Mr. Cochrane. ments with which he had been connected in 1875 and 1876, when the first steps were taken in this country, after certain indications given by Mr. Vital in the "Annales des Mines," that small coal-dust, *per se*, was explosive without the possibility of admixture with carburetted hydrogen. Probably everyone would be impressed by the perusal of the Paper with the idea that a slight admixture of firedamp was necessary for an explosion. He did not know what would be called an explosion, but if, as in an experiment which he conducted with Professor Marreco, in January 1876, in the laboratories of the Physical Science College at Newcastle-on-Tyne, a detonation and the projecting of two small cast-iron weights from the top of a model drift, one going uncomfortably near his head, and the other across the experiment room, were to be called an explosion, it certainly took place, with the use of coal-dust alone, there being no possibility of having gas anywhere near where they were operating. A Davy lamp gauze formed the roof of the model drift, on which the dust coal was placed, a small Guibal fan supplied the air-curret, and by rapping the side of the model drift the coal-dust fell, and a small pistol was fired into the drift. The result was an explosion, which ripped up the model and destroyed the Guibal ventilator employed to maintain the air-current. That showed that there was no necessity for the presence of even the smallest percentage of gas, which had been so much dwelt upon, and which the Author concluded was necessary.

*** Sir FREDERICK ABEL'S reply to the discussion will be found at the end of the Correspondence.

Correspondence.

Mr. Ashworth. Mr. JAMES ASHWORTH remarked that in general arrangement the Ashworth-Clanny lamp was similar to the Clanny lamps he sent to the Mines Accident Commission in May, 1882, known in the report as Clanny's Nos. 17, 18, and 19, which were the first completely shielded lamps tested by the commission; but the details of construction had been so greatly improved, that instead of the illumination produced by the wick flame being respectively 39, 64, and 56 per cent. of a standard sperm candle, the present lamp gave 79 per cent. as tested by Mr. Betley, of the Wigan Mining School. Attached to the screw ring which kept the glass in position, and at right-angles to it, was a thin metallic cylinder

Mr. Ashworth.

reaching nearly up to the level of the top of the wick-tube, and perforated by four holes at its base; the top of the oil-vessel was made of tin or some metal which was a bad conductor of heat. By this arrangement of parts air entering the lamp was brought down the combustion-chamber close to the side of the glass, through the holes in the new ring and over the top of the oil-vessel, thus keeping both the glass and the oil-vessel cool, and also supplying an air-feed to the flame in the best way to secure perfect combustion. The Ashworth-Mueseler, A type, was a combination of his gauze chimney Jack-Davy lamp (called Ashworth No. 2 in the Mines Accident Report), and his shielded Clanny. Its principal novelty was in the substitution of a chimney, consisting of a slightly conical gauze cylinder with a truncated conical metal base, to which this gauze and the horizontal gauze disk were attached, for the metal chimney of the standard Mueseler. Besides being a safer form of chimney, its construction enabled him to increase the illumination of the wick flame, and to reduce the liability of the lamp to become suddenly extinguished when thrown on one side. The B type only differed from the A type in being provided with a second shield (No. 4 of the Mines Accident Report) placed between the outer one and the cylindrical gauze, perforated near its base with a row of inlet holes, and having a conical outlet. The outlet was gauged to permit the products of combustion to escape easily under normal conditions; but when firedamp exploded or burned within the lamp, the outlet was insufficient, and the whole of the interior of the shield became so full of carbonic acid gas, that the inlet air was fouled and all light within the lamp was extinguished at once. This type had been tested by Mr. Rhodes, of Rotherham, by Mr. Morgan, with his blow-pipe apparatus, at a pressure of $1\frac{1}{2}$ lb. per square inch, and lastly by Mr. Clifford, in a horizontal current of upwards of 100 feet per second, without any failure. For officials and firemen, this type of lamp was furnished with a "shut off" on the inlet holes, which, when closed compelled the air of the mine to enter by the holes near the top of the outer shield, and thus to indicate the condition of the air within about $1\frac{1}{2}$ inch of the roof. As soon as the wick flame indicated the presence of gas, the "shut off" was opened to admit purer air, and to avoid the risk of an excessive quantity of gas extinguishing it. The Hepplewhite-Gray Davy lamp was an adaptation of the Gray inlet tubes to the shielded Davy lamp, the shield having a conical outlet similar to that of the Ashworth-Mueseler B, and was fitted with Ashworth's patent for making practical examinations for firedamp. In the Hepple-

Mr. Ashworth. white-Gray of the Clanny type the inlet tubes were protected from dirt falling down by a horizontal ring, which screwed on the body of the lamp, and formed a "shut off" of the most absolute kind. The shield was fitted with a conical outlet to prevent down currents, and to act also as a Mueseler chimney, and was protected from dirt and the direct action of the ventilating currents of the mine by the perforated top on which the "shut off" screwed. The slightly conical gauze inside the shield was not exposed to any dusty current, and as its only duty was to form another protection to the outlet, its dimensions were very small. Its base was furnished with spun copper rings which clipped the top of the truncated conical glass. This form of glass was extremely strong: first, to resist particles of coal or dirt which might be thrown against it, through presenting two inclined planes to ease the direct action of the blow; and secondly, in its adaptability to resist sudden expansion or contraction, because the increase of the diameter of the small end by heat was less than that of the large end, therefore the increase in length was compensated for by the increase in the larger diameter without perceptibly increasing the perpendicular height of the glass. A screwed ring secured this glass in the ordinary way, and was followed by a ring with rectangular openings covered by a strip of gauze, which ring, when screwed close up, left an annular space at the foot of the inlet tubes, and allowed the entering air free ingress to the wick-flame through the strip of gauze. One or more of the inlet tubes of the Hepplewhite-Gray lamps were furnished with Ashworth's arrangement for making practical tests for firedamp, consisting of a hole near the base of the tube, and covered by a slide. It had been discovered, that theoretically the Gray arrangement was the best for obtaining accurate indications of the state of the mine close up to the roof; but practically it was wrong, as when gas entered the tubes it was compelled to pass through the lamp before any fresh air could enter. Thus, in most instances, the wick flame was extinguished, and the lamp rendered useless for making further examinations until relit. When testing with the new arrangement, the slide was pushed up, and the hole in the tube left wide open, thus gas could enter by three tubes from the extreme top, and fresh air from the base of the other; and, supposing that gas did thus enter, it was consumed on one side of the flame whilst the flame itself was maintained by the current of fresh air on the other side. If, on reaching the highest point of the mine, in this way no gas was found, the official gradually closed the hole with his thumb, or with the shutter, and

if no trace of firedamp was then found, it was certain that the place was absolutely clear. He made all tests for gas with the wick flame at its normal height. Thinner strata and smaller percentages of firedamp could be detected with the Hepplewhite-Gray fireman's lamp than with any other shielded lamp. Mr. Ashworth.

Mr. J. B. Atkinson observed that the Author had devoted much attention to mine-accidents, and his high scientific attainments had been of great service to the mining community. But he thought the Author had not yet realized the full importance of the influence of coal-dust in colliery explosions. In stating this it might be remarked that, with no precautions against the existence of firedamp in the passages of a mine, disastrous firedamp-and-air explosions would be frequent; but considering that all the endeavours of mining engineers in the past had been devoted to the prevention of such occurrences, and that these efforts had produced a direct effect in promoting accumulations of coal-dust over long distances, and that in dry mines coal-dust in dangerous quantities was much more ubiquitous and continuous than firedamp, it was a matter of no surprise that the part played by coal-dust in mine-explosions was much more disastrous than the part played by firedamp. Several considerations in favour of the belief that coal-dust was often the main agent of destruction in mine-explosions, and of the view that explosions might originate from, and be propagated by, coal-dust under certain conditions, in air free from any firedamp other than a trace, were advanced in the book "Explosions in Coal-Mines," referred to by the Author. As some of the facts and opinions advanced therein were new, and had not been noticed by the Author, he would venture to refer those interested in the question to the book itself. On the 13th of March, 1884, a disastrous explosion occurred in the Pocahontas coal-mine, Virginia, U.S.A., involving the loss of one hundred and fourteen lives. From a report published in the "Transactions of the American Institute of Mining Engineers,"[1] it appeared that firedamp was unknown in the mine, which, however, was very dry and dusty. The report gave as a condition leading to the explosion "the probable existence of small quantities of firedamp slowly given off from the coal;" but it also stated that "the existence of firedamp in the Pocahontas mine is the disputed point," and nothing was advanced to prove its presence. The Author's statement that explosions ascribed by some to coal-dust and air alone was Mr. J. B. Atkinson.

[1] Vol. xiii. (1885) p. 237.

Mr. J. B. Atkinson.

open to the criticism, that "experimental results which serve to support" such opinion, "are more or less exceptional in character, or that they have been attained under conditions which do not approximate to those likely to occur in a mine," might be opposed by the following considerations. In the many miles of roads in dry mines where coal was led by engine-power against rapid currents of air, causing the formation of deposits of coal-dust of the finest and most inflammable character, in positions where the explosion of a shot must dislodge quantities of it, and where the speed of the air sustained it as a cloud, occasionally, conditions even more favourable than any yet provided in experimental researches, for the ignition of the dust, in air free from firedamp, might be attained. When it was found that shots fired in such roads were the rarest class of shots fired in a mine, and when it was further found that the firing of such shots was often accompanied by an explosion, was it unreasonable to conclude that what had been observed in experiment had occurred in practice; and, while not maintaining the absolute freedom from firedamp of the air (although many mine-managers would maintain it), yet to admit that, so far as evidence could be obtained, the air did not contain sufficient to have any influence on the result? Instead of its being an assumption, as the Author considered it, to maintain that the air in an intake air-way was so free from firedamp as to be perfectly safe, so far as it was concerned, whether coal-dust was present or not, the assumption was in supposing firedamp in definite volume to be present in the absence of any evidence. The fact that 2 per cent. of firedamp must be present, before it could be observed by the safety-lamp, afforded no presumption that a definite volume under 2 per cent. was present in an intake air-way where an explosion had occurred. As the lamp in such situations afforded no test, other considerations must be the guide, and it might be stated that the probable amount of firedamp normally present in intakes was more susceptible of estimation than that present in other parts of the mines. He differed from the Author in the opinion that, in the passages of a mine, the combustion of coal-dust in air was gradual, and attended with less violence than the combustion of firedamp and air, or of a mixture of firedamp, coal-dust, and air; his experience pointed to the reverse being true, with the following exceptions, which he thought might go far to reconcile divergencies of opinion:—(1.) Where the coal-dust was coarse and confined to the floor, as in working-places at the face and roads adjoining, the violence developed was small, even if, as must often be the

case in such situations, a definite but small amount of firedamp was present in the air. (2.) Where coal-dust in a fine dry state existed more or less on all the surfaces of a haulage road, from 50 to 80 yards from the point of origin of an explosion of coal-dust, with air free from firedamp other than a trace, no great violence was observable, and probably the passage of the flame had been gradual. (3.) If over a long distance in a confined passage in a coal-mine, a thoroughly diffused mixture in the most explosive proportion of firedamp and air existed, then probably great violence would be produced on its ignition. It was difficult to point to any great explosion where even the probability of the last condition could be asserted. In the return air-ways of a coal-mine, it might be expected with far greater probability than in the intake air-ways, but great explosions did not affect to any considerable extent the former class of roads. The speed of flame, or rapidity of combustion of a homogeneous gas-and-air mixture, probably reached its maximum within a short distance of the point of ignition, while the reverse was probable in the case of a coal-dust-and-air mixture; if this was true, no experiments had yet been made on a scale of sufficient magnitude to test fully the phenomena of explosions of coal-dust and air. As to the nature of the combustion of coal-dust in air free from firedamp, he would venture with great diffidence to make a few remarks. As a factor, possibly contributing to violence, it might be mentioned that, contrasting a firedamp with a dust-explosion, in the case of the former, if of the most explosive mixture, one-tenth of the amount of oxygen would be replaced by firedamp; while with the dust the road was filled with air, the amount of oxygen limiting the amount of combustion; there was in this way an advantage for the dust. The possibility of a further supply of oxygen existing in the fine dust on the upper parts of a haulage road was worth attention. The combustion in the case of coal-dust might be either that of the gas expelled from the dust, or, if the particles were very minute, possibly the solid matter might be consumed; but in either case, the finer the dust, the more rapid would be the combustion. Supposing the combustion to be that of gas expelled from the dust, then the Author's discovery of the power of finely-divided, even non-inflammable bodies, of promoting inflammation would further help to increase the rapidity of combustion.

Mr. J. B. Atkinson.

Mr. W. N. Atkinson.

Mr. W. N. ATKINSON remarked that various theories had been promulgated in order to account for the occurrence of explosions in coal-mines. Amongst them were blowers or sudden outbursts

Mr. W. N. Atkinson.

of gas, the accumulation of firedamp in goaves, or abandoned workings; the influence of atmospheric disturbances; movements of the earth's crust, or earth tremors; and the presence of coal-dust. It might be pointed out that the only one of these possible causes known to have been present in all extensive explosions, of which there were sufficient records to enable a judgment to be formed, was coal-dust. Sudden outbursts of gas were known to occur sometimes; but many explosions had been attributed to them when no evidence existed that such an outburst had taken place, and where, even if the outburst had occurred, it would be impossible to account for the result by it alone. Extensive explosions had happened in pits where there was no goaf, and in some cases where there were no abandoned workings. The most careful study revealed no sustained connection between large explosions and meteorological conditions, although it was well known that the movement of firedamp in goaves and open spaces was governed to an appreciable extent by atmospheric pressure. The usual opinion was that the period of greatest danger from firedamp was when the barometer was low, and that was probably correct, when modified by the knowledge that the gas was more sensitive to changes of pressure than the mercury. The "colliery warnings," now periodically given in the public press, appeared to indicate that the periods of high atmospheric pressure were considered the most dangerous, but on what grounds was not apparent. The possible influence of earth tremors on explosions had not been sufficiently studied to allow of any positive conclusion on the subject; it was as yet an entirely speculative question. With regard to the influence of coal-dust, it might be pointed out that no extensive explosion had taken place, in recent times, under circumstances which precluded the possibility that coal-dust might have been the chief agent in operation; and the same held good so far as could be judged from the records of explosions in former times. The conclusions arrived at as to the cause of colliery explosions, when the influence of coal-dust was not taken into consideration, were vitiated for that reason. It was a recorded fact that in many recent cases the explosions were confined to those passages in the mines which contained much coal-dust, and did not traverse any roads which were free from coal-dust; even although the roads containing the coal-dust were the intake air-ways, and the roads free from it and not traversed by the explosions were the return air-ways. Indeed, cases were known where the explosion was actually confined to the dusty main intakes, and did not penetrate to the working faces, or affect the return air-

ways. This was so at the Seaham Colliery explosions in 1871 and 1880; at Tudhoe Colliery explosion in 1882; at Mardy Colliery explosion in 1885, and at the Altofts Colliery explosion in 1886. In all the above cases, except Mardy, shots appeared to have been fired in the main intakes coincidently with the explosions. At Mardy the explosion was probably initiated by the ignition, by a naked light, of an accumulation of firedamp in a cavity in the roof where the stone had fallen, to the height of nearly 30 feet. It would probably not be difficult to prove by means of Liveing's indicator, or the Pieler lamp, that the large volumes of air passing along the main intake air-ways of such collieries did not contain even the very minute quantities of firedamp which these instruments were capable of detecting. The recently passed Act for the regulation of mines did not provide for the systematic damping of coal-dust in dry mines, so that, so far as the law was concerned, they might remain in the same state in that respect as they were before. The Act, however, provided that precautions should be taken to prevent the ignition of coal-dust either by gas or by explosive substances. For the purposes of the watering required by the Act, which was limited to the locality where shots were about to be fired, it was desirable that some efficient means should be introduced for distributing the water effectually. The Anchor engine referred to by the Author appeared to have this object in view, and a more detailed account of it would be interesting. Another method might be by the application of a small pump, or fire-engine, worked by hand and fitted to an ordinary water-tub; the water being forced through a flexible tube, and delivered in the form of spray. What was required was a means of applying the water with facility and precision to any part of a drift, whether roof, bottom, or sides. Efforts were now being made at several collieries to damp the dust in a systematic manner; but sufficient experience had not yet been obtained to indicate the most efficient way, which would probably vary according to the conditions existing at different collieries. In some cases small pipes containing water under high pressure were laid along the dusty haulage roads, with cocks at suitable distances apart, to which a hose-pipe was fixed. In this way every part of the passage could be literally washed. In other cases short branch pipes were taken from the main range into the centre of the drift, and the water was allowed to escape, against the air-current, in the form of fine spray, through a minute aperture. The distance to which the spray thrown out in this way would effectually damp all parts of the passage did not appear to be great, and

Mr. W. N. Atkinson.

Mr. W. N. Atkinson. if too much spray was thrown out at one place the bottom got too wet there. This might be obviated by having sprays at more frequent intervals, and only allowing every second or third one to be in operation at the same time. This system had the advantage of being self-acting, and requiring little attention. Efforts had also been made to cause the ventilating current itself to damp the dust, by raising its temperature and saturating it with moisture when it entered the mine. Methods for mechanically distributing water carried in tubs had been devised by Messrs. Archer and Robson, and by Mr. J. A. Ramsay. The proper use of the water-cartridge with high explosives in blasting greatly reduced the risk of igniting gas, or coal-dust, but at an increased cost. In the North of England it had not been found suitable for getting coal. The compressed lime-cartridges had been tried at several collieries in Durham, but their use had been discontinued. Under favourable conditions (which were, perhaps, not very general) the method seemed to be a good and safe one for getting coal. It was of little use for stone-work. It might be mentioned that on more than one occasion, where the paper in which the cartridges were wrapped was put into the cartridge-hole as stemming, the paper was ignited by the heat evolved from the lime, and was found smouldering when the coal fell. It was unnecessary to put paper, or other inflammable material into the holes. In one case a man was severely injured by a blown-out lime-cartridge shot. Trials were about to be made in Durham of some of the recently invented explosive substances said to produce no flame, or at any rate, to be incapable of firing gas or coal-dust. If such a substance could be found with explosive properties similar to gunpowder, and capable of being used in shot-holes of the same size as was necessary for gunpowder, it would be hailed with delight; for none of the new methods of coal-getting approached the use of gunpowder for general applicability, convenience, and economy.

Mr. Brough. Mr. Bennett H. Brough remarked that the results of the investigations described by the Author deserved careful attention, not only from coal-miners but also from metal-miners. For, unfortunately, firedamp was not confined to collieries. In a number of cases it had been met with in mines of lignite, of salt, and of metals. Indeed, the first fatal firedamp explosion recorded took place, in 1664, not in a colliery but in a salt-mine at Hallstadt in Austria. An illustration of the diastrous effects of a firedamp explosion in a metalliferous mine had been afforded by the lamentable accident at the Mill Close lead-mine, in Derbyshire, on the 3rd of November last,

when five men lost their lives, and others were injured, by the ignition of firedamp, caused by firing a dynamite charge. The deposit of lead ore at that mine occurred in dark limestone beds immediately below the Yoredale shale that separated the limestone from the Millstone Grit. This shale, whenever it occurred in beds of 25 to 35 fathoms in thickness, always gave off a little gas. Probably this gas had collected in the fissured limestone, and becoming ignited by a shot, forced down the rock masses upon the unfortunate miners. The mouth of the great adit level which drained many of the Derbyshire mines, known as the Hill Carr Sough, was in the vicinity of the Mill Close Mine. This adit or sough passed through the shale for 2 or 3 miles, and with a candle at the end of a stick, up to a very recent date, visitors used to light the thin stream of gas along the roof. This would flash along almost the whole length of the level. The gas was now exhausted, or was found in very small quantities, but, when new ground was cut, there was a decided emission of gas. Similarly, outbursts of firedamp had been observed at the Van lead mine, near Llanidloes, at the Silver Islet mine in Lake Superior, at Monte Catini in Tuscany, and at several of the Saxon metalliferous mines. Inaccurate mine-surveying was a frequent source of accident, which was dwelt on neither in the report of the Royal Commission, nor by the Author. A glance through the reports of H.M. Inspectors for a number of years would show that several of the accidents therein recorded were obviously due to a neglect of the variation of the magnetic meridian, to which mine plans were usually drawn. Thus, Mr. T. Evans recorded an accident in 1875 at a small colliery in Nottinghamshire, where the men holed into some old workings. The disaster was caused by the men working according to plans one hundred years old, which showed a barrier of 100 yards. Another accident from holing into old workings was recorded, in 1878, by Mr. J. Dickinson. The men were working, without any bore-holes in advance, and thus an inundation was caused whereby two lives were lost. In that instance there was a correct plan of the former work, but, by a mistake in the surveyor's office, a wrong direction had been set out. Now that the means of constructing accurate mine plans were more abundantly taught, such accidents would, it was to be hoped, be of rare occurrence. Mr. Brough.

Mr. T. Forster Brown observed that the thanks of the community were due to the members of the Royal Commission for the practical turn which they had given to the direction in which increased safety in working coal-mines could be secured. With regard to explosions of firedamp; thoroughly efficient damping Mr. Brown.

Mr. Brown. of the coal-dust would add immensely in reducing this risk. At large collieries with which he was associated, extensive lines of water-pipes had been laid along the main haulage roads, with a water-pressure of 100 lbs. per square inch, and with outlets giving off fine spray at intervals of about 40 yards apart, with most beneficial results. Not only had the dust been damped, but the temperature had been reduced. At Harris's Navigation Colliery the temperature had by this means been reduced 6°. Mr. Henry Martin, of Dowlais, had introduced a considerable improvement by combining water under pressure in pipes with compressed air, which enabled the moisture to be more finely disseminated throughout the passages of the mine. Upon the question of shot-firing, at the suggestion of Mr. Galloway, two or three years ago, blasting-gelatine tamped with wet moss had been adopted as an explosive with good results, and so far no flame had been observed to pass. The next great desideratum no doubt was a safe lamp, giving an effective light. Several of the improved lamps of the present day would resist a strong current; but apart from the question of danger from explosion, a considerable reduction ought to be expected in the loss of life due to falls from the roof and sides, if a thoroughly good light could be introduced into fiery collieries. This difficulty, however, seemed to be approaching a solution by means of the electric lamp. Mr. Swan had devised an excellent electric lamp, which in turn would be improved upon, and Mr. Forster Brown anticipated the speedy invention of a thoroughly efficient self-contained electric lamp. With such a lamp it would be practicable to light the main hauling roads with fixed lamps, and to reduce the number of riders upon the sets, and in that way diminish the risks upon the haulage roads. He had adopted in many cases in the main haulage roads, where compressed air was available, a system of engines at each end of the main planes, doing away in that way with the tail ropes, and simplifying the operation of hauling. With well-lighted haulage roads of sufficient width, and laid with heavy rails, the risks of injury and loss of life ought to be reduced to a minimum. The system of long-wall working, as practised in South Wales, as compared with any other mode of working was attended with the least risks; and having regard to the fact that, up to within 150 yards or 200 yards of the face of the workings, the ground settled on the goaf up to the surface, he did not go quite so far as to consider the goaves a source of accumulation of gas. It must be so, more or less, with regard to the width of goaf, which had not settled down; but when the face advanced to the rise, the gas flowed out to the face, and in the

case of the workings going to the dip, the tendency would be to accumulate in the goaf. With regard to shaft-accidents, the difficulty was to avoid increased complications. Taking the case of the Harris Navigation Colliery, where the load was 19 tons, running at the rate of about 30 miles an hour, in the middle of the pit, the guides being iron rails. Less weight would not suffice to obtain a reasonable output from such a great depth, and any apparatus in the shaft for counteracting a breakage of the rope would be extremely difficult to invent, and the cure would probably be worse than the disease. The course to adopt was, in his opinion, to have every part of the machinery of ample power, the engine well balanced, an automatic steam-brake attached, an efficient system of signalling from top to bottom and bottom to top, and detaching hooks below the pulleys. Mr. Brown.

Mr. S. B. Coxon, during the spring of the year 1887, by permission of the Imperial German authorities representing the Department of Mines, had the good fortune to witness a series of experiments on the properties of so-called high explosives; these were conducted by the mine-inspector of the district at the Government experimental works adjoining the König mine, Neunkirchen. As these works had been erected to enable the Firedamp Commission to carry out tests on a scale approximating to the conditions met with in coal-mines, the Government had spared no expense in rendering them complete in every detail. The works consisted of a tunnel 51 metres long by 1·70 by 1·20 metre, strongly built to resist the force of explosions, and strengthened by iron girders, hoops, and stays. The top of the tunnel was provided with large safety plugs and doors, which yielded to the effects of explosion, and formed, so to speak, so many safety-valves. At frequent intervals small squares of strong glass were let into the sides of the tunnel, to enable the observers to watch in safety the behaviour of shots in the various mixtures of firedamp and coal-dust in which they were tested. The firedamp was piped from a blower in the mine, and was received by a suitably constructed gas-holder, from which it was easily admitted into the explosion-chamber in such quantities as the experimenter might require; but, as a rule, the testing mixture consisted of 10 per cent. of mine-gas CH_4, and about 15 kilograms of finely pulverized coal-dust scattered over the drift, a large proportion being held in suspension by the air in the chamber. The shots were fired by electricity. The staff was well supplied with instruments, and possessed all that was necessary to carry out their experiments with scientific accuracy. The Government Inspector, Mr. Coxon.

Mr. Coxon. Mr. Fabian, illustrated the effects of blown-out shots in an atmosphere containing coal-dust in a fine state of division without any mixture of firedamp. The charge consisted of 230 grams of ordinary black blasting-powder. When the shot was fired a tremendous explosion took place; all the safety plugs and doors were blown out, and flames, accompanied by clouds of smoke, burst through every opening. After the explosion a layer of fine coke-dust was found deposited on the floor and sides of the tunnel. This experiment was twice repeated with like results; the explosions appeared to be almost as violent as when mine-gas formed part of the mixture. It might be well to mention that the coal-dust was from the Pluto mine; it was friable, bright and bituminous, in appearance not unlike the duff from the gas coals of the Durham coal-field. There could be no doubt that in these experiments the explosions were instantaneous, and no mere elongation or extension of flame. He thought it might not be without interest to place on record his experience of an explosion at a colliery under his management some twenty-five years ago, which appeared altogether due to a blown-out shot firing the dust in suspension in the mine. The circumstances, briefly stated, were as followed:—A drift was being driven between the down and upcast shafts for the purpose of erecting an additional ventilating furnace. The coal being friable, a quantity of dust became mixed with the ventilating current. After the drift had been carefully examined for gas, not only by a Davy lamp, but also with a naked light, a shot was fired, but having been unskilfully placed, it was blown out; the result was an explosion which burned severely a number of men who were working near the downcast shaft. The air-current, in volume over 150,000 cubic feet per minute, was checked, the separation doors were blown open, and the effect of the blast was felt at the bank. In this particular case not the slightest indication of gas was apparent, nor was any observed either before or after the explosion. No fall had taken place, nor had anything occurred to interrupt or derange the ventilating current. After a careful investigation of all the circumstances, the conclusion arrived at was that the accident was caused by the blown-out shot igniting the coal-dust. Granting that the examples given were faithfully represented, the lesson was of easy application, and would show that there was a strong probability that coal-dust had played an important part in many accidents, the proximate causes of which had been enveloped in mystery. It was to be feared that so long as ordinary blasting-powder was used in coal mines, blown-out

shots would be an ever-recurring source of danger. It would, Mr. Coxon.
however, appear that the time had arrived to take a new departure by substituting other blasting compounds. A cartridge had recently been invented that was quite flameless, and which had undergone the most severe tests in mixtures of firedamp and coal-dust. Perhaps the most noteworthy test to which this cartridge had been subjected was in 10 per cent. of mine-gas and finely pulverized coal-dust. A number of experiments were made in this highly explosive mixture, and in no case was it fired. Not less remarkable was the fact that when this cartridge enclosed dynamite or blasting gelatine, these powerful compounds ceased to emit flame without any apparent loss of strength. Photographs had been taken at the instant of firing, which might be cited as truthful and scientific testimony to the value of this discovery. It was not surprising that mining engineers, having the management of extensive and dangerous collieries, had long been seriously impressed with the risks daily incurred by treating the ordinary Davy as a safety-lamp. It was well known that these lamps, when exposed to inflammable mixtures, would pass flame in currents of a comparatively low velocity. A large colliery required a ventilation of from 200,000 to 300,000 cubic feet of air per minute, consequently many of the splits must of necessity attain high velocities. It was difficult to imagine a greater source of danger than when a loaded current at a high speed impinged on the unprotected gauze of the Davy type of lamp. Many of these lamps would fire an inflammable current if the velocity reached 8 or 10 feet per second. It was not necessary here to emphasize the danger from such a condition of things. Another fruitful source of danger arose from falls in goaves, which in deep mines generally contained accumulations of firedamp. When fractures occurred in the superior strata, and the roof fell, the contents of the fissures were driven into the working-places, and not infrequently filled the lamps of the workmen with inflammable gas; this contingency should be guarded against with the greatest care; indeed, there were many reasons why the attention of mining engineers should be directed to other sources of light and safety. Happily electric lamps pointed to a solution of the difficulty, and in what direction the end in view might be most easily attained. There could be little doubt that in the electric lamp there was the nearest approach to absolute safety, whilst the superior light would add much to the comfort of the collier, and tend in no slight degree to ameliorate the disagreeable nature of his vocation. A judicious selection of the kind of battery to

Mr. Coxon. be used was of the first importance, as, given the proper battery, the form and arrangement of the lamp were matters of detail. It might be of interest to show how closely electricity approached oil in point of economy. The result of several weeks' consecutive testing showed that the Schanschieff lamp (primary battery), yielding a light of 2-candle-power, cost only $\frac{7}{8}d.$ per shift of eight hours. This was a single fluid battery of high electromotive force and low resistance. The cells consisted of zinc and carbon, the solution being a basic sulphate of mercury. The action was remarkably constant; there was no danger from sparking; the lamp gave off no gas nor fumes of a disagreeable odour; there was nothing in either the construction of the lamp or the nature of the solution to produce a risk of explosion. The weight of a four-cell lamp was 4 lbs. 6 oz., and the three-cell was only $3\frac{1}{2}$ lbs. These lamps might be changed as easily and in a shorter time than it took to trim a Davy lamp.

Dr. Foster. Dr. C. Le Neve Foster, in reference to deaths from accidents and disease in metal-mines, said he had pointed out on more than one occasion, in his official reports, and in papers read before the British Association and the Statistical Society,[1] that the ore-miner had very nearly as dangerous an occupation as the collier, and that in some metalliferous districts, such as Cornwall, the average death-rate from accidents was higher than in coal-mines. In other words, as has been frequently shown, though the fact was scarcely rooted in the public mind, firedamp was not the miners' worst enemy. Nay, he would go further, and almost look upon it as a blessing in disguise. If it had not been for explosions in mines, there would have been less stringent regulations for their safety. The numerous dangers, which caused only one or two deaths at a time, would have been less carefully guarded against by statute, and ventilation would not have received that strict attention which was now an absolute necessity. Though not killed by explosions, the colliers would have had their lives shortened, by breathing vitiated air, like their brethren in Cornwall. In considering the well-being of a class of workmen, such as miners, it was necessary to look at the mortality from disease as well as the mortality from accidents. It had been shown by Dr. Ogle[2] that, in spite of accidents, the death-rate of coal-miners was not high. In order of comparative mortality, coal-mining

[1] Journal of the Statistical Society, vol. xlviii. p. 277.

[2] Supplement to the 45th Annual Report of the Registrar-General of Births, Deaths and Marriages in England. London, 1885, pp. xxvi. and xlix.

stood 30th in the list of ninety-four occupations which he cited, whilst mining in Cornwall was as low as No. 91; that was to say, only three of the ninety-four trades exceeded tin-mining in deadliness. His late colleague, Mr. Frecheville, called attention to this fact in his report for 1885, and ascribed this high mortality to inadequate ventilation, and excessive climbing of ladders from deep mines. He quite agreed with Mr. Frecheville in this opinion, and he had stated in his official reports that these evils, together with others, demanded an amendment of the statute of 1872, which regulated the working of metalliferous mines. Mr. Foster.

Mr. W. GALLOWAY stated, in reference to the Author's remarks on the quantity of air necessary to the combustion of 1 lb. of coal-dust,[1] that in January 1876, a month after the completion of his first experiments, with definite proportions of firedamp and air, and with undetermined quantities of coal-dust, he wrote in a Paper, published in the Proceedings of the Royal Society in the following March, that "It is always possible, however, that if coal-dust could be made fine enough, and were thoroughly mixed with dry air in the proportion of about 1 lb. to 160 cubic feet of air, the mixture might be inflammable at ordinary temperature,"[2] and so on. He arrived at 160 cubic feet of air by taking 12 lbs., the weight of air necessary for the complete combustion of the fuel given at p. 280 of Rankine's "Steam Engine," 1861 edition, and calculating its volume at ordinary pressure and temperature. It had appeared to him that if complete combustion of the elements of the coal-dust could be assured, without any surplus of oxygen, the best possible results would be obtained, and that might be explosion in a confined space. In a subsequent Paper published in March, 1879, he stated that "The proportion of coal-dust which gave the best results, was much larger than might at first sight be thought necessary, namely, about 1 oz. of dust to a cubic foot of air for all mixtures of gas and air, ranging between one of gas and twenty of air, and one of gas and forty of air. Also, in one of the experiments, with the return air of a mine, which I propose to describe in this place, the air requires to be literally black with dust before it will ignite."[3] The last mentioned results were afterwards corroborated by Messrs. Mallard and Le Chatelier. Mr. Galloway.

Mr. MAX GEORGI, of Zaukerode, thought that hardly sufficient importance had been attached by the Author to the subject of auxiliary ventilation. On the Continent, with the pillar-and-stall method of Mr. Georgi.

[1] *Ante*, p. 43.

[2] Proceedings of the Royal Society of London, vol. xxiv. p. 369.

[3] *Ibid.* vol. xxviii. p. 411.

Mr. Georgi. working coal generally employed, auxiliary ventilation was of very great importance. In driving narrow bords, and occasionally, in consequence of dislocations of the seam, or of great pressure of superincumbent strata, it was difficult or impossible to pass a ventilating current of air through the workings. In these cases the ventilation could be obtained only by diffusion. Still, this method would be a dangerous one; for with a violent outburst of mine-gas, diffusion would, under certain conditions, be insufficient to prevent the formation of explosive gas-mixtures, or of an air-mixture liable to cause a coal-dust explosion. It should be added that even the narrow dimensions of the bords driven in the unbroken ground might cause the gas at the firing of a shot to acquire greater velocity, and the coal-dust produced by the shot, or lying in the drift, to be whirled with greater violence to and fro. If this agitation of the coal-dust could not be prevented as long as blasting was permitted, all measures for avoiding accidents must aim at drawing the coal-gas away from each working place, or of mixing with it sufficient fresh air to prevent the proportion of gas exceeding a dangerous percentage. The colliery rules, promulgated by the Saxon Government on the 25th of March, 1886, insisted, paragraph 113, that those points, where men were at work, and where the ventilation was accomplished by a current of air, must be kept free from fire-damp by auxiliary ventilation. This might be effected either by the main ventilating current, or by an auxiliary air-current produced for the purpose. In the former case, if brattices were not to be employed, the main air-current must be further subdivided, splits being formed by means of pipes. The more the main current was interrupted and limited in this way, the more would its total effect be diminished, thus detrimentally affecting the whole of the ventilation in favour of certain working places. When, on the other hand, recourse was had to auxiliary ventilation for several working places, the application of the main ventilating current should be entirely avoided, or be limited to certain cases. The most simple, the most convenient, and the most successful method was the employment of compressed air, whether blown direct, or by a Körting blower or similar jet, into the ventilating pipes. Inasmuch as compressed air not only transmitted power, but also had a ventilating action, it far excelled steam or water-power for working blowers of the injector type. When available, either of the latter might be used more advantageously for driving a ventilator, turbines acting directly on the axle of the ventilator being especially suitable for the purpose. Dynamos were

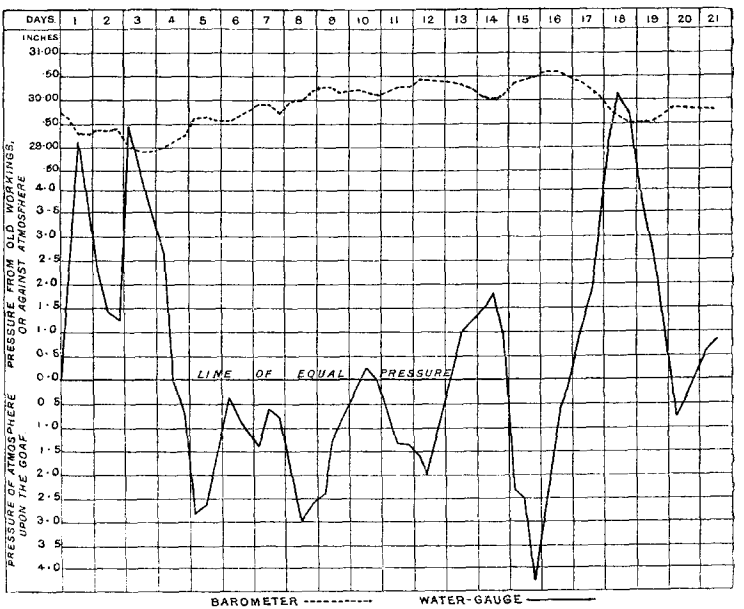
Mr. Georgi.

also extremely valuable for this purpose, especially where the source of power was at a greater distance from the place where the power was utilized. As a rule, all these machines were so arranged that, by blowing, they brought to the working place air free from gas. Recently, contrivances had been suggested for exhausting the gas, each working place being connected with a branch pipe, to suck the air from the highest point where the gases usually collected. The gas thus obtained would be conducted separately to the surface, where it might be advantageously used for heating boilers. Although this method was excellent in principle, it remained to be seen whether good results would be obtained in practice; since there must be a difficulty in keeping a long length of pipes air-tight, and at the same time regulating the exhausting action. Auxiliary ventilation was also of importance for mines containing carbonic acid gas. Although the immediate danger of accident was slight, as the presence of this heavy gas was generally indicated sufficiently early, by the extinguishing of the miner's light; still there was no doubt that a slow but constant poisoning by carbonic acid gas was the cause of premature marasmus, and that the irritation of the respiratory organs by carbonic acid gas was the cause of the diseases of those organs, from which so many miners had suffered. This was a danger to which, perhaps, as many miners had fallen victims as to firedamp, and to combat it no method seemed more efficacious than auxiliary ventilation combined with good total ventilation. Although the employment of the water-cartridge was a security against the danger of firedamp in collieries, it was, however, necessary to bore holes deeper than would otherwise be wanted, so that there was a great practical drawback to their use. This disadvantage was obviated by an invention by Messrs. Müller and Aufschläger, who incorporated with the explosive itself the water necessary for extinguishing the flames of the shot. He alluded to the so-called firedamp dynamite (*Wetterdynamit*). This invention consisted in mixing salts having a high proportion of water of crystallization with the dynamite; for example, about 40 per cent. of soda with ordinary dynamite, or of alum with gelatine-dynamite. Soda gave with gelatine a substance as hard as stone, and was consequently unfit to be used with gelatine-dynamite. This proportion of loosely combined water acted in a manner quite different to hygroscopic water, which completely destroyed the blasting power of gunpowder as well as of dynamite. The safe nature of the flame of the firedamp dynamite, especially of soda-dynamite, had been proved by experiments made by the Prussian

Mr. Georgi. Government authorities. It was now only necessary to consider its practical value in coal-getting, and of this trials were in progress.

Mr. Gresley. Mr. W. S. GRESLEY said, with reference to the intruments employed for indicating the effect of atmospheric pressure upon the gas pent up in the goaves of coal-mines, that he had found nothing superior to the ordinary U-shaped water-gauge, used, as he understood, for the last five or six years in the Seaham Colliery, Durham, as employed for ascertaining the friction or "drag"

FIG. 1.



Depth of pit, 690 feet; instruments about 570 feet below sea-level; observations taken every eight hours.

on ventilation. He had used this instrument for the last few years in a colliery in which the whole of the present workings were in main-road pillars, on either side of which were extensive areas of "wastes," or old workings, containing firedamp. These old places were sealed up by stoppings constructed of clay. The water-gauge had one leg connected to a pipe which passed through one of these clay dams into the old goaves, the other leg being open to the atmosphere. The practical use of this gauge was that its fluctuations, being eight to ten times as

great as those of the mercurial barometer, showed more clearly what the atmospheric pressure was at the time of observation. The water-column appeared to move as much as from six to twelve hours sooner than the mercury, thus enabling those in charge of the workings to know what to expect, and to exercise special care in cases where coming stormy weather was indicated. Fig. 1 (reduced from actual readings) was sufficient to show the great value of some such weather-indicator as this. He placed confidence in the water-gauge readings, far before those of the ordinary barometer, as a "Colliery-warning" Indicator. Mr. Gresley.

Mr. J. A. LONGDEN remarked that, at the Blackwell collieries, there were three hundred doors to regulate the air in the mine. Boys were not employed as trappers; and evidently it would be impossible to obtain three hundred boys to do this work. During the nineteen years he had been practically managing collieries he had only had one boy killed, and that was through the horse starting whilst the boy was coupling the wagons together. He thought that, if the causes of boys' deaths were arranged under different heads, it would be found that many more were killed through accidents whilst coupling wagons together than from the cause assigned in the Paper. He had used safety-hooks ever since they came out, and had reason to be thankful for having done so. Winding-engines at collieries now drew a weight of 7 tons and upwards a distance of 400 or 500 yards in not much more than half a minute. This meant that the engine started, attained a velocity in some cases of 50 miles an hour, and stopped in thirty seconds; and this was going on incessantly for nine hours every day. If, through any accidental sticking of the valves, the engine became unmanageable, as had happened a few times, no automatic brake would be of the slightest use, and the velocity at which the immense weight came up the shaft would smash the timbers away to which the disengaging-hook plate was attached, and thus cause a similar accident to that at Houghton Main. Safety-clutches had been tried in connection with wire guides, but nothing yet had been found of any service for high velocities with great weights where wire guides were used. It was surprising that hardly ever, if ever, was there any collision in the shafts, considering that, if the chairs were put opposite one another in the middle of the shaft, they could be made to hit each other by simply pulling one of them with one hand. The great diminution in the number of deaths through falls of roofs and sides, namely, 40 per cent., comparing the ten years ending 1880 with the ten years ending 1860, seemed remarkable, taking into account the much greater depth at which mines were Mr. Longden.

Mr. Longden. now worked, and that the working faces were so much further away from the bottom, which of course meant considerably more road to maintain, and much more road for the men to travel through to get to their work and back again every day. He had tried coal-getting by wedges, but found that in a soft seam, when the wedge expanded, it simply lost its effect by squeezing the coal, and did not fetch it down. No doubt wedges would do their work in a hard coal; but the misfortune was, that when the wedges fetched down a block weighing several tons, the coal had to be broken up for loading for removal from the pit. This involved nearly as much labour as if it had not been got down at all. No doubt that, for economy, nothing had yet been produced better than gunpowder. His impression was that many accidents in the past had been the result of using "germans," or straws, instead of safety-fuzes. He had tried these straws, and found that, when the shot took effect, the lighted end flew back in the goaf several yards, so that, in his opinion, they were highly dangerous. Whilst he should rejoice to see a satisfactory testing-apparatus for gas, it must not be forgotten that, in well-ventilated mines, the only gas to be found was in the breaks in the roof, which penetrated sometimes 3 or 4 yards. The method now adopted was for the fire-trier to stand on the top of a tub and thrust his lamp, on the end of his yard-stick, into the fissure as far as he could reach. Any method which did not enable him to reach the same altitude would be practically inefficient. With respect to outbursts, he was glad to notice that the Author spoke highly of the long-wall system. He considered it the safest method of working, so far as outbursts of gas were concerned. Explosions had been far fewer, and attended with far less deadly results, where the long-wall method had been adopted, than with any other system. He had heard of a goaf being 20 acres in extent without any support. The natural effect of this was that either the floor or the roof would give way, and cause a cavity which would be filled with gas, and as soon as the floor or roof finally burst, the gas which had been penned up in the cavity would be given off. He was of opinion that this was how some of the most serious outbursts of gas had originated. With the long-wall system of packing every few yards, and the roof gradually falling behind the face, this was an impossibility. Compressed lime, he was afraid, must be considered a failure. When he tried it, the lime charred the coal for several inches round the hole, and spoilt the character of it, so that the coal had to be cut out as unmarketable. The same objection applied to compressed lime that he had before

indicated in the case of wedges: it brought down a great weight of coal in a block, which had subsequently to be broken up. The difficulty of illuminating mines by electricity, where wires were connected with batteries at the bottom, arose from the falls of the roof and sides, which would be constantly putting the men in darkness. The objection to the self-contained electric lamp was that the miner would still need a safety-lamp with him to examine if there was any gas in the face. He was one of the Committee in connection with the Chesterfield Institute which conducted a series of experiments on coal-dust. One particular dust, from the North of England, was highly explosive without the addition of any gas whatever. On the other hand, none of the dusts from the neighbourhood of Chesterfield were nearly as explosive, and the dust from Blackwell Colliery could not be fired under any circumstances. But what constituted the inflammability in dust? No doubt some coal-seams yielded dust much more liable to explode than others. There seemed to be an inclination just now to attribute to coal-dust more importance than, in the estimation of many mining engineers, the case deserved. If some Committee could take up the question of the relative risk of explosion, from various dusts under varying conditions, he thought valuable information would be elicited as to the danger of working some seams, and the almost total absence of danger in working other seams of coal. He should like to ask the Author his opinion concerning the origin of firedamp. It had been held by many mining engineers that firedamp could not exist except in the neighbourhood of coal-seams, and that it was not generated by shale or bind. The late explosion in Derbyshire at Wass's lead-mine, which, he supposed, was in the limestone below the Coal Measures, brought forward this question again. Mr. Longden.

Mr. A. R. SENNETT stated that the safety-lamps chiefly used in Germany were the Mueseler, the Säarbrucker (Boty), the Westphalian, and the Wolf Benzene. The flame of the lamp was in each case enclosed in a glass cylinder, it evidently being considered that the extra risk from breakage was more than compensated for by the extra candle-power obtained. Safety-lamps of any form might be made use of, provided they fulfilled certain requirements drawn up by the Rhenish Mining Board. The control was vested in this Board and five other similar Boards for the various districts, all of whom would shortly issue the conditions they required the lamps to fulfil. Mr. Hasslacker, the Secretary of the Accidents in Mines Board, had informed him that little or nothing had at present been done in lighting mines Mr. Sennett.

Mr. Sennett. by electricity, and that no satisfactory portable electric lamp, either primary or secondary, existed. Neither were firedamp indicators, either as indicators or as recorders, made use of. On this the Board was of opinion that so long as oil lamps were employed the former were scarcely necessary, as it was considered that the lamps themselves acted sufficiently well as indicators. Belgium also was divided into districts controlled by inspecting engineers, the requirements of the lamps being modified according to the nature of the coal. With regard to electric lighting and portable electric lamps in fiery mines, Mr. Sennett felt that it should not be assumed that lamps were absolutely safe, unless provision was made that short-circuiting of the terminals could not take place in the event of the lamp being accidentally broken. The bulb of the glow lamp should, of course, be so enclosed that the miner could not detach it in the mine and thereby produce a spark. Also, there should be no switch nor other gear external to the lamp, or open to the atmosphere of the mine, which the miner could move or tamper with, or which might be accidentally moved. The requisite alteration of the connections for charging and discharging should be performed automatically, so that no skilled attendance should be required in connection with the lamps. Mr. Sennett had constructed a lamp to fulfil these requirements about five years ago, one of which was shown. It was intended to sustain a light equal to about 5 candles for fourteen hours. It was far too heavy and bulky for convenient use, if the accumulators then obtainable had to be used. The contrivances for extinguishing the lamp and arranging the contacts for re-charging the accumulators, for putting the lamp again in circuit and connecting up for discharging, were all contained in an air-tight compartment of the lamp, without any movable connection with its exterior. When the lamp was first put together, compressed air was passed through the plug at the top of the lamp, which was provided with an ordinary oil-skin air-valve, to retain it when the syringe was removed. The effect of the compressed air was to cause the corrugated sides of a small metallic box to collapse, and thereby establish contact through the lamp. The lamp would then continue to burn, but should the glass cylinder become cracked or broken, or the lamp otherwise damaged, the lamp was switched out of circuit, and all connection with the terminals disestablished. When the lamp needed recharging it would be brought to bank and placed on the charging-table. The action of an electro-magnet beneath the charging-table would cause the lamp to be switched out of circuit,

and the accumulators would be put into connection with two studs at the bottom of the lamp, and which came into contact with the charging terminals of the table. When the lamp was required for use, on its being taken off the table, it immediately became lighted, and all connection with the aforementioned studs was broken. He was not aware if the Commissioners considered it safe to employ electric glow lamps in the ordinary way, in portions of mines likely to contain an explosive mixture. If this were so, it appeared to him that in positions where a fall of roof was likely to occur, the danger of firing the mixture by the spark on breaking contact, when the cables were torn asunder, would be greatly minimized by employing, instead of two separate leads (one − one +), a single cable enclosing both leads encased in an insulating material much more elastic than copper, so that the wires might be broken and the sparking take place before the envelope was broken. This should be in conjunction with automatic gear at the bank, that the circuit might be simultaneously broken there, so that no electrical difference of potential should exist at the fractured ends. And further, the insulation between the leads might be plastic, so that in the event of a large mass of coal or other material falling on the cable, and there being danger of the latter having its leads laid bare, the plastic insulator would yield, and short-circuiting take place within the insulating envelope, and by suitable gear at bank the short-circuiting might cause the cables to be instantly disconnected. Much labour and responsibility was entailed in connection with safety-lamps, on account of the necessity of unlocking, lighting, and re-locking the lamps at bank before they were taken down the shaft. Whilst in Belgium recently he had seen an ingenious lamp, invented by Mr. H. Pieper, of Liége, which obviated this. It was an oil lamp, and similar to other lamps in which a glass cylinder was employed. The wick, however, was furnished with a platinum spiral, to which could be conveniently attached the terminals of an accumulator or primary battery, by means of which the lamp was lighted. It was also provided with an arrangement whereby the light would be extinguished were an attempt made to remove the oil-reservoir, &c., from its glass and gauze case.

Mr. Sennett.

Mr. M. H. N. STORY-MASKELYNE, M.P., wished to refer to a matter which appeared to be vital to the success of any good miners' lamp in which glow-lights would have to be employed. Only incandescent lamps could be used underground if electricity was to be the means of illumination. A lamp, weighing only 4 lbs. 2 oz., had been exhibited, with which he had a good deal to do in carry-

Mr. Story-Maskelyne.

Mr Story-Maskelyne.

ing it to its present position of excellence. It had been tried under every condition proposed by the mine managers of the North, and had withstood every ordeal to which it had been exposed. But for a practical application, on a commercial scale, of the principle involved in this or any other electric lamp for the use of miners, it was absolutely essential that their public use should not be barred by extortionate conditions to be imposed by any of the patentees of the manufacture of glow-lamps. Mr. Maskelyne therefore desired to direct attention to the state of the law in this regard. By the Act of 1883 (Patents, Designs, and Trade Marks Act), clause 22, this difficulty was entirely met. A patentee was bound to grant licenses on reasonable terms, and, failing his doing so, the Board of Trade might order the patentee to grant licenses on such terms as to the amount of royalties, security for payment, or otherwise, as the Board, having regard to the nature of the invention and the circumstances of the case, might deem just, and any such order might be enforced by mandamus. It would be an outrageous thing if a patentee, having the monopoly of the manufacture of glow-lamps, were, by unnecessary delay in their supply, or by demanding exorbitant terms for their use, or for the license to manufacture them, to prevent the great boon of a really safe electric lamp being supplied to the miners at a reasonable cost. The persons who, with himself, were sanguine enough to believe that the problem of supplying such a lamp had been solved, were resolved that the clause in the Act should be immediately put in force, if this difficulty should be found to impede their efforts to supply such an economical and efficient electric safety-lamp.

Mr. Sopwith.

Mr. ARTHUR SOPWITH remarked that the Author had alluded to the utter inadequacy of the light given by certain safety-lamps, including the Clanny, and this statement could not, he thought, be materially modified in the case of any of the lately improved types of lamps, more especially as the bonneting or shielding of the gauze affected the upward diffusion of light. As the safety of many lamps, even under extraordinary conditions in an explosive mixture of gas, was practically assured, it followed that any decided improvement must be looked for in the form of increased illumination rather than in the way of greater immunity from explosions. Although there might yet be some little margin for providing a more efficient light, in the present types of lamps, it would appear that practically a limit had been reached in the illuminating power of oil safety-lamps, and it must be accepted that electric lighting was the only system

from which material benefit could be expected. An experience extending over a considerable time with half-a-dozen Pitkin lamps (which had been in the hands of the colliers and therefore subjected to rough treatment in the working face), was fairly favourable as regarded working efficiency, and at any rate sufficiently so as to afford grounds for believing in the ultimate success of such a system of lighting. Necessarily there was much to be done before the practicability of using portable electric lamps, economically and on an extensive scale, could be determined. It must be considered, however, that while the light of primary or secondary-battery portable lamps was, relatively to ordinary safety-lamps, an adequate one, it was necessarily limited by the requirements of lightness in weight and long-continued action in the cells, and any considerable increase in the illumination of workings must result from the adoption of large accumulator cells, and the use of leads and branch wires. Whether it were desirable or not to aim at an illumination of mines which might more or less approach a luxury, he did not consider that the Author was justified in so arbitrarily dismissing the system of having attached wires to lamps, on the mere ground that they could not be protected. The various details connected with the easy removal, and at the same time protection, of the wires in the workings could hardly have been determined by the trials alluded to, and the matter had, he thought, received insufficient attention. That the system was applicable to working faces must, in the absence of prolonged trials, be taken as a mere opinion, but it was based upon consideration of details in workings where great difficulty was experienced from falling roof and heavy timbering. The statement, made by the Author, as to the obvious liability of the men to get their feet entangled in the leads, presupposed the use of lamps without any order or method ; but it must be considered that the necessity of frequent removal of lamps, or alteration in leads, was reduced by the increased amount of light obtainable. Thus 8-candle-power lamps placed 12 yards apart gave a comfortable working light throughout a stall face. In the case of long-wall working (to which alone he had confined his attention in respect to this system of lighting) there seemed little difficulty in protecting the leads and branch wires and lamps; the former could be run along the foot of the cog or pack wall, and the latter against the face of the wall, and so not only completely out of the way of the men, but in a practically secure position. Moreover the routine of lighting presented little trouble. As the working was carried out right and left from the way end, the leads could be gradually extended to the limit of

Mr. Sopwith.

Mr. Sopwith. this stall, say 30 yards on either side. After each "drift," or holing was worked off, no more labour was entailed than the coiling up of the lead and letting out 6 to 7 feet of the main cable, laid along the road from the accumulators, to cover the advance of the face. Apart from the broad question as to whether the introduction of wires should be admissible into fiery mines, there were many difficulties to overcome before the system of lighting with wires attached to lamps could be recommended; but the special difficulty, mentioned by the Author, was in all probability not so insuperable as he implied. Although it was quite probable that the use of leads and branch wires might be proved to be inapplicable as a universal system, the partial lighting by such system might be a useful adjunct in working faces, and it appeared important that the consideration of the protection of, and practical way of economically and efficiently dealing with, cables or branch wires in a mine should not be lost sight of. Apart from the more difficult and intricate question of bringing electric lighting into use at the actual working face, he would direct attention to the facilities that existed in collieries for the economical extension of electric lighting in respect of main cables. This referred to the use of old iron or steel ropes for such purpose. At Cannock Chase Colliery some 4,000 yards of old rope had thus been utilized, and in one instance a cable had been laid having only a resistance of $\frac{1}{25}$ ohm for 1,400 yards, a condition of profuse cable that would not have been thought of if copper cable had been in question. In any extensive system of lighting in bye-roads and stations, the importance of cheap cable was evident. Approximately the relative values of old iron ropes and bare copper cable were, after allowing for difference in conductivity, as 1 to 5, and he could point to conditions where the difference was considerably greater. Some of these ropes had been laid together in a trench on the surface and only insulated with coal-dust and tar, so that little trouble was involved in insulating them in a dry mine. In fact, iron ropes laying side by side on the ground in an underground road, and extending over a distance of 140 yards (single distance) had been found to show no appreciable leakage. The practical experience gained in laying down the cables alluded to, in trenches on the surface, in wet shafts and in roadways underground, and the economy and efficiency of the rough methods adopted in insulating, tended to prove that the problem of extensive lighting underground did not present such great difficulties as might at first be anticipated. He knew of no obstacle, beyond the cost and as yet unproved certainty of any prolonged life of cells, to

very large extensions of electric lighting underground, and he was by no means sure that the question of lighting the actual face of a working was yet disposed of. Mr. Sopwith.

Mr. A. L. STEAVENSON observed that the fact that "miscellaneous" accidents had not apparently diminished, since 1851, was satisfactorily accounted for, in face of the large quantities of minerals now dealt with, and the high-pressure speed at which all the operations were carried out. He thought not merely the Government regulations, but the increased intelligence and care of the workmen, deserved credit, in that these accidents had not increased. On the other hand, the shortening of the hours of labour resulted in the miner working at a higher rate of speed, which perhaps accounted for the "deaths from falls of roof and sides" constituting a larger proportion of the total deaths in recent years than they did thirty years ago. To provide against these accidents, although forming 76 per cent. of the whole, not much benefit could be expected from the labours of the Royal Comsioners or scientific men; but these labours had afforded great help in all matters relating to explosions of gas or dust, and especially as to explosives and safety-lamps, and to these subjects the Author had naturally devoted the most of his address. It was very instructive, with existing views of the dust theory, to look back at the particulars of explosions in former years, practically never fairly accounted for, say, for instance, the Seaham explosion in October, 1871. Every witness agreed that the explosion occurred at a given point on the main intake. The man who fired the shot survived to say he went about 30 yards out of the way of the shot, and both shot and explosion came together (stone was being blasted at night); he said, "There was no possibility of any gas where we were exploding, as there was sufficient air to drive a windmill;" in fact, 78,000 cubic feet of air per minute were passing this point. The result was that the explosion was assigned to a sudden outburst of gas. Twenty-six persons lost their lives, and in this case, as in almost every one of the explosions in the North of England, dust alone was the only explanation which met all the difficulties which cropped up in the inquiry. Before leaving this particular case he would refer to the Author's allusion to a second or back explosion (p. 22, of the report of Mr. Willis, Inspector of Mines).[1] Witness, a coal-miner, said, "Altogether I heard two explosions after Hutchinson's shot;" the first was a heavy explosion, but the second was not so severe. He had him- Mr. Steavenson.

[1] Reports of Inspectors of Mines for year 1871.

Mr. Steavenson. self observed the evidence of a second explosion, when examining the workings after the explosion at Tudhoe Colliery. Baulks of timber, as thick as a man's body, were broken in two, in clearly opposite directions, and although he did not at that time believe in the dust theory, no doubt it was the proper explanation of that accident—from a shot which had been fired on the main intake. With the Author's objections to shot-firing in coal he entirely concurred, and for these and other reasons he had promoted the use of the coal-wedge. At Tursdale Colliery sixty-four miners were now using it, with a great improvement in the proportion of large coal, and, of course, absolute freedom from danger; and, as the cost of using the wedge compared favourably with that of high explosives and of water-cartridges, it appeared to him to almost entirely obviate the necessity for using them in coal; their necessity had, in fact, ceased to exist; this referred not merely to long-wall working, but to the system of board and pillar. To the fact that water, when used with high explosives, would obviate their sudden and crushing effects, he could not at present assent, but would take an early opportunity of testing it in Cleveland Ironstone, where a slow rending action was an absolute necessity. His experience of the water-cartridge had not been large, but hitherto had been very unfavourable, on account of the cartridges bursting during insertion. With respect to the flame from a blown-out shot, he had found that not only was the tamping blown out, but the large grains of powder also, in a state of incandescence. The greater prevalence of mine explosions in the winter months, especially during intense frosts, might, he thought, be accounted for by the dryness of the air robbing the dust of its moisture in the main air-ways. The distilling action of the heat of explosion upon coal-dust, which of course produced gas, had not received the general attention it deserved; it met the objection, still raised by many persons, to the possibility of dust alone affording an explosion. In none of the experiments upon coal-dust did he find the question of the fineness of the dust sufficiently appreciated. Whether the dust from that or the other colliery was most explosive, seemed to him to be entirely dependent upon the fineness of the particles. He had employed the Liveing Indicator ever since its first invention, and considered that in the hands of the colliery manager, or good overman, it was a very valuable invention; but it was not suited to the hands of every rough experimenter; the test was a delicate one, and must always have careful, and to some extent skilful, manipulation.

Mr. Stokes. Mr. A. H. STOKES thought the Author, p. 38, appeared to question his remarks published in a Paper read before the Chesterfield and Midland Counties Institution of Engineers, namely, that the

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excess of gas given off from goaves upon the sudden reduction of atmospheric pressure was carried away unnoticed. The Author had given an illustration, showing that for a diminution of 0·01 inch of barometric pressure, a goaf of only 1 acre in area and average height of 3 feet might part with about 44 cubic feet of its gaseous contents; but he had not mentioned the number of cubic feet of air in the ventilating current, which would probably have swept past the goaf during the fall of 0·01 inch of the barometer. However, supposing the barometer to have fallen 0·01 inch in five minutes—a very sudden fall—probably in most collieries there would have passed by the goaf 25,000 cubic feet of air in five minutes, and certainly 44 cubic feet of gas in 25,000 cubic feet of air would escape unnoticed. The references in Mr. Stokes' Paper were solely to accumulations of gas, and not to outbursts; and he considered the Author's remarks, vol. xc. p. 189 referring to "the majority of British coal-mines, which are now provided with ventilation amply sufficient to cope effectually with any such possible variations in the condition of the air in the workings," scarcely in unison with the criticism passed upon the comments named by the Author, *ante* pp. 38 and 39. The ventilation of a mine should always be far in excess of what was required, and beyond the reach of constantly recurring barometrical changes, having a surplus of air which would be more than sufficient to meet such emergency; and any mine in which the rise and fall of the barometer was the balance of safety should be considered unfit to be worked. With regard to the lime-cartridge and the "remarkable comments" published in the Transactions of the Chesterfield and Midland Counties Institution of Engineers, at the time those comments were penned he fully believed, from experiments which he had seen, that the lime-cartridge was a failure in the parts of a mine where such an appliance was most needed, namely, at the gate ends, or brushing, in the roadways; and at the present day he believed there was not a single coal-mine in the whole of the Midland district using the lime-cartridge, except Shipley Colliery, where the cartridge was made. The use of the lime-cartridge was not free from danger, as could be seen by reference to the accidents from its use, recorded in the Annual Reports of the Inspectors of Mines. He would also like to direct attention to the great difference between "bricklayers continually" handling "with impunity" mortar which had been thoroughly slaked and left without heat, and the collier handling caustic lime in the process of being slaked. He could only repeat the assertion, previously made, that the colliers loading coals in damp mines,

Mr. Stokes. where the lime-cartridge had been used, had to protect their hands from the effect of the unslaked lime; and even workmen in hot and dry mines, and perspiring freely, found the moisture of their hands caused the lime-dust to wear and eat away the skin, unless protected; and he repeated this assertion from actual investigation and from seeing and hearing the colliers themselves. Personally, he would like to have seen the lime process an unqualified success, for all and every case where explosives were used in mines; but he yet feared, in its present state, its successful application was only very limited for coal-getting or other mining operations.

Sir Frederick Abel. Sir FREDERICK ABEL, in reply upon the discussion and the correspondence, said he would in the first instance notice the criticisms of Mr. Bainbridge, that the subject of wedges had been incompletely dealt with by him; of Mr. Sydney Walker, that he had not discussed electric-signalling appliances; and of Mr. George Seymour, that he had confined himself to the consideration of accidents in coal-mines, to the exclusion of metalliferous mines. He would point out that, in the concluding part of the Paper, he had disclaimed any attempt even to deal completely with the comprehensive subject of accidents in coal-mines, having confined his subject to the most prominent only of the causes of accidents in collieries, and to the knowledge of those means by which their disastrous effects might be diminished. It would have been presumptuous in him, as an amateur in the study of mechanical appliances connected with this subject, to have criticised in detail the relative merits of different systems of wedges for coal-getting, or to have done more than give the conclusions arrived at by his colleagues on the Royal Commission and himself, from the evidence collected respecting the value of detaching hooks, of safety-hooks or clutches, and of other mechanical devices to guard against shaft-accidents. He might point out, however, that although he had not dealt separately with sources of accidents which might be peculiar to metalliferous mines, he had, in the first part of his Paper, incidentally discussed the subject of the employment of ladders, cages, and man-engines, in mines of that class to which Mr. George Seymour had referred. While concurring in Mr. Walker's view that the adoption of electric-signalling appliances in mines was attended with important advantages in underground work, he could scarcely regard them as being directly connected with the subject of prevention of accidents, and he had therefore omitted their examination.

It had been stated by Mr. Lupton that the danger of a goaf as a lurking place for firedamp-and-air mixtures "depended

upon two things, the depth of the mine and the age of goaf;" but, surely, the possibility of danger from goaves was also closely connected with the question of the extent to which the old workings, where these goaves had been formed, were originally filled up, and the consequent degree of liability to the formation of large cavities, by the subsidence of large irregular masses of hard stone, which would not become filled up, in course of time, as assumed. Mr. Lupton dismissed the question of danger arising from accumulations of gas in goaves in a very facile manner, by saying that if the goaf was "properly ventilated, there was comparatively little danger." But it had been pointed out in the Paper that the great difficulty of dealing with the ventilation of goaves, in an effectual manner, constituted a most important and obvious source of danger; and that the possibility of connections being established between gas-laden cavities in the interior of goaves, and localities situated at no great distance from them where shot-firing was carried on, was also a probable element of danger in connection with imperfectly packed goaves, which merited grave consideration. This view of the importance of giving serious attention to the possibly intimate connection of goaves with many coal-mine explosions, had been confirmed by Sir Warington Smyth's remarks on this head; and the observations of Mr. William Morgans, who had done good service in carefully examining into this subject, were well worthy the consideration of Mr. Lupton. With respect to the inquiry made by that gentleman, as to whether there appeared to be any connection between the depth of a mine, and the pressure of gas in the coal of that mine, the results of the pressure-measurements referred to in the Paper as having been made in several coal-mines in the North of England and in South Wales, did not indicate any connection of that nature; thus, in one particular mine, the pressure of gas in a hole bored into the coal, at a depth of 2,400 feet, was 150 lbs. per square inch; while in another hole in the same mine, at a depth of only 900 feet, the pressure was 280 lbs. In a second instance, a pressure of 430 lbs. was recorded in a hole at a depth of 1,480 feet, while in a hole in the same mine 20 feet deeper, a pressure of 318 lbs. was indicated. It was also found that the direction of the hole, with reference to the cleavage of the coal, had no influence upon the gas-pressure indicated; and that, as mentioned in the Paper, several holes bored to different depths parallel to, and within a short distance from each other, gave very different maximum pressures of gas.

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It had been suggested by Mr. Henry Hall that the late Commission should have given information as to the explosive

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force capable of being exerted by definite quantities of firedamp; he stated that it was difficult to say how much gas was dangerous, and that officials treated the discovery of large volumes of gas here and there, during inspection, as being of no moment, saying that it was not dangerous. The Author could only reply that any statements, with regard to the explosive force capable of being exerted by different volumes of pure marsh-gas, would be of no practical value in reference to the possible destructive effects which roughly estimated accumulations of firedamp of unknown composition, in admixture with unknown proportions of air, might exert. The information, now widely disseminated, regarding the effects of dust (existing almost everywhere underground) in adding to and carrying on firedamp explosions, should, however, suffice to warn those entrusted with the inspection of mine-workings, that surrounding circumstances must indeed be most exceptional which would warrant the treatment with indifference of a considerable volume of gas, found in any part of a mine.

The observations of Mr. Lupton, with regard to the part played by coal-dust in mine-explosions, were good illustrations of the nature of arguments advanced by ardent advocates of the view that coal-dust alone was the cause of many explosions. There was some originality, however, in the view that if the results of analysis of the air of a mine in particular places demonstrated the existence in it of a small quantity of firedamp, there should be an inclination to discredit those results, because Mr. Lupton's arguments demonstrated, to his satisfaction, that no gas whatever ought to be found there. Other observations in the course of the discussion illustrated the diversity of views, still entertained by competent authorities, as to the sufficiency of the evidence, experimental and inferential, which had been advanced or collected in favour of the view that explosions originated with, and were carried on by, coal-dust in the complete absence of firedamp. Thus, Mr. Morgans had pointed out the insufficiency of evidence in the case of two explosions which had been ascribed to coal-dust alone, and Mr. Henry Hall, an eminent inspector of mines, who (without any detraction from Mr. Galloway's merits) had been the first to make experiments with coal-dust upon a scale nearly approaching in magnitude the condition of things existing in a colliery, while stating his conviction that explosions were greatly aggravated by the presence of coal-dust, had, at the same time, expressed his belief that no explosion had occurred in a mine of importance where there was no firedamp. On the other hand, Mr. Sawyer

had referred to a case in which, in his opinion, an extensive explosion had been caused by coal-dust, with probably only a "trace" of firedamp in the air. The opinion as to the probable amount of firedamp present was, of course, based upon the application of the usual (lamp-) test, which failed to detect less than 2 per cent. of gas, in the hands of experienced observers. This was an instance of the indefinite kind of information upon which the assumptions that no firedamp was concerned in particular explosions in dusty mines were always based, and which was not of a nature to combat the validity of the very definite statements advanced by the French authorities, Messrs. Mallard and Le Chatelier, namely, that all explosions of magnitude, in which dust had evidently played an important part, had occurred in mines in which firedamp existed; and that no explosion had been known to occur in lignite-mines, which were quite free from firedamp, although they were very dusty, the dust being highly inflammable. Mr. Bedlington had, in the Author's opinion, expressed the rational view with regard to the coal-dust question, when he stated that, while he was not convinced that dust alone would serve to account for explosions of magnitude, which should be of very much more frequent occurrence if such were the case, he admitted that, where much dust was present, explosions were greatly aggravated thereby. Sir Frederick Abel.

In the opinion of Mr. J. B. Atkinson the Author had not realized the full importance of the influence of coal-dust in colliery explosions. A perusal of the Paper would, however, show not only that the Author had there given the fullest weight to the facts and views contained in the Messrs. Atkinson's instructive work on Explosions in Coal-mines, but also that, after summarizing, he believed in a thoroughly impartial manner, the existing evidence and views regarding the part played by coal-dust (which he had to discuss in much greater detail in that part of the Royal Commissioners' Report which dealt with this subject), he had laid the greatest stress upon "the serious dangers arising from the existence of dust-accumulations in collieries," and upon the great importance of not "allowing any accumulation of dry dust to exist in workings where shots are fired." He had only argued (and in this action he was supported not merely by the writings of Messrs. Galloway, Atkinson, and others, but also by the observations which had been made during the discussion of the Paper), that the "serious dangers" liable to arise "from the existence of dust-accumulations in collieries," could certainly not become more impressed upon the mining public by the contention that particular explosions had been examples of "pure dust explosions," when all that could be

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said in reference to the asserted freedom of the air in the mine, at the time of the explosion, from firedamp, was that it was practically free from gas, or that only traces of firedamp existed, or ought to have existed, in the air of the mine. Certain experiments of Mr. Hall, of Professor Marreco (to which Mr. William Cochrane referred), of the Author himself, and most recently of the Prussian Firedamp Commission, had demonstrated beyond doubt that explosions, of a more or less violent character, might be brought about by coal-dust possessing particular characteristics, in the complete absence of any trace of firedamp, and this had been clearly pointed out by him in the Paper; but those experiments also demonstrated as conclusively that a combination, in coal-dust, of the characteristics of extreme fineness of division, high inflammability and peculiar physical structure or condition, essential for the production of explosive effects and for very rapid transmission of flame, was very exceptional. Thus the "Leycett" dust, used in his experiments, the "Pluto" dust (and one other), with which the Prussian Firedamp Commission obtained, at Neunkirchen, violent explosive effects in the absence of firedamp, such as described by Mr. S. B. Coxon, were exceptional dusts among a great variety of fine, dry coal-dusts experimented with, many of which exhibited comparatively very little, or no, tendency to propagate flame rapidly and to a considerable distance, in the complete absence of firedamp, even when they were much more thickly suspended in the air than there would be any probability of their being in actual practice. The statement made in the communication from Mr. J. A. Longden, of Alfreton, a member of the Committee of the Chesterfield Mining Institute, by whom a most important series of coal-dust experiments had been carried out, afforded valuable confirmation of the truth of these observations. He stated that, amongst the very large number of dusts experimented with, there was "one particular dust, from the North of England," which "was highly explosive, without the addition of any gas whatever. On the other hand, none of the dusts from the neighbourhood of Chesterfield were nearly as explosive, and the dust from Blackwell Colliery could not be fired under any circumstances." Mr. Longden concluded, from the results of his special practical and experimental experience, that "there seemed to be an inclination just now to attribute to coal-dust more importance than, in the estimation of many mining engineers, the case deserved." Mr. J. B. Atkinson's criticism of the Author's statement that experimental results, of more or less exceptional character, or obtained under conditions which did not approximate to those likely to occur in a mine, was

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answered, not only by the foregoing facts, but also by the illustration which Mr. Galloway's communication furnished, of the unpractically exceptional combination of circumstances which had attended some of the experiments made in support of the so-called "pure coal-dust theory," when, with the return-air of a mine, the freedom of which from firedamp was not maintained, the air required to be literally black with dust before it would ignite.

In order to favour the pure coal-dust theory, it became necessary (as was done by its advocates), while admitting that firedamp existed in the air of most mines, to dismiss it in special instances, as a "trace" (which it was assumed to be upon theoretical considerations), and therefore, of no account as a factor in the origination or the development of explosions. This was a method of dealing with it not warranted by the results of experiments, nor by the fact that it had hitherto been the custom to consider the air of a mine free from all but "traces" of firedamp, when it had not furnished indications of gas by means of the safety-lamp test, but which might nevertheless contain at least 2 per cent. of gas. Mr. W. N. Atkinson's statement, that "it would probably not be difficult to prove by means of Liveing's indicator, or the Pieler lamp, that the large volumes of air passing along the main intake air-ways of such collieries did not contain even the very minute quantities of firedamp which these instruments were capable of detecting," suggested an obvious direction in which the advocates of the pure coal-dust theory could seek for positive evidence in support of their views. At the same time, the Author would not desire to suggest that further labours in this or other directions, with the object of supporting particular theories regarding the precise manner in which coal-dust operated as an element of danger in mines, would serve the least practically useful result; for while, on the one hand, both the possibility of serious explosions being caused in mine-ways and workings, where the air might be assumed to be absolutely free from firedamp, by the existence in abundance of coal-dust, possessing certain essential characteristics, and also the very exceptional occurrence in coal-mines of a sufficiently abundant supply of dust possessing those characteristics, had been thoroughly demonstrated, the serious dangers arising, in other ways now well known, from any kind of dust-accumulation in coal-mines, had, on the other hand, been not only conclusively established and elucidated, but had also become fully recognized by the mining community and officially, and means both practical and effectual had been prescribed for avoiding or diminishing those dangers. He considered that, in the present state of knowledge, it

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would have been unreasonable to provide, in the recently passed Act, for the systematic damping of coal-dust in all parts of dry mines, which Mr. W. N. Atkinson seemed to think should have been done; but that the prescription of precautions, to guard against the ignition of coal-dust during shot-firing, must certainly be regarded as one of the most important improvements effected by that Act; and it had been very satisfactory to have learned, in the course of this discussion, the nature of several efficient means of damping coal-dust in mines which had already been elaborated and applied, and which were obviously susceptible of further important development.

It had been stated by Mr. J. B. Atkinson that his experience pointed in a direction opposed to the accepted fact, mentioned by the Author, that the combustion of a mixture of air with a finely-divided inflammable solid was gradual in comparison with that of a mixture of inflammable gas and air; but Mr. Atkinson had unfortunately not given the nature of his experience. On the other hand, he had mentioned several conditions under which he conceded that the Author's statement would hold good, and the argument advanced in favour of his view, upon which he appeared chiefly to rely, was embodied in the statement that, while the "rapidity of combustion of a homogeneous gas-and-air mixture probably reached its maximum within a short distance of the point of ignition," the "reverse was probable in the case of a coal-dust-and-air mixture." The Author would venture to ask whether this statement did not point to the conclusion that the transmission of flame by the gas-and-air mixture was the more rapid of the two?

It was to be regretted that the labours of some of those who had contributed to a recognition by the mining public of the dangers of coal-dust, had, by developing in those workers a tendency to place it in a pre-eminent position among the elements of danger existing in collieries, led to a depreciation by them of the dangers due to sudden outbursts of gas, which had been so forcibly, but certainly not too seriously, dwelt upon by Sir Warington Smyth, and also by Mr. R. Bedlington, and to the accumulation of gas in, and its emission from, or possible explosion in, goaves, which Mr. Morgans had so lucidly discussed. That such was the case, however, must be evident to those who would peruse some of the observations elicited by the Paper. Without assenting to the remarks, made by Mr. Stokes, which tended to the dangerous inference that the possible escape of gas into the main-air from accumulations in goaves could not be matter for serious consideration, he feared that many mine-owners

and managers would not consider that the conditions to be fulfilled by the ventilation of a mine, as laid down by Mr. Stokes, were such as they should be compelled to comply with. Sir Frederick Abel.

The particular source of accident to which Mr. Edward Combes had directed attention, namely, the occasional escape into workings of choke-damp, or carbonic acid gas, from goaves or other lurking places, had received the consideration of the late Commission; but no other means could be suggested of guarding against its dangers than the constant careful inspection of localities liable to be invaded by escapes of the poisonous gas, the presence of which fortunately was indicated by its effects upon the flame of a lamp or candle before it could exert its deadly action. The maintenance of powerful air-currents, in localities liable to be infested by it, was an obvious precautionary measure, and the observations of Mr. Max Georgi on the importance of supplementing the regular system of ventilation by a system of auxiliary ventilation, and on the course of action taken by the Saxon Government in reference to this important additional safeguard, well merited consideration in especial regard to the dangers of choke-damp.

Sir Frederick Abel did not think that the remarks made by Mr. Harries, in support of his view that accidents were most prevalent during anticyclonic disturbances, needed any addition by him to the observations made in the Paper, in respect to the extent to which importance could be attached to the various views advanced regarding the connection between atmospheric disturbances and coal-mine explosions. Mr. Sawyer had made some very cogent remarks, in which he entirely concurred, in support of the conclusion, that it was idle to attach importance to attempts to establish a regular connection between barometrical variations and colliery explosions. Variations in dryness and in temperature of the external atmosphere might, on the other hand, in the present days of powerful ventilation, influence considerably the magnitude of explosions, in reference to the great influence of moisture upon the inflammability of coal-dust.

In referring to the increase of accidents due to falls of coal and stone in mines, Mr. Bainbridge had pointed to what certainly might be considered as one probable cause, namely the gradual exhaustion of seams having the best roofs, and the consequent increase in the work done in seams with insecure roofs. Sir Warington Smyth had laid stress upon the importance of providing the miner with a good light; and the Author felt bound to state that, while he concurred with Mr. Henry Hall in his view that too much importance had been attached to the provision of a large

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amount of light by the lamps furnished to miners (especially as regarded miners' electric lamps), he must point out that he certainly had not advanced the obviously untenable view assigned to him by Mr. Hall, that falls of roof would be less frequent if the men had better light than was now provided. What he had maintained was, that casualties from falls would be diminished, if the men could apply sight in addition to ear in judging of the degree of imminence of danger threatened by a coming fall.

The information which he had brought before the Institution in his Paper respecting recent improvements in the construction of safety-lamps, and the progress made in the application of electricity to the illumination of mines, had been very usefully supplemented by the interesting exhibition of recent work in these directions.

Some points had been referred to in the discussion with respect to general details of construction in lamps of modern types, a few of which he would briefly notice. He concurred in Mr. Bainbridge's view, that a lamp which could be confidently depended upon as safe in a current velocity of 30 feet per second, was for all practical purposes a safe lamp in most mines, and that many designers of new lamps had fallen into the error of resorting to very complicated and costly arrangements, for enabling their lamps to withstand exceptionally severe tests. Such lamps presented the additional defect that they were heavy, and that their various parts were difficult to put together properly, so that reliance could not, especially in the absence of a gas-test, be placed upon their reaching the miners' hands in a safe condition. The most recent lamp of Mr. Bainbridge's construction certainly possessed the merit of simplicity; the readiness with which it could be cleaned and the arrangement for leaving the glass untouched, were very good points.

It would certainly not be found by Mr. Hall that the Author had especially recommended lamps with glasses; he had distinctly stated that, although such lamps were obviously superior in point of efficiency as illuminating agents, they were open to objection on the score of uncertainty of safety which the glass presented; and he had gone into considerable detail with respect to the various possible causes of the doubtful safety of such lamps, even when provided with double glasses. Sir Warington Smyth had referred to two unquestionable drawbacks presented by the hood or "bonnet," with which the majority of modern lamps, from the Marsaut to Mr. Bainbridge's latest lamp, were provided. The additional heating of the lamp, due to the retention of heat by the metal

envelope surrounding the gauze, was no doubt a source of occasional inconvenience; but the more substantial objections were that the bonnet prevented the men from seeing what was going on inside the gauze, and also obstructed the distribution of light above a certain plane, so that the roof of a road or working was even more imperfectly illuminated than by the old gauze lamps. The first of these objections was not difficult to remedy; by cutting two narrow slots opposite to each other, in the bonnets, and fitting these with mica plates, which could be easily done, small windows could be provided, through which all that took place inside the enclosed gauze cage could be readily seen, and the protection afforded by the bonnet would not in the least degree be diminished. He had fitted several bonneted lamps in this way, for the purpose of seeing how they behaved in powerful currents of explosive gas-mixtures, and the arrangement answered perfectly. The obstruction of light in the upward direction was inevitable, and this was undoubtedly a sacrifice in efficiency, which, however, was considered as more than compensated by the safety which the use of the bonnet secured. At any rate, the most experienced lamp-makers, such as Messrs. Bainbridge, Ashworth, and Marsaut, like other inventors of new forms of lamps, mostly adopted the hood or bonnet as an essential element of safety. Mr. Sawyer, one of H.M. Inspectors of Mines, had said that even Mueseler lamps should be fitted with bonnets, which should be easily movable, to facilitate the examination of the gauze by the fireman, and the Author believed that the bonneted Marsaut lamp had come into extensive use in some districts, with no inconvenient results, the superior illuminating power of the lamp compensating for the partial obstruction of the light in the upward direction. Sir Frederick Abel.

Members of the Institution had an opportunity afforded them, by the interesting exhibition of lamps of various kinds in the building, of forming some judgment for themselves whether he had been too sanguine in predicting that the safe and thoroughly efficient application of electric light to the purposes of the miner would speedily be accomplished. How far the cost and the weight of self-contained miners' electric lamps would be susceptible of sufficient reduction, to bring them thoroughly into competition with safety-lamps of the best modern types (for they would scarcely be likely to compete with the older forms of lamp in these respects), would probably be determined within a brief period. Certainly the present original cost of the secondary battery in lamps was prohibitive, as pointed out by Mr. Tylden-Wright; while their weight, although it had been

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already considerably reduced, was still inconveniently great. On the other hand, the lightest of the improved forms of safety-lamps were at least double the weight given by Mr. Tylden-Wright as that with which the electric lamps had to compare. He could not agree with the view, taken by Mr. Sydney Walker, that the eventual method of applying electricity to the illumination of the face of the coal would be by supply-mains, or main conductors. The objections to fixed lights, and to the attachment of lamps to main-conductors by branch wires, had been pointed out in the Paper. Those objections appeared to counterbalance the advantages to be secured, and they were not met by Mr. Walker. Moreover, the lamp which gave light to the miner for his work should also be available for lighting his path to and from work, the distances to be travelled rendering the illumination of the mine-roads throughout generally quite out of the question, from the point of view of cost alone. As to difficulties in the application of secondary-battery lamps, at collieries where electric-light installations already existed, consequent upon necessary complications of arrangement, he could assure Mr. Walker that practical experience had already given a satisfactory answer in the negative to this supposed objection. The chief advantages, at present possessed by such primary-battery lamps as had assumed a practically useful form, consisted in their comparative lightness and their lower cost. Mr. Tylden-Wright and Mr. J. A. Longden had pointed to two important objections to the general use of electric lamps to the exclusion of ordinary safety-lamps; they afforded to the miner no means of warning him of the existence of foul air or choke-damp, nor could the air of the mine be tested for the presence of firedamp by their means. There appeared at present no mode of meeting the first objection; with respect to the second, he had pointed out that Mr. Swan had already applied an electric gas-detector as an adjunct to his miners' lamp; it remained to be seen whether this would furnish a reliable and readily applicable substitute for the safety-lamp or other more sensitive gas-detectors now known.

It having long since been generally acknowledged that some more sensitive indicator of the presence of firedamp than the Davy lamp, or such other forms of safety-lamp as were preferred by some for inspecting purposes, was much needed, he had felt some surprise that Mr. Lupton should have dismissed the subject of gas-indicators by a reference only to the earliest instruments of this class, the Ansell indicators, which had long been well known to possess radical defects, as pointed out in the

Paper. Mr. George Seymour had also summarily dismissed the subject of gas-indicators generally with the statement that "experience" had demonstrated them to be of but little practical use; but he had not even mentioned the kind of indicators of which he or others had acquired this unfavourable experience. He was glad to find, on the other hand, that Mr. Steavenson had spoken of the Liveing gas-indicator, from personal experience, as a very valuable instrument in the hands of a good overman. He felt convinced, from his own experience, that this instrument would not be at all difficult to use after very little practice; and he could assure Mr. Hall that the handle, which actuated the arrangement for heating the little test-coils, did not require to be turned at a certain fixed speed in order to furnish uniform results. He felt confident that, for purposes of special inspection, at any rate, this gas-indicator would be a valuable acquisition; and he believed that a form of eudiometrical gas-detector would also ere long be perfected as a reliable instrument. It could scarcely be denied that, while the skilful use of particular varieties of safety-lamp furnished the means of detecting small percentages of firedamp in mine-air, it was desirable that overmen or firemen should be furnished with, and become accustomed to the use of, apparatus by which very small proportions of firedamp could be detected, and their amount estimated with considerable accuracy. It had been thoroughly well established that a proportion of firedamp in the air, which would altogether escape detection by means of a safety-lamp, might constitute an element of great danger in dry and dusty mines. Sir Frederick Abel.

In referring to the subject of safety-lamps, Mr. Tylden-Wright had defended the alteration, made in the House of Lords, of the general rule relating to safety-lamps, which, as adopted by the House of Commons, excluded "unprotected" Davy, Stephenson, and Clanny lamps from the category of safety-lamps, and Sir Frederick Abel was surprised to find Sir Warington Smyth in agreement with Mr. Tylden-Wright on the subject, because when the former and the Author were Members of the Royal Commission together, Sir Warington's views regarding the dangerous character of the unprotected lamps in question, when used in any part of a mine where only a very moderate ventilating current was met with, were so strong, that he had no hesitation in assisting in the preparation of a letter, addressed to the Home Secretary, on the 15th of December, 1880, which he signed as Chairman of the Commission, the object of this letter being to recommend that it should be made known as soon and as widely as possible, that

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"the employment of the ordinary Davy lamp without a shield of metal or glass, in an explosive mixture, when the current exceeded 6 feet a second, is attended with risk of accident almost amounting to certainty. The Clanny lamp, when tested in a similar current, has proved to be scarcely, if at all, less dangerous."[1] Moreover, in the unanimous final Report of the Commission, presented in March 1886, the following statements were made[2]:— "It results then, from the improved ventilation of mines, that if the current becomes sufficiently charged with firedamp, the Davy and Clanny lamps" (which are frequently exposed to current-velocities of from 20 to 25 feet per second in the air-ways, and might occasionally be exposed to currents having velocities of from 30 to 35 feet per second) "cease to be in any way safety-lamps, and the Stephenson (Geordie) lamp may often cause an explosion." After having stated that the "insecurity of these lamps" had been conspicuously shown by the results of the Commission's experiments, and had previously been demonstrated by various Societies of Mining Engineers, the Report proceeded:— "Under present conditions as to ventilation, the danger of relying upon Davy and Clanny lamps seemed to us so great that we felt it our duty, at an early stage of our investigations, to address a letter to the Secretary of State for the Home Department, calling his special attention to the insecurity of these lamps." He could not comprehend on what grounds a simple reiteration, though in less emphatic terms, of this condemnation of unprotected Davy and Clanny lamps, of which Sir Warington Smyth was joint Author, was characterized by him as an "onslaught" on these lamps. Nor could he understand what the exclusion of unprotected Davy, Clanny, and Stephenson lamps from mines where it was necessary to use safety-lamps, had to do with mines in "many districts in the country where no gas had been perceptible from generation to generation," and where, therefore, naked lights would still, as hitherto, be used without any interference. As regarded such mines, which, according to the late Chairman of the Commission, "were scattered broadcast throughout the land, as in the Forest of Dean, South Staffordshire, and other districts," where "gas was never noticed," the retention of the House of Commons Clause, with respect to unprotected lamps of the kind specified, would certainly not have led to any dictation to the people work-

[1] Accidents in Mines, Final Report of Her Majesty's Commission, 1886, p. 188.

[2] *Ibid.*, p. 67.

ing in them to "take some new patent lamp capable of withstanding the effect of a strong current," as there was certainly nothing in that clause to enforce the use of lamps in place of naked lights, where no gas had ever been noticed. The Commons' Clause did not even prohibit the use of Davy and Clanny lamps in any mine, but only insisted that they should be protected; and no one knew better than Sir Warington Smyth, from the large number of experiments in which he had taken part, as well as from the practical trials he had witnessed, that these lamps, which he had considered it his duty to condemn as unsafe, could be protected by very simple and inexpensive adjuncts, and had been so altered in very large numbers by mine-owners, so as to render them as safe in the highest current-velocities ordinarily met with in mines at the present time, as they were in the first days of their invention, when only currents of very low velocity existed underground, and thus preventing their exclusion by the terms of the general rule, either as it now stood or as it was approved of by the House of Commons. Mr. Sawyer had pointed out that, in the district in which he was Inspector, unprotected lamps were rapidly disappearing in all fiery mines; but there might be districts in which such action, being purely at the option of the mine-owners, managers, or men, might be neglected, or very difficult to enforce, in consequence of the ambiguous wording of the general rule as it now existed, and of the ardent advocacy of the lamps in their original state by such influential gentlemen as Mr. Tylden-Wright. Sir Frederick Abel.

That gentleman had said that nothing could be more definite than the present clause in the Act relating to safety-lamps, as amended by the House of Lords; but he went on to show that intelligent men (under which head the Author ventured to couple himself with Mr. Tylden-Wright) might put two very different constructions upon it, and thus to demonstrate the obvious ambiguity, as pointed out by him, of that passage in the rule which spoke of "that part of the mine in which the lamps are for the time being in use." Sir Warington Smyth well knew that currents of exceptionally high velocity might occasionally be encountered by men carrying unprotected Davy or Clanny lamps in mines in which "the current ordinarily prevailing" would not involve danger, and Mr. Sawyer had directed attention to the important fact that the safety of an unprotected gauze lamp, "when it was carried against an inflammable current of the smallest velocity, depended entirely on the rate at which the person who was carrying it was

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travelling," and that "this varied much and could not be regulated." A stronger argument in favour of the wisdom of the course which the House of Commons had agreed to adopt could not well be imagined, and Mr. Sawyer had aptly illustrated it by reference to a recent accident, which was ascribed to a Davy lamp, carried by a collier, who was hastening at the time in a direction contrary to an inflammable current which had, at the place and time of the explosion, a velocity of only 2 feet per second. He would commend to the notice of Mr. Bainbridge this accident, as being only one of several due to lamps which, in his comparatively brief experience, he had heard of.

As a man of science and a chemist, he could not yield to Mr. Tylden-Wright in his admiration of Davy, and of his beautiful researches which led to the construction of his safety-lamp, but could not admit that his great name would come under any "obloquy," because the Davy lamp, in its simple original form, was no longer the safe lamp which it undoubtedly was for many years after its first introduction, until other important advances in applied science had altered the conditions which presented themselves to Davy as those to be met by a safety-lamp. But it appeared that, after all, Mr. Tylden-Wright was mainly desirous of retaining the unprotected Davy lamp in use, not for the general purposes of the miner, but because it was looked upon in South Staffordshire as the most delicate and best practical apparatus for testing for gas in mines. Mr. Tylden-Wright was, perhaps, not aware that a protected Davy lamp could be most easily taken out of its case, when the fireman arrived at a place in a mine which had to be examined for gas; but even this was unnecessary, for Sir Warington Smyth had stated, upon the high authority of Mr. Lindsay Wood, that the protected, or cased Davy, which stood very well in point of safety in the Commission's experiments, and was, indeed, thoroughly safe for all ordinary conditions, could be as readily and effectively used for testing purposes as the unprotected lamp. He was glad that reference had also been made, by Sir Warington Smyth, to the fact that competent practical authorities were by no means in accord in accepting the Davy lamp as the most sensitive lamp for purposes of inspection. Mr. Sawyer's published experiments, which were very complete, had established the superiority of the Mueseler lamp, which had been confirmed by Messrs. Mallard and Le Chatelier; while Kreischer and Winkler had been led by long experience to give the preference to lamps of the Clanny and Boty types. Mr. Sawyer had also stated, and no one was more competent to know than he, that men

who had become used to the Mueseler lamp were now as wedded to it as they had been to the "Old Davy," and that no difficulty was experienced, after its use for a short time, in carrying it even in steep mines without fear of its being extinguished. Too much importance must, therefore, not be attached to Mr. Tylden-Wright's local experience, as to the unprotected Davy being indispensable; no doubt it was so considered by those who had always been accustomed to use it, but in several collieries the men who had been wedded to it were now equally attached to the cased Davy. He therefore maintained, against Mr. Tylden-Wright, and even against so high an authority as Sir Warington Smyth (whose own words, however, had strongly supported his contention), that the prohibition of the dangerous "unprotected" lamps, which was all that was contemplated by the House of Commons' general rule, would neither have dimmed in the least the lustre of Davy's name in connection with his safety-lamp, nor have resulted in any hardship to those who had hitherto used the unprotected lamps. Sir Frederick Abel.

He would assure Mr. Tylden-Wright that he was quite aware of the fact that hundreds of collieries in the United Kingdom were at a long distance from gas-mains; but he could also assure him that, if a gas-test for lamps had been established by law, there would have been no difficulty in providing, at little outlay and trouble, for the maintenance of the small gas-supply necessary for the systematic application of the test to the lamps in regular use. The bearing of Mr. Lupton's observations, with reference to the value of a gas-test for lamps, was difficult to fathom; he would only state that the value of such a method of testing, and the feasibility of applying a reliable and searching gas-test, were beyond question, and he felt confident that Mr. Lupton would have no difficulty in himself arranging such a gas-test as would furnish that check "upon the eye and skill of the lamp-man," which even the most implicit trust in that official rendered highly desirable.

There could be no doubt, as pointed out by Sir Warington Smyth, that blown-out shots, which had been a fruitful source of accident, and the starting-point of many serious explosions, were far more frequent than they should be in coal-mines, if more knowledge, skill, and care were brought to bear in the selection of the spot for the charge of explosive, the placing of the hole, the process of charging, and the adoption of simple measures for facilitating the operation of the charge. The neglect to hole and cut the coal at the fast-places before shot-firing, and the bad

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selection of places for the shot, had also been pointed out by Mr. Sawyer as constantly conducing to the occurrence of blown-out shots, and of consequent accidents. So long as knowledge and intelligence were not brought to bear on these important points, there was little hope of a general realization of Mr. Bainbridge's picture of the present freedom from risk of serious accident in well-regulated mines, from the occurrence of blown-out shots. Mr. Bainbridge had expressed his belief that the use of certain explosives of recent invention, such as roburite and carbonite, would have the effect of putting an end to the dangers arising from blown-out shots, and based his favourable opinion of the first of those materials upon the personal observation of a single "blown-out shot" underground, from which he saw no sparks produced. Sir Frederick Abel had repeatedly seen the same result with other explosives, which were not, however, invariably confirmed in repetitions of the trials; and that the same was the case with roburite had been demonstrated by experiments in this country, which had been noticed in the public prints, and by experiments in Germany. Thus, in some official trials at Neunkirchen, two charges of about 8 oz. of roburite had been fired, as blown-out shots, into atmospheres containing 6 per cent. and 8 per cent. of fire-damp. No explosion occurred in either case, but in two repetitions of the trial in the firedamp- and air-mixture, a violent gas explosion was produced in each case by the blown-out shot. He had given reasons in the Paper (p. 59) why the explosive carbonite, to which Mr. Bainbridge had also referred, could not be expected to secure immunity from the dangers due to blown-out shots, and there was no reason to believe that securite, nor any other high explosive, applied *per se* in a shot-hole, could be relied upon to secure freedom from the projection of matter sufficiently highly heated to ignite an explosive gas-mixture, when a blown-out shot was produced.

That the principle of cooling down the incandescent or highly-heated matters projected by a shot, by means of water, applied in one way or another, was now receiving beneficial application in connection with shot-firing, was a source of great gratification to him. He had, as Sir Warington Smyth kindly pointed out, laboured quite disinterestedly to bring to bear, as a safe and efficient method of working in coal, the system of distributing the explosive force exerted by a detonated charge through the agency of water, by which it was completely surrounded, which he had elaborated fifteen years ago. He felt sure that if Mr. Tylden-Wright would pursue experiments a little further, he would find that certain nitro-glycerine preparations, such as gelatine-dynamite, would, through

the agency of water, do work in coal quite equal to that performed by powder used in the ordinary way. He should add, in reference to a suggestion of Mr. Tylden-Wright, that it would be labour thrown away to endeavour to ensure safety in the use of powder through the agency of water. This matter had been thoroughly dealt with in the report of the Commission. The only objection to the water-cartridge which had been raised was that mentioned by Mr. Hall, and by Mr. A. L. Steavenson, namely, the weakness of the water-bag or envelope; this certainly did not exist in any form of cartridge which he had used, and was easily guarded against. Mr. Sawyer had wisely pointed out that care and intelligence were necessary to ensure success, with the use of the arrangements for blasting in conjunction with water, as in any other operation needing attention to simple precautions. He was glad that Mr. Forster Brown had successfully employed, and had acquired confidence in, the comparatively simple method of using water in conjunction with a porous body, such as moss, of the efficiency of which, in conjunction with high explosives, the Commission had been led by experiment to entertain a high opinion. Sir Frederick Abel.

Proposals, which had been repeatedly made, to apply as tamping materials, substances which contained water or carbonic acid, or both, in considerable quantities, and which parted with those constituents more or less readily when exposed to heat, had been commented upon by the Author as possessing no value from the point of view of promoting safety in coal-blasting, because the extremely brief period during which portions of such tamping would be exposed to heat, upon the firing of the charge of explosive in rear of them, would be altogether insufficient to expel a quantity of either aqueous vapour or carbonic acid from them, adequate to exert any effect in extinguishing, or materially reducing the temperature of, the highly heated products of explosion or of projected flame and sparks. He had much desired to test the correctness of his views by the results of actual experiment, and since the reading of the Paper he had succeeded in doing so. A large cast-iron shell had been compactly filled with powdered soda crystals, a cavity being afterwards made in the centre, for the reception of a charge of gunpowder. The shell was closed with a metal screw-plug having a perforation through which a fuze was inserted into the charge. Upon exploding the latter, the shell was not burst, but the products of explosion gradually escaped through the perforation in the shell-plug. The crystallized carbonate of soda was therefore exposed to the heat, developed by the explosion, for a much longer

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period than it would have been had it been employed as tamping in a shot-hole and at once projected, by the rush of escaping gases, if the shot had blown out. A portion of the contents of the shell which was nearest to the gunpowder charge was found to contain 62·04 per cent. of water; a sample of the soda crystals with which the shell was charged was found to contain 63·25 per cent. The exposure of the salt to the heat of exploding gunpowder, under more severe conditions than those which obtained in the case of a blown-out shot, did not, therefore, expel a proportion of water sufficient to produce any practically useful effect in cooling down the products of explosion.

It was not improbable that a very different result would be obtained if a substance, containing large proportions of volatile constituents, such as soda crystals, alum, or an ammonium-salt, were intimately mixed with an explosive agent, in such proportions as not to interfere too greatly with the transmission of explosion or detonation through a charge of the diluted material; as in that case portions of finely divided crystallized salt, or volatile substance, would be individually exposed on all sides to the heat developed at the instant of the explosion, and the cooling effect, due to the conversion into vapour, and expansion, of the water or other readily volatilizable constituents, would be brought to bear upon the products of explosion almost instantaneously upon their generation. Experiments, which had been quite recently made in this direction in Germany, appeared to have furnished very promising results. Preliminary trials, conducted by the Rhenish dynamite company, with charges ranging from 8 to 18 oz. of a mixture of Nobel's No. 1 dynamite with finely-powdered soda crystals, by firing them as blown-out shot in a gallery containing an explosive gas-mixture with much fine coal-dust suspended in it, showed that only in one case, when the proportion of the salt that had been mixed with the dynamite was very small, was an explosion of the gas-and-dust mixture produced. The experiments were then taken up by Mr. Hilt, President of the late Prussian Firedamp Commission, and carried on in the large experimental gallery at Neunkirchen, with comparatively heavy charges of the soda-dynamite, it having been observed by Mr. Hilt, in the course of experiments with roburite, securite, and carbonite, that explosive gas-mixtures were seldom ignited by small charges, while they were generally exploded when heavier charges were used. Mr. Hilt stated that, so far as the experiments with this modified dynamite had been carried, the effect of dilution with the soda crystals was to modify the violent action of

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the original explosive, so as to assimilate the results which it furnished in coal-getting to those obtained with gunpowder. The experiments were still being pursued in Germany, and Mr. Max Georgi even went so far as to assert that the perfect safety of soda-dynamite (*Wetterdynamit*) had been quite established. At any rate, the results obtained appeared to the Author so important, in reference to the provision of an efficient blasting agent for use in coal-mines, which would not require any adjunct, or the adoption of any other than the ordinary method of charging holes, to ensure perfect safety, that he was taking steps to carry on searching experiments with it, the results of which he hoped ere long to communicate to the mining public.

The conflicting nature of the observations made in the course of the discussion, and in the correspondence, with regard to the merits of wedging, and of lime-cartridges, when employed as substitutes for gunpowder in coal-getting, seemed to show that the important and really obvious fact was frequently lost sight of, that neither of the two systems was calculated to do the same character of work in different varieties of coal, and that neither the inventors of particular forms of wedges, nor the elaborators of the compressed lime-cartridge, maintained that the explosive agent could be replaced by either in working all descriptions of coal. The somewhat extreme views of Mr. Stokes with regard to inconveniences and supposed dangers, attending the use of lime-cartridges, were evidently not shared by Mr. A. R. Sawyer, whose observations on this subject, also based upon personal knowledge, had, on several important points, confirmed the conclusions arrived at by the late Royal Commission.

In answering the various questions raised in the course of the discussion, he had endeavoured to deal separately with each important subject on which it appeared necessary for him to comment and reply, and in order to do this thoroughly he had included in those replies the consideration of some of the communications of correspondents. Mr. Forster Brown had supplied interesting information on some other matters included in the Paper. With regard to his remarks on the subject of goaves, they appeared after all to admit that extensive accumulations of gas might occur in these. Mr. Coxon's account of the experiments with dust, which he had witnessed at Neunkirchen, confirmed the statements made in the final report of the Royal Commission respecting the experiments of the Prussian Commission. With regard to his description of an explosion, which he ascribed purely to dust, the assumption that this was so was open to the objection that he assumed the absence

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of gas in the drift where the explosion occurred, simply upon the results furnished by inspection with a Davy lamp and a naked candle. This subject had, however, been thoroughly discussed in the Paper.

It was well known that Mr. J. Ashworth had devoted much labour to effecting improvements in safety-lamps, and those described by him would doubtless, like that of Mr. Bainbridge, receive the attention of mine managers. Mr. Forster Brown was one of the few practical men who could already speak from somewhat considerable experience of the value of electric light in mines, and it was satisfactory to find that he looked forward with confidence to the speedy provision of thoroughly efficient self-contained lamps. As regarded fixed lamps, he did not appear to contemplate the future extension of their use beyond the main haulage roads, while Mr. Arthur Sopwith shared the view advanced by Mr. Sydney Walker, that the future would see electric light applied to the face of the coal through the agency of main conductors, rather than by means of self-contained portable lamps. Mr. Sopwith made light of the objections which the Author had raised against the attachment of lamps, required at the working places, to main conductors by branch wires; but he did not suggest how these necessarily very light leads were to be protected from the liability to injury by falls of coal or stone and rough usage, to which Mr. Longden and Mr. Sennett had referred. The whole question of the application of electric light underground had, however, only passed through the first stage of its development, and there was no doubt that practical electricians would, with proper encouragement from the owners of mines, and by wholesome competition with each other, achieve successes which were at present only foreshadowed. The importance of bringing the cost of electric lamps within such limits as to allow of their competing, from an economical point of view, with safety-lamps of the ordinary and improved types, if any such really extensive trial was to be made of the new system of illumination as could alone lead to its thoroughly successful development, gave force to the observations made by Mr. Story-Maskelyne, which he would venture to commend to the consideration of those who, at present, controlled the supply to the public of the only form of electric light which was susceptible of safe application in coal-mines.

In conclusion, the Author would only say that he cordially agreed with Sir Warington Smyth in the observations he had made, and which were in harmony with those of several other highly com-

petent speakers, that the safe working of collieries must always be in a far greater degree dependent upon the experience, judgment, constant vigilance and care, of those entrusted with their management, and upon the intelligence and ceaseless watchfulness of the subordinate officials, than upon inspection by Government officials, however much it might be increased and elaborated. Sir Frederick Abel.