, as it did in one or two instances—at Altofts and Liévin. As the dust for experiments is prepared mechanically from pure coal, and may be made far finer than the average of that found in any colliery, it follows that the velocity and pressure of explosions in the artificial galleries may be, and no doubt in many cases are, far greater than those that occur in an explosion in a dry and dusty mine, for in the latter the dust swept up by the airwave which precedes the flame contains a mixture of coarse and fine particles of both combustible and incombustible matter. But the coarse particles of both and the fine particles of incombustible matter reduce the temperature of the flame, and, consequently, both its velocity and pressure must necessarily be reduced in a corresponding ratio.

It is recognised, then, that the conditions under which experiments are made in an artificial gallery are not quite the same as those which obtain in a mine, and that the results observed in the one case may be essentially different in many respects from those experienced in the other. Hence it arises, probably, that although experiments have been assiduously carried on in artificial galleries for several years, no distinct pronouncement has yet been made as to the best means of either preventing or arresting explosions.

The Altofts gallery has been lent to a joint committee consisting of the original committee of colliery owners and members of the Royal Commission on Mines, which is stated to be about to undertake further experiments; M. Taffanel, who conducts the experiments for the French colliery owners, continues his experiments, and has sketched out a programme for many more; the Austrian investigators have made experiments with mixtures of coal-dust and cement-dust, with watered zones, and with what they designate water-curtains, which have not given satisfactory results; and, lastly, the experiments at the Pittsburg gallery have been only of a preliminary character so far as described up to the present, and have shed no particular light on the subject.

So far, then, no finality has yet been arrived at, and all the investigators have intimated that they have many more experiments still to carry out. But since these experiments were begun, and since the dangerous nature of coal-dust has been publicly demonstrated by their means, two explosions, fit to take rank with the most disastrous of last century, have occurred in this country, showing that the demonstrations have been futile so far as stimulating spontaneous action on the part of some managers to take even ordinary precautions is concerned. Partly for this reason, and partly because we may have to wait for some years longer before the investigators arrive at a unanimous decision as to what they think ought to be done, it would perhaps be well in the meantime to adopt a course that would undoubtedly have the effect of vastly reducing, if not entirely eliminating, the risk of explosions, both in damp and dry mines, by establishing three simple rules of the following import:—

(1) That in all dry mines the dust within the radius of a shot-hole now specified by the Coal Mines Act be damped *with sprinklers attached to a water-main.* (I am of opinion that the distance of 20 yards from the shot-hole, within which the dust is required to be watered according to the existing law, is unnecessarily great, and that with the short-flaming explosives and water-cartridges now in use a distance of 10 yards is ample.)

(2) That in all dry mines the dust be damped within a certain minimum radius of every accumulation of inflammable gas, or place in which the air shows a cap of one-quarter of an inch or upwards in height, by the same means as those mentioned in the first case.

(3) That all work be prohibited in both damp and dry mines within a certain minimum radius of every accumulation of inflammable gas, or place in which the air shows a cap of more than one-quarter of an inch in height, excepting only that required for the removal of the accumulation, or foul air, respectively.

[6] Cinquième Série d'Essais sur les Inflamma'ions de Poussières, Août, 1911, p. 68.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

BIRMINGHAM.—The Coal Owners' Associations of the South Midland district, realising that rescue work in mines is a subject in connection with which research is desirable, have arranged with the University for the appointment of a lecturer in mine rescue work. The stipend of the lecturer will be defrayed by the Coal Owners' Associations, the amount offered being 250*l.* per annum. The functions of the lecturer will be not only to give lectures and instruction in the subject at the University, but also to be responsible for the organisation of rescue work, and to superintend the equipment and training of rescuers throughout the district.

Mr. John Furneaux Jordan has been appointed Ingleby lecturer for the current year.

LONDON.—The report of the Royal Commission on University Education in London, recommending a central building for the University, to which we referred in an article published in NATURE (January 4), has already produced an important scheme for the acquisition of a vacant site of more than 100,000 square feet immediately behind the extension of the British Museum. The site consists of four plots, two on each side of the new British Museum Avenue, on one of which it is proposed that a spacious hall should be built for the University, the other three plots being used for administration, library, small lecture theatres, rooms for graduates, and headquarters of the Officers Training Corps. The site is part of the Bedford estate, and it is stated that the Duke of Bedford is pre-