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T. HAWKSLEY, President, in the Chair.

No. 1,342.—"Explosive Agents applied to Industrial Purposes."

By Frederick Augustus Abel, F.R.S., Treas. C.S.[1]

Discussion.

Professor Abel said he had endeavoured to give a general account of the nature and characteristics of the several classes of explosive agents produced, and to a more or less extent used, as substitutes for gunpowder in industrial operations, and he trusted the discussion of the Paper would serve to elicit information, with regard to their use and relative merits, from persons practically acquainted with their employment.

He had pointed out certain defects of gunpowder, some of which, he believed, were fully established, while others might be open to question. Amongst these were, the variation in its composition and preparation, and consequent want of uniformity in its action. Its deterioration by the absorption of moisture was due to the fact that it was made with special regard to cheapness. The amount of smoke produced in underground operations was a cause of delay and difficulty in blasting; and an important objection was the inevitable liability to violent explosion whenever, either from carelessness or from accidental causes, it was reached

[1] This paper, with the addenda to it, was printed in extenso in the last volume of the Minutes of Proceedings, vol. xxxiv., pp. 327—371. The discussion upon it extended over portions of two evenings, but an abstract of the whole is given consecutively.

by flame or fire of any kind. Many of the accidents in ordinary mining and quarrying operations were undoubtedly due to carelessness; and there was reason to be grateful for the zealous and successful labours of Major Majendie, recently appointed Inspector of Powder Magazines, who had already induced and enforced the adoption of precautions which would greatly guard against accidents in its use and storage.

He might refer incidentally to some experiments at Woolwich Marshes, in which it was demonstrated that the expenditure of heat, by the conversion of water from the solid condition to that of vapour, might serve as a means of effectually protecting powder against the action of fire. It was extremely probable that such arrangements—where the powder was enclosed within fire-proof magazines, which protected it for long periods from important change by the action of violent heat—would prove great safeguards against accident in the storage of small quantities for the purposes of trade.

Chlorate of potash, he had pointed out, yielded preparations more violent, because more rapid, in their action than gunpowder, but also more dangerous, and more liable to accidental ignition by moderate concussion. A few of comparatively safe character had been produced as blasting agents, and to some extent used; amongst these were 'Horsley's powder' and 'tutonite,' and also a material obtained by the saturation and coating of bibulous paper with a mixture of chlorate of potash, charcoal, and other oxidisable substances, first devised by Hochstädter for use in small-arms, and recently proposed by Reichen for blasting purposes.

Several preparations had lately been brought under public notice, which, when fire reached them accidentally, or when otherwise exposed to heat in the unconfined state, would behave less violently than gunpowder. The type of these, manufactured at Plymouth some years ago, consisted of spent tan saturated with saltpetre and sprinkled with sulphur. The two most modern preparations of this class were called 'pyrolithe' and 'pudrolythe.' These undoubtedly burnt less violently in open air than the mildest description of blasting powder. In some special experiments instituted to exhibit their powers, they were described as having produced effects which bore advantageous comparison with those of gunpowder.

In the Paper he had entered as fully as the limits permitted into the history of gun-cotton and nitro-glycerine, with reference to their application to industrial purposes. He had described the manner in which Mr. Nobel had succeeded in applying nitro-glycerine, the most violent blasting agent at present known, which, under favourable conditions, might be handled with comparative safety. He had also pointed out that nitro-glycerine was uncertain and highly dangerous for technical purposes, until Mr. Nobel overcame most of its defects by employing absorbent materials as media for its application. The special absorbent which he used was a siliceous earth called 'kieselguhr' obtained from Germany. This earth was saturated with a large proportion of nitro-glycerine, and the material known as 'dynamite' was produced, which was sufficiently solid to be conveniently handled and packed into paper cartridges, and it was readily fired by a detonating arrangement, also introduced by Mr. Nobel. Subsequently to the invention of dynamite, various substances, akin to it in nature, had been brought forward. One of these was 'colonia powder,' a species of gunpowder saturated with glycerine; others were 'dualine,' 'Horsley's powder,' 'glyoxiline' and 'lithofracteur,' the latter differing in some respects from dynamite, but being the nearest to it in general characteristics.

In giving an account of the relative properties of gun-cotton and nitro-glycerine-preparations, such as dynamite, he had dwelt upon the difficulty of instituting accurate comparisons of the force evolved by different explosive agents, and had pointed out that the many experiments in this direction had been attended with only partial success. Very precise statements were often made with reference to the powers of particular explosive agents, as compared with gunpowder. He believed that such statements were all more or less fallacious; they were generally based upon erroneous assumptions with regard to the uniformity of the material operated against, and of other conditions of the experiments, and upon the sanguine views of those interested. If it were possible to devise some method of ascertaining the powers of explosive agents, applied to destructive purposes, in as trustworthy a way as was adopted in testing the strength of iron, steel, and other materials, so that definite values might be assigned to them, it would be one of the greatest benefits that practical men, connected with mining, quarrying, and engineering operations, could have conferred upon them. In America some experiments had been made in this direction which appeared to be of a promising character, but they required further elaboration before they could be put forward with confidence.

In speaking of the relative merits of dynamite and gun-cotton, he had pointed out that in the former, there were advantages which might be considered as counterbalanced by others possessed by gun-cotton, and that both exhibited special defects. One great defect of dynamite which still had to be remedied, and which it was doubtful if in the present state of knowledge could be thoroughly set aside, was the danger of reducing it from a comparatively inert frozen condition to a state in which it could be readily used. Accidents had repeatedly and even recently occurred through the difficulty of introducing or enforcing simple regulations for the thawing of dynamite, or for the application, in a simple and safe way, of the heat necessary to reduce the dynamite from a solid to a plastic condition in which it could be readily used as an explosive agent.

In the case of gun-cotton, little experience in connection with industrial operations could be added to that obtained previous to the last twelve months. Certain defects still remained to be overcome before gun-cotton could be effectually applied under every circumstance as a blasting agent for industrial purposes. He might mention, however, that while the gun-cotton trade had been at a standstill, considerable progress had been made in the Government factory in perfecting its production, and that some new points had been worked out with reference to its application, which promised to be fruitful of important results in naval and military operations, and perhaps also in connection with the industrial uses of the material. For example, it had been found possible, by incorporating gun-cotton with considerable proportions of oxidising agents and compressing the mixtures, to increase the explosive force of the material and at the same time to reduce its cost. As a last point he might notice that gun-cotton could be used in a very damp condition as an explosive agent. It had been thought impossible to use gun-cotton in a damp blasting hole, but it had been proved by Mr. Brown, of Woolwich, that it was possible to detonate gun-cotton even when thoroughly saturated with moisture—a condition in which it was quite uninflammable by ordinary means—simply by exploding it through the agency of a small priming charge of dry gun-cotton fired by a detonating fuze. Charges actually immersed in water, and with water intervening between the separate masses composing the charge, had been exploded by means of a waterproofed priming charge, and the results appeared to be in no way inferior to those obtained in the usual way. He mentioned these last facts as a few points of novelty since the Paper had been written.

Mr. Sopwith remarked that the examination of gun-cotton as an explosive material had come under his attention, and had been the subject of many experiments reported in Parliamentary Papers.[1] These were readily accessible, and were much more accurate than any information he could give from recollection. The only practical point to which he wished to direct attention, was that in comparing the explosive force of different materials it was extremely difficult to form a conclusion by experiments upon rocks, on account of their great variety of structure, and therefore undue inferences might be drawn when the precise character of the rock was not perfectly known. He wished, whenever further experiments were tried, that some endeavour should be made to provide a solid object, as nearly as possible, of uniform density and texture. Such a material he thought would give results more to be depended upon, and approaching nearer to geometrical accuracy, than any that had been yet found in the course of actual experiments in mines and quarries.

Mr. J. G. C. C. GODSMAN said there was one point he would like Professor Abel to refer to in his reply. Many years ago, when he was in the Navy, the interior of the guns frequently became 'honeycombed' by the action of the gunpowder then in use. Some gutta-percha impressions of the damaged portions of the present service guns had been recently laid upon the table of the Institution, and he noticed, notwithstanding the modern improvements in artillery and in the manufacture of gunpowder, that the same process of 'honeycombing' went on. He attributed it to the action of the powerful acids, generated by the gunpowder, which were evolved at a high temperature during its confined combustion. He should like, therefore, to hear whether or not the new explosive compounds referred to in the Paper were free from that serious disadvantage?

Mr. R. S. FRANCE said he should be happy to give the Institution the benefit of any practical experience he had acquired in the working of quarries in the use of various explosive

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[1] Gun-Cotton.—Reports relative to the application of Gun-Cotton to Mining and Quarrying operations (House of Commons, 30th April, 1869), contains :—

1. Report of Gun-Cotton Commission, on experiments made at Allenheads on *Ordinary Gun-Cotton*, in October, 1864.
2. Memorandum of the Results of experiments made by Mr. Sopwith and Mr. Abel in September, 1865, with *Granulated and Compressed Gun-Cotton.*
3. Memorandum of the Results of further experiments made by Mr. Sopwith and Mr. Abel in February, 1869, with *Compressed Gun-Cotton fired by means of detonating primers.*

materials. Professor Abel had mentioned several explosives adapted for mining and quarrying purposes, but it was a fact that one, perhaps more, of those explosives, was prohibited from use in this country by Act of Parliament.

Now to those who were in the habit of using many tons of explosive agents, it was a matter of the highest importance that they should be at once powerful and safe to place in the hands of quarrymen. This question of safety was, no doubt, matter for discussion. The power of an explosive could not be recognised without considering its relative safety; and so far as theory had gone, the whole scientific opinion of the country had been at fault. Professor Abel had laid down the theory that gun-cotton was an absolutely safe explosive. That opinion had been endorsed by Major Majendie and other gentlemen of the War Office, and on the faith of it gun-cotton had been extensively manufactured and used. How far that opinion was correct let the explosion at Stowmarket bear witness. He would go further than the manufacture, and say his attention was called to the matter by explosions in his own quarries. There, two men one hot day were nearly blown to pieces while simply pressing gun-cotton into the holes in the ordinary manner. The result was, his men would not again use that material, and he was thrown back upon gunpowder, which was not adapted to all the purposes of quarrying. The accident happened early in the afternoon, and it was a singular coincidence, that gun-cotton explosions had always taken place between noon and 2 P.M. He had no pecuniary connection with the manufacture of any explosive, and was solely interested, as a quarry proprietor, in obtaining the best that could be procured. He must pay the highest compliment to Mr. Nobel for bringing nitro-glycerine from a raw preparation into a condition in which it could be safely used. It was just at the time of the gun-cotton explosion in his quarries that the nitro-glycerine preparation, in the form of Nobel's dynamite, was introduced, and he wished to distinguish it from pure nitro-glycerine. Undoubtedly, pure nitro-glycerine was the best explosive that could be used in quarrying operations, provided only absolute safety could be ensured in its transport; he would not say storage, because he was not aware of any accident from storage; but if safety in transport could be secured, he believed it would be found the cheapest and most effective. Unfortunately, however, the accidents at Carnarvon and Newcastle had proved it to be a highly dangerous material to transport, and a legislative restriction on the transport of raw nitro-glycerine was properly considered necessary. Now it must be borne in mind that Professor Abel, as the Chemist of the War Office, was mainly instrumental in advising the total exclusion, not only of nitro-glycerine, but also of its preparations, in lieu of which he advised the use of gun-cotton. No inquiry was ever made into the alleged dangers of nitro-glycerine preparations. The measure was taken up and carried by the Government at the instigation of their officers. It was said in the Paper, "This discovery led at once to the production by Nobel of solid, or more or less pasty, preparations of nitro-glycerine, which, under the name of dynamite, were first brought before the public in 1867, and the most perfect of which constitutes, as now manufactured, one of the safest, most powerful, and most convenient explosive agents applicable to industrial purposes."[1]

He had observed that no evidence was taken before the Parliamentary Committee as to the desirability of passing the prohibitory Act with regard to nitro-glycerine and its preparations. The Bill was hurried through Parliament. It came before a Committee of the whole House at 3 A.M. But there were not wanting at that hour, advanced as it was, representatives of the mining and quarrying interests, thoroughly informed of the non-desirability, in fact the mischief, of passing so prohibitory a measure with regard to new explosives. The question at last came on for discussion, and arguments were raised on both sides; and it was at one moment rather doubtful which way the discussion would go, when Sir John Hay read this letter from Professor Abel:—

Woolwich, 10th July, 1869.

"Dear Sir John Hay,

"In reply to your inquiries respecting nitro-glycerine, the production and properties of which have been made the subject of careful study and extensive experiment by me, I have to express my firm conviction that such appalling accidents as that which recently occurred in Wales, cannot be guarded against by the enforcement of any measure short of an absolute prohibition of the importation, transport, and storage of nitro-glycerine, or of any preparation of that material. The explosion near Carnarvon was but a repetition of catastrophes of similar nature which have occurred within the last few years in other countries, and are ascribable to the readiness with which nitro-glycerine explodes when subjected to concussion or friction, especially if it be undergoing spontaneous change, to which it is very prone, however

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 343.

perfect the system of manufacture. No apprehension need be entertained that the enforcement of prohibitory regulations however stringent and complete, with respect to nitro-glycerine and its preparations, would be detrimental to the interest of mine and quarry owners. The discoveries recently made with regard to the application of gun-cotton as a blasting agent have placed this material quite upon an equality with nitro-glycerine as regards its power; and there is this important difference between the two materials. No effectual means are known of guarding against the accidental explosion of nitro-glycerine, which must inevitably be productive of fearfully destructive results; while compressed gun-cotton (the only form in which it is now manufactured) may be transported with quite as much safety as gunpowder, and, if ignited by any accident, produces considerably less destructive results than even the latter material, because gun-cotton simply burns without explosion, unless very strongly confined (as in guns, shells, or blast-holes), or unless it is fired with a particular kind of fuze. If proprietors of mines and quarries continue to cling to a preference for nitro-glycerine or any preparation of it, such as the substance called dynamite, for special kinds of blasting operations, the explosive agent should be manufactured exclusively at the particular localities where it is to be used, and only in such quantities as are required from time to time, no reserve stores being permitted.

The preparation of nitro-glycerine is not a difficult operation, and the above system is pursued in some localities on the Continent where that substance is employed.

By introducing the restrictions above indicated with respect to nitro-glycerine and its preparations, such accidents will still not be guarded against, as occurred not long ago at Newcastle, consequent upon the great readiness with which nitro-glycerine freezes (whereby it becomes much more sensitive to explosion by concussion or a blow), and upon the generally dangerous character of the material; but these accidents and their disastrous results will become confined to the localities where the nitro-glycerine is actually used, although even then, others employed in or near such works, may suffer through the instrumentality of those who persist in having recourse to this fearfully dangerous explosive agent. I am, dear Sir John Hay,

Yours faithfully,

(Signed) F. A. Abel."

"Rear-Admiral Sir John Hay, Bart.,
M.P., F.R.S."

Now the experiments which the War Office Committee made at his quarries proved—and it was so admitted in the Paper—that nitro-glycerine, in its frozen state, was not sensitive to concussion or explosion. But the Author now said dynamite was the most satisfactory explosive that could be used. This matter was to him and to other quarry proprietors of far higher importance than the question whether Professor Abel had contradicted himself within the last few years. It was of the highest importance also to the community, because every fraction of the material which came from the quarries was removed from the solid rock by explosive agents, and it was eminently desirable that they should not only be safe but economical. The question of cost was one of considerable importance to those using explosives. Let there be free trade in this as in other things, and let it be proved by practical use whether the explosives were safe or not.

He now came to speak of explosives as far as he had had experience in them, and he was the only quarry proprietor to whom some of the materials had been sent for trial. Taking them in their order, gun-cotton was a fine and clean explosive, and did its work very well, but it nearly killed his men in using it. Then dynamite was at first prohibited, but he did not think a more powerful or a safer explosive could be manufactured. The infusion of nitro-glycerine with earth made it compact for putting into holes in cartridges; whereas, in a liquid state, certain portions of nitro-glycerine always adhered to the sides of the bore holes. On that account Mr. Nobel's plan of forming it into cartridges was a great improvement. Gunpowder was excluded from the term explosives, from which it differed in action. When a bore-hole was charged very tightly with gunpowder, it often acted as a cannon, and the ramming was blown out. He would explain the term 'explosives' by saying that if it were attempted to fire a ball from a cannon with nitro-glycerine or gun-cotton, the cannon would be broken into a thousand pieces before the ball reached the muzzle. Dynamite was undoubtedly a great improvement upon raw nitro-glycerine, but while science went on improving the manufacture of explosives, he was sorry to say that England could not lay claim to any of the inventions or improvements. The seat of the invention of gun-cotton and nitro-glycerine was in Germany, where patents were difficult to obtain, and where considerable enterprise had been shown in making the necessary experiments and trials. Dynamite was an improvement upon raw nitro-glycerine, but it was faulty in some respects. Nitro-glycerine in a raw, or even in a compound, state was exceedingly sensitive to cold, and remained frozen at a temperature of 50°. He did not think it could be thawed under 60° or 70°. The best mode of thawing he found to be by placing it in a heap of horse-dung, and it was a less dangerous plan than thawing it by fire. Recently, near Carnarvon, two men were thawing dynamite upon a hot stove, when it exploded and killed them. It was desirable to guard against such an occurrence by the introduction of a preparation not quite so sensitive to cold, and which would stand the changes of climate better than dynamite. He would like to see a committee of practical men belonging to the Institution devote their attention to the subject, and he would give them all the assistance he could in the use of his quarries and materials in arriving at a decision.

The inventors of litho-fracteur had added to a dynamite composition a certain amount of explosive material, and reduced, not only the quantity of nitro-glycerine, but also the proportion of earthy matter. Dynamite consisted of 75 per cent. of nitro-glycerine and 25 per cent. of infusorial earth. Litho-fracteur consisted of 52½ per cent. of nitro-glycerine, 22½ per cent. of infusorial earth, and 25 per cent. of explosive mineral substances which Messrs. Krebs had, up to this time, kept secret. When he saw the account of what the Prussians did with litho-fracteur in the late war, he assumed it would be serviceable in quarrying operations, and, on his application, Messrs. Krebs sent over an agent with some of the material. He had satisfactorily used it for nearly two years, and he could not detect any diminution of strength in consequence of the less percentage of nitro-glycerine. Now looking to the mistakes scientific men had made in these matters, he was not desirous to be thought a 'scientific man.' He believed as soon as science was introduced in the working of quarries they would cease to pay. Quarry proprietors must look after the safety of their men, and must give them the best explosives. Whilst there was no diminution of power in the litho-fracteur, it proved to be an explosive more readily available under the varying conditions of temperature. He had, during the month of October, 1872, on several days fired holes with dynamite and with litho-fracteur, the same means of detonation being used in each case, and the litho-fracteur was unquestionably the surest in exploding.

There were other modes of proving this. He had been asked to go with the directors of an insurance society to the Bristol Channel to blow up a vessel that had sunk there in a depth of 40 ft. of water. He went with them, but, unfortunately, owing to the Government restriction, they had not enough litho-fracteur, and had to make up the deficiency with dynamite. The experiment took place last March, on rather a cold day, when the dynamite sent down for the purpose was frozen and useless. He looked round and saw some brick-yards about a mile distant. The dynamite, about 3 cwt., was put on the shoulders of six men, and carried to the brick-yards in the hope of thawing it. The brick-kiln was too hot to be walked on, and the wooden cases of dynamite, when put on the top, got so hot that they could scarcely be touched; but paper being a non-conductor of heat, and the cartridges being packed in paper, though the wood outside was so hot the paper was not even warmed. Upon this, the cartridges were unpacked and placed upon the walls of the kiln, and after they were well warmed, they were repacked, and the vessel was blown up with them. He repeated that Mr. Nobel's preparation was a valuable one, but he had to deal with a material extremely sensitive to cold, and practical men wanted the explosive which would give the best results with the least risk and trouble.

There was one other explosive he had been using for the last month, called 'pudrolythe.' It was a simple-looking substance, but it was a remarkably good explosive, better than gunpowder, gun-cotton, dynamite, or litho-fracteur, or any other explosive he had used, under certain circumstances; but those circumstances were so exceptional, that it was difficult to use it to any great extent. If a hole, perfectly tight, and sunk in very hard rock, could be ensured, with no chance of any of the material escaping, then pudrolythe was the safest and best explosive, because it had not the tendency that gun-cotton and nitro-glycerine possessed of shattering particular classes of stone.

The application of gun-cotton or nitro-glycerine to homogeneous stone shattered it so that it entailed much loss; whereas an explosion of the pudrolythe, owing to its slow burning, lifted up the whole mass of stone and dislodged it. He hoped the general interest evinced on the subject would lead to improvements, and he believed that with fair play explosives would be improved; but so long as manufacturers were hampered by Government restriction, there would be no progress. He thought it was no concern of the Government if quarry proprietors chose to blow off their own heads. Such fatherly legislation should be reprobated: let there be fair-dealing and no favour.

Major Beaumont, M.P., R.E., said he should not touch upon the chemical aspect of the question, because that was a subject with which he did not profess to be acquainted, but on the practical working of explosives. There was no desideratum connected with mining which was likely to receive satisfactory solution at the hands of scientific men of more importance than the manufacture of safe and efficient blasting agents. The question of applying machinery to the driving of drifts was one apart from this; but as soon as the holes were made, it was necessary to have recourse to explosives as the only means by which the rock could be shifted. When a given number of holes were put into a heading, the powder was only able to shift a certain amount of rock; the position of the holes might be altered for the purpose of attacking the rock to more advantage; but it was obvious in any case, the increased efficiency given by more powerful explosives—even with hand labour—must have greatly accelerated all mining operations. In the case of machine-drilling, it would be more obvious than in the case of hand-boring, as the position of the holes was less readily changed; therefore any means by which the power of explosives could be improved, very materially assisted industry in connection with mines; and he thought he was in a position to say that was practically the case. With the use of any of the powerful explosives under discussion—whether it were gun-cotton, dynamite, or litho-fracteur—it might be calculated that a gallery could be driven 25 per cent. quicker in hard rock than where gunpowder only was employed. With machine-drilling, the difference would be from 30 per cent. to 50 per cent. in the increase of speed—irrespective of that due to the use of machinery—and where a material could be employed as powerful as pure nitro-glycerine, he had little hesitation in saying the difference would be much greater.

He would give results of his experiments with reference to gun-cotton, dynamite, and litho-fracteur. His experience had been confined almost entirely to tunnel-driving by machinery, and therefore he had been compelled to use these explosives; and he did not think he had fired any holes, made by machinery, with powder. He commenced with gun-cotton, the material in the market at the time, and the results were such as to show he had not over-estimated the value of that explosive in his calculation of increased progress of the work, namely, from 20 per cent. to 30 per cent. The gun-cotton was made by Messrs. Prentice, under the patent of Professor Abel. He found it simple to handle, and he believed it was less dangerous to transport than gunpowder. It did not require to be kept drier, but although it shifted a greater amount of rock, it was more expensive. The question was, whether the extra cost was, or was not, compensated for by the extra speed of the work, a matter which would depend on the circumstances of each case. He thought he could shift a larger amount of rock with a given value of gunpowder than of gun-cotton; but it would take a longer time.

The diamond drill he used made a cylindrical hole, true to the $\frac{1}{16}$ of an inch. It was important that there should be no air-space between the blasting agent and the rock, so that the charge should completely fill the hole. Messrs. Prentice made some gun-cotton charges, the successive diameters of which varied by $\frac{1}{8}$ of an inch, and the cartridges had therefore to be jammed into the hole, when the diameter of the latter was in excess of that of the cartridge. In nine hundred and ninety-nine cases out of a thousand the results were satisfactory; but the time came when, in forcing the cartridges into the holes, an explosion took place. Unless the ramming was very violent, according to the theory of the action of gun-cotton under such circumstances, it ought only to burn. In some cases the gun-cotton, in being forced home, had done so, but in others it exploded with a violent detonation. With precautions against this source of accident, he thought it might be safely used, as it was quite equal in explosive qualities to litho-fracteur or dynamite.

The explosion at Stowmarket resulted in throwing gun-cotton out of the market, and in extending the use of dynamite, which, being uninfluenced by water, could be employed in shafts and headings without water-proof cases, and, being plastic, could be squeezed into the holes so as to fill them entirely, by which means the difficulty with gun-cotton in the cylindrical form was got rid of. The explosive force of gun-cotton and dynamite was about the same; and the smell, as far as he knew, was as powerful in the one as in the other; but a person could retire in time to prevent any bad consequences. He had been in headings where the men worked for a considerable time together, and they would not take the trouble to lead a pipe from an adjacent air-supply to bring up fresh air; in fact, the smell need be no bar to the use of these materials in headings; but at the same time, it was necessary to supply some special means of ventilation. When machinery was worked by compressed air, nothing else was necessary. The only opportunity he had of trying litho-fracteur was in experiments made by Mr. France, who fired two or three shots in a heading, driven by the Machine Tunnelling Company at Wigan. The trial was not sufficiently extensive to enable him to speak with confidence as to the relative power of the material, because a single trial was not enough to judge by, and the circumstances of each case were so different, that half a ton of explosives might be used before an opinion could be formed as to the relative value of each. He believed litho-fracteur to be, for practical purposes, fully as powerful as dynamite and gun-cotton; and as far as he could judge, he did not think there were was any decided difference between the three. Whether the component parts of litho-fracteur were as permanently blended as in dynamite he would not say; but he was inclined to believe that the nitro-glycerine in the former was not so well held as it was in the latter; and, consequently, if he had a couple of tons of litho-fracteur to store, he should look more carefully to see that there was no exudation, than in the case of dynamite. Exudation was the real source of danger in this class of material. Perfect litho-fracteur or perfect dynamite, he believed would, under ordinary circumstances, be safe; but if they remained for a length of time in store, or were subject to the shaking of railway travelling, danger might be anticipated.

He had used dynamite at Bristol in the construction of a tunnel for the Great Western and Midland Railway Companies, and one difficulty experienced in using it consisted in the fact that it froze at a temperature higher than the freezing point of water. To overcome this difficulty, tin cases were made with double linings, the cases being put in connection with the exhaust pipe of an engine, so that the tins were kept hot without pouring water into them. At that time he had no idea that any danger would be likely to arise from this process: he had believed that while the temperature was not above 212°, the dynamite would not explode, but he had to alter that opinion. The tin was about 2 ft. long, 11 in. wide, and 11 in. deep: and it held sufficient cartridges for two shifts. The cartridges were supposed to be cleared out at the end of each shift or firing; but it transpired on one occasion that two or three cartridges having been left in for an indefinite time, exploded. The amount of material was only of the value of 9*s.* or 10*s.*; but the engine-house, built of wood, was blown down; and the windows of houses on the opposite side of the road, about 150 yards distant, were driven in. Fortunately, no lives were lost. It was concluded that the dynamite, having been left in the tin for a prolonged period, and having been thereby subject to alternate raising and lowering of temperature, had been decomposed; a change aided, perhaps, by the dynamite touching the metal of the case, and producing spontaneous combustion. Under such circumstances it did not burn, but went off with a violent detonation. Afterwards he gave orders that the dynamite should be thawed with water poured in at a lower temperature than 212°, and that only immediately before the charges were used; he also directed the tins to be lined with felt. It was most desirable to determine in an authoritative manner the dangers incidental to the use of explosives; as it was a matter of extreme importance for practical men to have the best it was possible to produce. It was no use to say the chemist was able to prepare safe compounds in his laboratory if they could not be employed by practical men. One reason against the use of dynamite was that the railway companies would not carry it. When he wanted a ton he had to cart it, however distant, to the place of destination. He was of opinion that it was less dangerous than gunpowder, both to transport and to store. It was clearly the duty of the Government to take such action as should determine whether it was, or was not, a dangerous material to carry. The question submitted to the late War Office Committee referred only to lithofracteur; but the inquiry should have included in its scope the whole question of explosives. If any new compound of that nature was invented, it should be experimented and reported upon, so that the real danger in carrying, or storing, it might be known. As a Member of Parliament, he would do his best to urge that course upon the Government.

Mr. Perry F. Nursey said that whatever objection might be taken to some of the clauses of the Act—and some of them were open to objection—he considered it to be, as a whole, one of the most salutary acts that had ever been passed. At the time of its introduction, explosions of nitro-glycerine, attended with disastrous results, had occurred in England, Wales, the United States, Australia, the West Indies, and other places. It was therefore necessary, for the public safety, that restrictions should be placed upon the transport, storage, and use of that dangerous though highly useful compound. At that time, however, science was developing new combinations of nitro-glycerine and other substances, the effect of which was to reduce, if not to remove, the danger attending the use of nitro-glycerine compounds. Mr. Nobel especially had controlled the power of nitro-glycerine in his dynamite, and Messrs. Krebs had effected a similar object in their litho-fracteur. The Act of Parliament in question specially provided that if it could be proved to the satisfaction of the Secretary of State that any nitro-glycerine compound could be transported, stored, and used with safety, then, that he should authorize its introduction for industrial and other purposes. That was the point which should be explained to those who were anxiously desiring a powerful and safe explosive for the prosecution of their works, and to those who were under the impression that the Act utterly prohibited the introduction of those compounds. That it was not so, was proved by the circumstance that the Government not long since had granted a license for the manufacture of dynamite and of Horsley's blasting powder. The War Office Committee on explosives had reported unfavourably upon litho-fracteur with regard to two points—the exudation of nitro-glycerine under heat, and the ready dissolution of the compound in water. In practice, no case of exudation had ever been met with, but it was conceivable that a slight supersaturation had taken place in the manufacture of the samples experimented with by the War Office Committee, which would result in exudation under heat. But steps had been taken to prevent the possibility of any recurrence of the defect, and that, coupled with the fact that ready dissolution in water had been overcome by substituting nitrate of baryta for the nitrate of soda previously used, led to the expectation that, at no distant period, the Government would sanction the introduction of litho-fracteur as it already had, that of other nitro-glycerine compounds.

Turning to the immediate subject of the Paper, he would refer to the statement made by the Author, that litho-fracteur was a compound of nitro-glycerine, 52 parts; siliceous earth and sand, 30; powdered coal, 12; nitrate of soda, 4; and sulphur, 2. That was not the exact composition of litho-fracteur, which consisted of 52½ parts of nitro-glycerine, 22½ of kieselguhr or infusorial earth, and 25 of other explosives. What those other explosives were would shortly be known to the public, as litho-fracteur had recently been patented in England. The Author also stated, that with respect to power, it was difficult to conceive that a considerable proportion of the nitro-glycerine contained in dynamite could be advantageously replaced by a crude explosive mixture, less powerful in its action than that liquid. Mr. Nursey would not combat that statement with his own opinion and experience, but would meet it by an extract from a "Report on Litho-fracteur, &c., from the Engineer Company of the Guards under General von Kamecke, President." The report was issued by the Prussian Government, and bore date the 18th of November, 1869. It concluded with the following *résumé*. "The advantages of litho-fracteur over dynamite and dualin consist especially in the fact that, relatively to the other explosives named, it possesses the greatest power in the smallest bulk." The Author further stated, that with regard to safety, it was obvious that the ready susceptibility of a particular nitro-glycerine preparation to explosion, by blows or concussion, was likely to be in direct proportion to the amount of nitro-glycerine which it contained. That being the case, it followed that as litho-fracteur contained only 52½ per cent. of nitro-glycerine, whilst dynamite contained 75 per cent., the former compound must possess the element of safety in a higher degree than the latter.

As regarded the application of violent explosives to industrial purposes, three conditions mainly had to be met by any substance which might be utilized for that purpose: the first was safety, the second power, and the third economy. He had both made and attended numerous experiments with various explosives during the last six or seven years. Many of the compounds promised well, but practically, gun-cotton, dynamite and litho-fracteur, were the only violent explosives which had outlived experiments, and had become recognised agents in the prosecution of industrial enterprise. The experiments and practical trials to which he had referred had established the existence of the three conditions already named. In July, 1868, Mr. Nobel carried out a series of experiments with dynamite at the Merstham quarries, illustrative of those points; several charges were fired in the workings, which gave excellent results, such as put into the shade the ordinary performances of gunpowder there. Perhaps the most striking experiment was that made with a cylindrical block of wrought iron 11¼ in. diameter, 12½ in. long, and bored through the centre with a hole 1 in. diameter. The hole was filled with dynamite, about 7 oz. or 8 oz. being used, and when exploded, the cylinder was split in two, one-half being thrown 80 ft. in one direction, where it was stopped by a rock, and the other half in an opposite direction, being stopped 50 ft. away by a railway bank. A singular circumstance in connection with that experiment was, that on examining the iron after the explosion, the bore hole was found to be enlarged to 1¾ in. at the centre, tapering to the original diameter at a distance of about 3 in. from the ends. The bore was not plugged, and the explanation of the enlargement probably was that the explosion, although practically instantaneous, commenced slowly at one end, where a portion of the charge was exposed to the resistance of the atmosphere only —its intensity gradually increasing as it neared the centre, where it reached its maximum, and as gradually declining towards the other end of the bore which was open to the atmosphere. The area of metal thus torn through was about 120 square inches.

A great number of experiments had been made during the past two years with litho-fracteur, with the view of demonstrating its safety and strength, and its applicability to industrial purposes. It had been proved to be safe under all ordinary, and many extraordinary, conditions. It had been subjected to a temperature gradually increasing to 374°, when it merely smouldered away; it had been tried in various ways under the condition of a railway collision, by being jammed between railway trucks descending, unchecked, an incline 500 yards long, with a gradient of 1 in 8; it had been thrown from great heights, and burned in confined spaces without any explosion occurring. Its power had been illustrated in the workings at Mr. France's quarries at Nantmawr and Breidden, where, in one instance, about 20 tons of limestone were brought down with 17½ oz. of litho-fracteur. As a proof of its great energy, two double-headed rails, 4 ft. 6 in. long, weighing 75 lbs. to the yard, were laid on each other, side uppermost, the ends being supported on timber bearers 18 in. high, the rails having a bearing of 3 ft. 6 in. On the top of the rails in the centre, was placed 1 lb. 5 oz. of litho-fracteur tamped with paper —the wrappers of the cartridges—and five pieces of old railway sleepers. The explosion made matchwood of the sleepers, hurling the fragments in all directions, and breaking both rails; the halves of the rails were thrown some distance apart, and a depression or basin was blown out of the ground under the line of the explosion. The combined area of metal severed in the two rails was 17·2 square inches; a wrought-iron girder, having 17 square inches sectional area, placed in a similar position, would require about 100 tons to break it, so that it was clear an enormous power was developed by the 21 ozs. of litho-fracteur exploded in an unconfined condition on the rails. Numerous experiments had been successfully carried out under water with litho-fracteur, which illustrated its usefulness and reliability in sub-aqueous operations. Another instance of the absolute amount of work done with a definite quantity of that compound recently came under his notice in some blasting operations at the porphyry quarries of Quenast, in Belgium. Two holes, 5 ft. deep, and 2 in. diameter, were bored vertically into a plateau of the hard graystone rock. The plateau, which was of irregular shape in plan, measured 32 ft. long by 25 ft. wide, and the holes were charged respectively with 1 kilogramme and 1½ kilogramme of litho-fracteur tamped with water. The explosion displaced about 40 cubic inches of rock, and cracked and rent the plateau throughout its entire length and breadth, for a depth of 10 ft. down to the bottom of the quarry. Practical work had been done with litho-fracteur for the past five years in Germany, during which period it had been used for industrial and engineering, as well as for military purposes, without any accident occurring. It was, in fact, perfectly safe, as was also dynamite, except where carelessness or foolhardiness brought about disaster. The only danger was in the preparation of the nitro-glycerine for dynamite, from which, he had been informed by Mr. Nobel, accidents had resulted. In preparing the nitro-glycerine for litho-fracteur, Messrs. Krebs had introduced a new principle which insured immunity from accident, and no casualty had occurred at their works during the five years they had been in operation. The boring of the St. Gothard tunnel was to be carried out by means of litho-fracteur, 25 tons having just been ordered for that purpose. The extent of the work, and the hardness of the ground, might be inferred from the fact, that it was estimated by the engineers that at least 1,500 tons would be required to complete the work.

Mr. C. Douglas Fox thought it might be interesting to the members to see the result of the experiment with dynamite at Merstham to which reference had been made, and he had therefore placed upon the table the piece of wrought iron which had been torn asunder as described. He had also brought a piece of plate iron, into which, during the same experiments, a tin canister had been driven in small fragments by the explosion of the dynamite.

Major Majendie remarked, in regard to what had been called "paternal legislation," and especially in reference to the allegation that, "it was no concern of the government if quarry proprietors chose to blow off their own heads," that such a view of the question was really altogether beside the issue. As a matter of fact it was not the heads of quarry masters that were blown off, but those of their unfortunate workmen. He was not aware of a single accident having occurred to the person of a quarry proprietor. The sufferers in a recent accident near Carnarvon were the foreman and workmen. The people imperilled by the accident referred to by Major Beaumont, and by the accidents in Cornwall from the explosion of dynamite, were not the mine or quarry proprietors, but the workmen; while the persons blown to pieces by the accident near Oswestry were four workmen and two little boys. It seemed to him if the workmen were the persons who suffered, they would be the proper parties to contend for free trade in self-immolation. But even supposing they as a body said, "We object to this legislation; we don't want to be interfered with; we will take the risk;" that would not be sufficient ground for the absence of all restrictive legislation. The public had surely some voice in the matter, for it would be anything but safe to have free trade in the manufacture and transport as well as in the use of explosives. One of the great dangers with nitro-glycerine was in its transport, that was to say, outside the quarries altogether. In the accident at Colon, where about forty lives were destroyed, and in the accidents at Carnarvon and Newcastle, the occurrences were entirely independent of the working and use of these explosives, but were occasioned solely in their transport. The position in which the factories ought to be placed, in respect of the isolation of the buildings and the protection of the workmen, should also be considered, and the manufacture and storage ought not to be carried on independent of all restriction. The public had a right to require that no manufactory of explosives should be established without sufficient isolation from habitations; and if these materials were to be carried along the public highways, they had a fair right to ask for due protection from the consequences of accident in the transport. As a matter of fact the public appreciated these things very keenly, and if they had their own way with regard to explosives, the restrictions would really be more severe than any that had yet been applied. Take, for example, the action of railway managers. Major Beaumont stated he was precluded from using certain kinds of explosives, not because of legislative restrictions, but because the railways refused to carry them except at prohibitive rates. Major Majendie had collected the presentments of eleven coroners' juries within a few years, in which they had urged the necessity for strong measures with regard to the manufacture, transport, sale, and storage of explosives; and all who had witnessed an explosion, or had seen the victims of it, were compelled to believe that there was another view of the question, quite distinct from that of the quarry proprietor. In short, it was useless to argue that there should be free trade in explosives because the non-use of explosives interfered to some extent with mining operations. But while he thought restrictive legislation was necessary with regard to these materials, he was prepared to define the limits to which restrictive legislation should go. These limits were correctly laid down by Sir George Grey, when, in 1864, he directed Colonel Boxer to make inquiries with a view to amended legislation. Sir George Grey then stated that restrictive legislation in trade was to be justified only by considerations of public safety. He thought that dictum was perfectly correct. Restriction in trade was bad in itself, and ought only to be adopted to remedy something worse, which could not be remedied in any other way; and he thought if that principle was applied to the existing legislation as to preparations of nitro-glycerine—which was an extreme example of legislative interference—it would be found that the Nitro-glycerine Act satisfied the test. It was necessary, within reasonable and moderate limits, to restrict the use of explosives, and up to the point of public safety it was clearly necessary that legislative restriction should be adopted with regard to them.

Mr. A. A. Langley said he had no interest in any quarry nor in any patent relating to explosives, but he had used gunpowder, gun-cotton, and nitro-glycerine in carrying out extensive mining operations. He let the work to the men "by the piece," they providing their own stores, powder, gun-cotton, &c.

He invariably found that the miners used gun-cotton in slate rock, which he considered the best proof that they were enabled to make most progress with it. From his own experience he had no hesitation in stating that its use effected a great saving in labour in mining operations in slate rock, such as driving headings or levels. It was a common practice with miners to drill a hole about 2 ft. deep, and to charge it with two or three cartridges of compressed gun-cotton, each about $1\frac{1}{2}$ in. long, and about $\frac{7}{8}$ in. diameter, and then to add a layer of about 2 in. of ordinary blasting powder. On one occasion he drove by hand, using gun-cotton, a level 7 ft. high by 7 ft. wide, in slate rock, 22 lineal yards forward in one month, and he had not heard that a greater progress had ever been made without boring machines. Gun-cotton, however, was not applicable to quarrying slate blocks for manufacture, being so sudden in its action that it cracked the rock and rendered it worthless for slate making. He believed it to be quite as safe as ordinary blasting powder when the men were accustomed to it.

He had used oil of glycerine in flint and other rocks of that description, and he believed a saving of at least 20 per cent. or 30 per cent. was effected in some cases. But it was impossible properly to compare the value of one explosive with another, unless the description of work performed was also taken into account. What was suitable for one rock might be bad for another. It depended upon the nature of the rock, the number and direction of the joints, and the manner in which the mining had to be carried on.

He believed if railway contractors would turn their attention more to these matters they might often effect a considerable saving in tunneling by the employment of gun-cotton and other explosives of a similar nature.

Mr. T. Mason said he wished to give a brief history of the manufacture and use of a new explosive called 'pudrolythe.' The advantages claimed for it were, that it was safe when surrounded by the atmosphere, and, unless tightly tamped, would not explode; that it was considerably cheaper and one-third more powerful than gunpowder, and that the system of manufacture was easy; that there was, comparatively, an absence of smoke on explosion; that water would not spoil it—for when dried on a hot plate, it was just as good as it was previous to being wetted; and that no deleterious gases were emitted by the explosion. He was confirmed, in these statements, by certificates from distinguished Belgian chemists and engineers, and in Belgium there was no hesitation on the part of railway managers to its transport as ordinary traffic. It had received the approval of Mr. Hayward of Carnarvon, where the dynamite explosion had taken place, who stated that he considered pudrolythe was the best explosive yet introduced. Mr. Mason had witnessed numerous experiments with it by Mr. George Farren, Assoc. Inst. C.E., the manager of the Welsh Granite Company, the results of which he submitted to the Meeting. Understanding that the powder he had first received had been made some time, he thought it might possibly require keeping to improve by age, and with the view of testing this question he arranged it in four distinct parcels, for experiment, on different kinds of rocks, at Lord Penrhyn's quarries, and he found that within fifteen minutes after mixing the compound it exploded a charge. A like course was adopted on the following day at the Festiniog Quarries. The experiments were also carried on underground for four hours within a distance of half a mile, in the Lisborne Lead Mine, Aberystwith, and the workmen unanimously said the smoke generated was not so great as from gunpowder, and that it had no ill effect upon them; that particular course of trials was completed at Llanymynech Lime Rocks, all the experiments resulting satisfactorily. Similar reports had been received from Cornwall.

The material consisted of 3 parts of nitrate of soda, 3 of nitrate of baryta, 3 of spent tan, 5 of sawdust, 12 of sulphur, 8 of charcoal, and the balance of one hundred was made up of nitrate of potash. It was used in the same way as ordinary blasting powder, and the charge was rammed down with an iron bar, as pudrolythe would not explode by fire from flint and steel, nor by concussion. It might be struck on an anvil without exploding. As compared with ordinary blasting powder, only two-thirds the quantity of pudrolythe would be required. If slate was to be removed bodily from the bed, the hole was lightly filled with the powder, or the strength of the charge reduced, when, instead of shattering, it would lift the rock directly off the bed. Greased cartridges were used when the holes were wet, and a particular form of cartridge to exclude the atmosphere when the holes were faulty.

Mr. C. J. Appleby had seen nitro-glycerine used in larger quantities than had been spoken of. At Harling there was an old sunken jetty which it was necessary to remove. It had been constructed in a depth of from 10 ft. to 15 ft. of water. The parties who took the contract brought their plant to the spot, consisting of two large dredgers, with apparatus for drawing piles; but the piles were so worm-eaten that they broke off, leaving the stumps, which injured the buckets, and gave them very great trouble. After they had been at work for six or eight weeks it was resolved that they should blow the jetty up piecemeal, and take away the fragments by degrees. Both dynamite and litho-fracteur were used in the first instance, but it was found that a better result was obtained from litho-fracteur than from dynamite, and, in consequence, dynamite was abandoned and litho-fracteur used entirely throughout the remainder of the work. The mode of working adopted was suggested and carried out by M. J. J. van Rietschoten. About 10 lbs. of litho-fracteur were put into an ordinary wooden box, the centre cartridges having detonating fuzes attached to them. The box was slid down a pile and was held by a pole at the point where the explosion was required. They generally fired from five charges to ten charges per day. Sometimes they had a miss-fire, in which event they simply lowered another box of litho-fracteur on the top of the first, and, when fired, both shots were heard and felt. Adopting the litho-fracteur for the removal of the jetty had proved a complete success, and the work was executed for one-half the money and in one-tenth of the time estimated.

Mr. Orlando Webb said that a statement had been made that, in consequence of the great diversity of the structure of rocks, the only way to arrive at a practical conclusion on the value of explosives was from actual results. He chanced to have obtained the statistics of driving a railway tunnel with gunpowder, gun-cotton, and dynamite, to which he would briefly refer. The distance driven in a given line with gunpowder was 8 yards forward, with gun-cotton 14 yards, and with dynamite 15 yards. The quantities used of each explosive were—for the 8 yards with gunpowder, 756 lbs.; for the 14 yards with gun-cotton, 169 lbs.; and for the 15 yards with dynamite, 165 lbs. The tunnel was an ordinary railway tunnel. The number of bore-holes or shots per yard was 31 with gunpowder, 18 with gun-cotton, and 17 with dynamite. Taking the value of gunpowder at £2 per barrel of 100 lbs., it gave $4\frac{4}{5}d.$ per lb.; gun-cotton, at £10 per cwt., gave 1*s.* 10*d.* per lb.; and dynamite, at £10 10*s.* per cwt., gave 1*s.* $10\frac{1}{2}d.$ per lb. For 15 yards the cost of each of these explosives would be, with gunpowder, £28 7*s.*; with gun-cotton, £16 12*s.*; and with dynamite, £15 9*s.* 4*d.* In every respect, including labour, dynamite had a slight advantage over gun-cotton; but each had a decided advantage over gunpowder. Mr. Nobel calculated the relative powers of nitro-glycerine, dynamite and gun-cotton to be—nitro-glycerine, 1; dynamite, 0·72; and gun-cotton, 0·69.

In an experiment made before the Gun-cotton Committee, at which he was present, a piece of iron was cut off the end of a shaft of a steam-engine; the diameter was $15\frac{3}{4}$ in., and the depth 9 in., and this was bored with a hole $1\frac{3}{8}$ in. diameter. That hole was filled with dynamite, without tamping or closing at either end, and the effect of the explosion was to rend the iron in two, and to throw the portions a distance of about 12 yards, one of the pieces being carried up a bank 12 ft. high. The power of dynamite, therefore, could not be questioned.

It was a fact beyond dispute that dynamite had been carried in Germany and in this country to a great extent—in Germany to the amount of hundreds of thousands of lbs., and for thousands of miles. In this country it had been carried in common carts hundreds of miles in large quantities, and no accident had been known to take place either in transport or storage. He produced before the Gun-cotton Committee some cartridges of dynamite which had been in his possession since 1868; and, considering the material was of a highly pasty character, it retained that character in a most remarkable degree. He could not discern the slightest difference in the appearance of the material from the time it was imported, in 1868, down to that time, 1872.

He thought that the restrictions in respect to explosives had not been instigated by the Government. The Nitro-glycerine Bill was introduced into Parliament by Mr. Alderman Lawrence, M.P., and by Mr. Graves, M.P. It was a notorious fact that nitro-glycerine in its liquid state had been imported into the city of London, and carried along the streets of Liverpool; but in this condition it was most unquestionably a dangerous article to transport, and therefore it was not unreasonable that those gentlemen should promote a Bill for the object of protecting both lives and property in the port and city of London, and in the port and town of Liverpool. That Bill was brought into Parliament late in the session, and in the month of August was re-committed in the House of Commons at 3 o'clock A.M. He wished to point out that it was partial and unreasonable in its provisions, and that gun-cotton, although more sensitive to percussion than dynamite, was not referred to in the Act, but the restrictions were confined to nitro-glycerine and dynamite. With reference to the accident which had been mentioned as having lately taken place at Wein Fawr, it did not appear to be known that the proprietors were not aware that dynamite was being used in their quarry. The foreman of the quarry, who was killed, had himself obtained the dynamite, and had used it most improperly, heating it at a cast-iron stove, in opposition to the printed instructions to the contrary.

The Paper was very fair and correct in most of its statements; but there was one point which had been omitted. Reference had been made to the quality and power, weight for weight, and to the difficulty there was with regard to gun-cotton being rigid, and not capable of being formed so as exactly to fit the bore-hole, while, on the contrary, dynamite, from its soft, plastic character, left no vacancy or interstices; but this circumstance had been lost sight of, that dynamite was much heavier than gun-cotton, so that more force was concentrated in a small space with dynamite than with gun-cotton.

The power of tutonite, which was no doubt a valuable production, was far inferior to that of dynamite. He might state, in proof of this, that when Mr. Hayward made the experiments at Carnarvon which had been referred to, there was a piece of cast-iron lying with a hole in it, weighing about $3\frac{1}{2}$ cwt. Some tutonite was put into it, and it fizzed and burnt, but the iron remained uninjured. He afterwards put a cartridge of dynamite into the same hole, and it blew the iron to atoms.

Mr. S. P. BIDDER, through the Secretary, desired to make a few remarks in reference to the use of gun-cotton for blasting mines and quarries. In 1863, Messrs. Prentice brought out their patent gun-cotton, made in accordance with Baron Lenk's process. It was formed into ropes of various diameters from $\frac{7}{8}$ in. to 3 in. These were cut into pieces 6 in. long. So far as strength was concerned, this explosive worked very well.

In 1867, Professor Abel introduced compressed gun-cotton, and the demand for it was steadily increasing up to the time of the Stowmarket explosion in August, 1871. The advantages claimed for this explosive were its great power, its portability, and its safety in working.

The many severe and fatal accidents with gun-cotton could all be traced to the carelessness of workmen disregarding a few simple printed rules. They had been clearly accounted for in the official inquiries that followed; and he was not aware of any accident that could not be traced to neglect. The agent for the manufacturing interest in North Wales generally carried some compressed gun-cotton in his pocket, feeling satisfied that it would not explode if accidentally ignited.

He had recently carried out a series of experiments with gun-cotton in some coal-mines in North Staffordshire, and the result of these experiments proved that it could be used for blasting coal with great advantage. There was almost an entire absence of flame; the cartridges were portable, and could easily be divided, to suit the various thicknesses of coal to be blasted. Further experiments were made in stone-drifts with the following results, as regarded the relative efficiency of gun-cotton and gunpowder:— Gun-cotton always took the rock out to the bottom of the hole, and frequently from a lower point: gunpowder seldom broke down to the bottom, especially in very hard and jointless rocks. Again, gun-cotton was six times more powerful than gunpowder, and the blast-holes might be drilled to a greater depth and be placed further from the face of the rock; consequently a larger quantity of material could be removed without additional cost of boring. Gunpowder applied in this manner would not work unless the holes were of great diameter, to allow a sufficient quantity to be inserted. The tamping would be too short, and would probably be blown out, perhaps breaking the upper part of the hole and leaving the lower portion unbroken.

He had recently inspected several of the largest quarries in Wales, and found that gunpowder was the explosive in use without a single exception, because gun-cotton could not be obtained, although the quarry proprietors were quite willing to pay a large price for it. Dynamite was at hand, and the men had permission to fetch it from a neighbouring store, but they seldom used it. To show the confidence the men had in gun-cotton, one of the quarrymen, in reply to an inquiry, said, "When the cotton got wet, he put it in the sun to dry; but when there was no sun he took it to bed with him and slept upon it, and by the morning it was nicely dry." At the time of the Stowmarket explosion sixty quarries in Wales, employing sixteen thousand men, were supplied with gun-cotton.

Nitro-glycerine was the strongest explosive known, but the uncertainty of its action was a barrier to its employment. Several accidents had occurred in England and Wales, on the Continent, and in America, which had been destructive to life and property. It laboured under a double disadvantage, as both the full and the empty packages were dangerous to handle. He would enumerate a few instances. The explosion which took place at Newcastle, when the Mayor of the town was killed. At Mr. Darbishire's quarry near Carnarvon, a slight leakage had occurred in a sheet-iron slate truck in which nitro-glycerine, packed in tins, had been taken up. Before loading it with slates the nitro-glycerine was carefully wiped up, and some hot ashes put upon the place so wiped; but the men being still dissatisfied, before loading, retired behind a wall and threw a piece of slate into the truck, when a terrific explosion took place. A parcel of nitro-glycerine was delivered at Lord Penrhyn's quarry; one of the tins leaked, the material spreading over the bottom of the cart; on returning home the cart was blown up. An empty can, picked up by a workman at Festiniog, was taken home, under the impression that there was oil in it. It was put by the fire, but as nothing was found it was thrown under the grate, when it exploded, injuring the workman and his wife and blowing the windows out. A man at Llanberis struck an empty can with his foot; his leg was blown off. Another was killed while boring a hole at Llanberis; it was supposed that he struck some nitro-glycerine which had percolated into a crevice reopened by a previous blast. The last accident in Wales was the explosion of two carts on the high road to Llanberis, when not a vestige was found of the carts, horses, or men.

The high temperature at which nitro-glycerine froze was a great obstacle to its adoption. To overcome this difficulty, the tins containing it were first put into a pan full of hot water.

Dynamite was one of the best and least dangerous explosives now in use: it, however, laboured under the same disadvantage as nitro-glycerine—it froze at a high temperature. He was not aware of any accident that had occurred in the process of blasting, but two severe explosions had taken place in the process of warming preparatory to putting it into the blast-hole; one in a tunnel near Bristol, and the other in a slate-quarry near Carnarvon, when two men were killed.

None of the nitro-glycerine compounds could be relied upon to work with in cold weather; and the tempering or warming process must always be dangerous. Mr. Webb had mentioned that the men had no authority for using dynamite at the quarry where the explosion took place; but this could not affect the degree of safety, as all explosives must be placed in the hands of miners and quarrymen. Mr. Webb had also claimed for dynamite that more work was done in less time and for less money than could be done by gun-cotton. In some situations, for instance, when the rock was traversed by joints, and when water ran into the blast-hole, dynamite might be the more economical explosive; but when the rock was excessively hard and free from joints, it would be found that gun-cotton would be preferred by the miners, especially in underground work; and the safety and efficiency of an explosive were best proved by the extent of its use. The Welsh Slate Quarry Company used it extensively; and the manager, Mr. Chessel, had informed him that no accident had occurred for the last fifteen months; the number of men using it varying from three hundred to four hundred. The same gentleman told him that the cost of driving underground work had greatly increased since the supply of gun-cotton was stopped; and he and other quarry-managers said that the workmen, both above and under-ground, preferred gun-cotton to any other explosive. Mr. Bidder had no hesitation in stating his belief that this safe, handy, and efficient explosive would take precedence of all that had been brought before the public.

Mr. R. S. France observed, through the Secretary, that he had hitherto always considered it safe to thaw nitro-glycerine cartridges by hot water; but Major Beaumont's statement showed that these cartridges, whether of dynamite or of litho-fracteur, could explode accidentally when treated in this manner. He had accordingly given instructions for this mode of thawing to be discontinued in his quarries; and as Messrs. Lee, the Admiralty contractors for Dover Harbour, had taken all their instructions from him as to the mode of using the litho-fracteur, with which they were now deepening Dover Harbour, he had written to them not to again use the hot-water tin process, but that he would arrange some other plan; and as the men were very thickly at work in the harbour while the preparations for blasting were going on, it was possible that the discussion on the Paper might be the means of saving a considerable loss of life both at Dover and in his quarries.

Mr. J. J. Curling, R.E., through the Secretary, stated that some extensive mining operations were being carried out at Astoria, in Long Island, New York, in removing a rock that interfered with the navigation at Hell-gate. This rock was of gneiss, and was very tough and hard, numerous garnets being found in it. The following was an extract from a letter received from Lieut. Herrer, United States Engineers, who was in immediate charge of the works: "Our work commenced in October, 1869, since which time we have blasted and removed about 23,000 cubic yards of rock. The cost per cubic yard has varied considerably, say from $10 to $20: at present it costs about $16. We are using nitro-glycerine at the rate of about 22 oz. to the yard of rock, and drilling almost entirely by machinery. We also find that it requires about 6 ft. of boring (holes 2 in. diameter) to produce a yard of rock. Our drilling machines each average about 3 ft. progress per hour." Lieut. Herrer had also informed him that gunpowder and gun-cotton were both tried at first, but owing to difficulty in procuring the cotton, and to nitro-glycerine being found more economical than either, that material had been alone used during the greater part of the work. It was manufactured on the spot, and the charge was contained in metallic cylinders, which exactly fitted the holes. Tamping was not required, and hitherto no accident had occurred.

Messrs. Reeves and Co., through the Secretary, stated that they were about to bring before the public a special preparation of their 'gun felt,' which had hitherto been chiefly used for sporting, in a condition suitable for engineering and mining purposes. About three years ago many successful experiments were made with it in blasting various substances; the comparative strength, weight for weight, was eight times that of gunpowder; and the question of carriage, stowage, and general safety in use were satisfactorily proved. The expense of manufacture at that time was too great to enable it to compete with gunpowder, but the article could now be produced at a much lower price. Similarly with gun-cotton, the basis of the material was pyroxilin, but the subsequent processes rendered it more regular in its action, while it was free from the liability of spontaneous combustion, or of ignition at a lower temperature than 380° or 400°.

Mr. W. W. Evans (of New York), through the Secretary, stated that he had recently received a communication from Professor George M. Mowbray, who had been engaged in the United States in making experiments in reference to explosive compounds, some particulars respecting which he thought might be interesting. Professor Mowbray's attention had principally been directed to the introduction of explosive substances into chemical combination, as distinguished from mechanical, or rather semi-mechanical admixture. He had in the first instance purchased a series of samples of the various mixtures sold in the United States as 'dualine,' and had found that it was practically impossible to manufacture them in quantities sufficiently large to ensure uniformity in their explosive properties. This defect was notable in the samples of the same article successively purchased, and it was probably owing to their complicated ingredients having been brought together with a different amount of moisture. He had also generally come to the conclusion that to mix nitro-glycerine with corn-meal, paper, pulp, rotten stone, sand, sponge, &c., diminished the explosive force of the nitro-glycerine, and occasioned a loss of power, which was unjustifiable in the present state of chemical science. In every case he found that diminution of force was not in exact proportion to the smaller quantity of nitro-glycerine contained, but that generally there was only one half of the force, and in some cases only one third the force, which the nitro-glycerine would have evolved without the admixture. Professor Mowbray stated that all these mixtures entirely changed the nature of the explosive, as when a liquid exploded, the blasting or disruptive force was exerted in an inappreciable space of time; but when the particles were separated, the peculiarity of the force of the nitro-glycerine as an explosive agent was destroyed, and it became like gunpowder, which ignited not simultaneously, but by a 'flash,' which process, though performed in a period of time practically inappreciable, was yet a complicated operation, the chemical and mechanical decomposition going on from particle to particle instead of the whole mass becoming instantaneously converted into vapour. When gunpowder was fired the following operations took place:—the sulphur ignited—the nitrate gave out oxygen—the carbon combined with the oxygen—the sulphur and potassium (by deoxydation of the potash) combined, and these processes occurred, not simultaneously, but in succession as the various particles came into the focus of heat, or under the operation of a raised temperature. In order to approximately endow gunpowder with the destructive explosiveness of nitro-glycerine, or in other words, to decompose the whole bulk instantaneously, every granule would require to be heated so that each atom would be nearly at 240°, the melting point of sulphur. Then, by further increasing the temperature, a point would be attained when the carbon or charcoal in its fine state of division—if he might so describe it—invited the nitrate to decompose; and at that instant—at which by his experiments the temperature approximated to 600°, —an explosion, that was, a conversion of every particle into gases with fulminating violence, as in the case of the ignition of nitro-glycerine, would ensue. While, on the contrary, if it was required to reduce nitro-glycerine in its effective blasting force, it would only be necessary to reduce or subject it to the conditions under which gunpowder was ordinarily fired, namely, by separating its particles, so that its fluidity was interfered with or entirely destroyed.

In the course of his experiments Professor Mowbray had arrived at the conclusion that differently constituted nitro-glycerine could be produced, possessing different congealing points; and also that temperature, as well as the presence of water in the glycerine, modified the nitro-glycerine produced. In the severe winters of the United States, he had been enabled to separate the various resulting modifications by freezing (with salt water) a mass at a very low temperature, namely, from 10° below zero to 25° below zero; and then by very slowly allowing the temperature to rise by successive stages to 32°, 38°, and 40° above zero. At the higher temperatures the nitro-glycerine presented the appearance of a granulated substance, which by gentle pressure on blotting-paper left a white mass, the paper itself absorbing an oily matter. This oily matter readily exploded by a blow, but in a congealed or solid form, the white mass could not be exploded. Having made this discovery, by using acids of suitable strength, and glycerine free from water, or nearly so, Professor Mowbray succeeded in producing an article which he had named 'Tri-nitro-glycerine.' In the first instance he had experienced great difficulty in exploding it. He found that five grains of fulminate of mercury and a vial full of gunpowder put on the top of it and covered with sand would not explode it. When cold and congealed it would not explode, and the absolute conditions of explosion seemed to be inexplicable, when finally he found that ten grains, or twelve grains of fulminate in a copper cap immersed below the surface of the liquid would explode it every time the experiment was tried.

The destructive effects of the tri-nitro-glycerine were almost incredible. With holes drilled 14 ft. deep into a heading, and charged quarter full, the rock was torn out from the bottom. It was tried at Erie Harbour in the winter of 1869–70, and by the report furnished to Professor Mowbray, it appeared that 1·6 oz. of tri-nitro-glycerine was sufficient to remove 1 cubic yard of rock at an average depth under water of 8 ft. The advantages claimed for the tri-nitro-glycerine were, that it was chemically pure, stable, and uniform; that it was difficult to explode under any circumstances, even to the extent of needing special explosive substances to ensure its ignition, and that it was free from danger by concussion, cartridges having been thrown down a distance of 40 ft., breaking the cartridges, but without exploding them.

Professor Abel said statements had been made to the effect that the Nitro-glycerine Act had been mainly introduced by Government at his instigation, and also that its action had been prohibitory, and, to a great extent, had deterred practical men from using nitro-glycerine explosives. Large dynamite works had, however, been established near Glasgow, and explosive agents of those characters had been for some considerable time extensively used in mining districts. The Act in question, and those who had contributed to its introduction, did not therefore deserve the condemnation which had been awarded to them. The Act was necessary and salutary, as had been amply demonstrated since its introduction, and, though he could not claim even an indirect share of the merit due to those who introduced it, he would take this opportunity of recording his strong conviction that its enactment had not been prejudicial to mining interests, but had been instrumental in effecting great saving of life and property.

In reference to the letter written by him to Sir John Hay, M.P., in July 1869, and used by that officer in his advocacy of the Nitro-glycerine Bill, he desired to state that he was ignorant of any intention on Sir John Hay's part to read it in the House. With the knowledge then possessed he could not have desired to have modified it in any way, had he then known it was to become a public document. He did not lay down the theory, in that letter or anywhere else, that gun-cotton was an "absolutely safe explosive," nor was there anything in the letter relating to nitro-glycerine, in the unmixed or liquid state, at variance with the statements in the Paper—although written after an interval of three years had elapsed—except the statement that nitro-glycerine was specially susceptible of explosion when in the frozen condition. He had pointed out in the Paper the reasons for the opinion, very generally entertained within the last three years, that solidified nitro-glycerine was more dangerous than the liquid—an opinion since shown to be erroneous. The fact remained, that sad accidents had repeatedly occurred with frozen nitro-glycerine, no doubt from specially reckless handling of the material, to which its apparent inertness had probably given rise. Dynamite, the only other nitro-glycerine-preparation (except Mr. Abel's glyoxilin), was known to him in 1869, and was then supplied in the form of a loose damp powder, from which the nitro-glycerine appeared to have a considerable tendency to exude. It was decidedly inferior, as regards safety, to the firm, dry, but somewhat plastic rolls, now manufactured. Continued experience and the improvements in the manufacture of nitro-glycerine had caused him to acquire, during the last three years, considerable confidence in the stability of the properly purified material, and he believed there were few scientific and practical men who had not been led, by accumulation of their knowledge and experience, and by the progress of science and industry, to modify views, recorded at one time in perfect honesty of conviction, even to a much greater extent than had been the case with him in reference to nitro-glycerine preparations.

He had listened with interest to Mr. France's narrative of the relative merits of dynamite and litho-fracteur, and of the difficulties he had experienced through dynamite being in a frozen condition, while on the same occasion the litho-fracteur was not frozen. While experiencing some surprise at the temerity with which that gentleman exercised the privilege he so warmly claimed for quarry owners of doing their best to blow their heads off, the Institution must be congratulated upon the happy escape of one of its most distinguished Members, who had assisted at the experiment described. What he believed Mr. France had really wished to promulgate by his account was, that litho-fracteur would not freeze as readily as dynamite, and that certain special chemicals introduced into the composition of litho-fracteur enabled the miner to explode it when in a frozen condition; whereas dynamite was not susceptible of explosion by the usual means under similar circumstances. An Engineer officer in the Prussian service, whom Mr. Abel had met shortly after the war, and who had been specially charged with operations of demolition in which litho-fracteur was employed by the Germans, had told him that, while in many instances it was most effective, many failures had occurred, in consequence of the material being in a frozen, and consequently inert, condition. As bearing on this point, he would also refer to an account published in 'The Times' of some experiments made at Mr. France's quarries, near Shrewsbury, with litho-fracteur, last February, in the presence of the Gun-cotton Committee. Its safety in transport and in use having been demonstrated by what appeared to him excellent practical experiments, the applicability of litho-fracteur to military operations was to be demonstrated, and, among other experiments, a stockade was to be demolished. This was intended to be effected by means of a long species of sausage stuffed with litho-fracteur. But this sausage, having been exposed to a keen wind for a few hours, had become frozen, so that at the first trial only a small portion of the charge exploded; and, though the remainder was repeatedly re-fused, it did not explode, but only burnt, without any injury to the stockade. At any rate, therefore, it appeared that dynamite and litho-fracteur were about on an equality with regard to the difficulties resulting from the freezing of the materials. It was said that improvements had recently been made in the preparation of litho-fracteur, and possibly these might to some extent diminish the difficulties referred to; still up to the present time no superiority appeared to have been satisfactorily established for litho-fracteur either in this respect, or with regard to explosive power. Such special experiments, as had been described by Mr. Nursey and another gentleman, had been carried out with equal effect both with dynamite and with gun-cotton; and it was only by systematic employment upon one and the same class of work, that the relative power of those agents could be satisfactorily established.

Pudrolythe appeared to be an old acquaintance under a new name. He had some years ago to report upon a site near Plymouth, where it was proposed to manufacture a blasting-powder, composed of spent tan mixed and impregnated with nitrate of potash, and sprinkled with sulphur. It was comparatively harmless if inflamed when exposed to the open air, but in a good blast-hole was said to do very fair work. This preparation, known as 'Kellow's powder,' was so far safe to manufacture, that the works were partly burnt down twice without explosion. It appeared to him pudrolythe was, in point of fact, this old material revived under a new name, with this difference, that a little nitrate of baryta and a little sawdust and charcoal powder were added. He would suggest to powder-makers that they might possibly make the old blasting powder compete with pudrolythe, if they were to use imperfectly burned charcoal, and either to supply the powder ingredients only roughly mixed, or to sell them separately, to be mixed as required. He really failed to discern the existence of any merit in spent tan and sawdust as constituents of a blasting powder. He must say that the statement that pudrolythe evolved no deleterious gases when exploded was to him startling in its originality.

He had hoped that the Paper would have elicited more information with regard to the practical working of explosive agents. Mr. Webb had, however, given some valuable data regarding the relative power and cost in working of powder, gun-cotton, and dynamite, which were confirmatory of the statements in the Paper, and showed that dynamite and compressed gun-cotton were about on an equality in point of power and cost. One point in the comparative value of gun-cotton and dynamite had been referred to, namely, the difference of weight of equal volumes of the two. True, dynamite was heavier than gun-cotton; on the other hand, dynamite contained 25 per cent. of inert matter; and he doubted whether it would be found that there was any difference in the weight of actual explosive material in the two substances, or any difference, favourable to dynamite, in the force exerted by equal volumes of the two materials.

The experience of Major Beaumont with regard to the work done by the violent explosives would have been instructive if that officer had given some comparative estimate of the time occupied in performing a given amount of work, as the great advantage of violent explosive agents over gunpowder, and their merits in relation to each other, existed chiefly in the saving of time of which their employment was productive. The accident with dynamite to which Major Beaumont had referred was evidently due to a spontaneous decomposition of a portion of nitro-glycerine—accidentally exposed for a long time to heat, in contact with metal—having exuded from some of the dynamite charges. The numerous fatal accidents which occurred in the thawing of dynamite, though they were doubtless ascribable in part to carelessness, must be taken as a set-off against the few accidents which had occurred in charging holes with gun-cotton, the cause of which had been fully explained by him in his Paper.[1] Similarly, the explosion at the Stowmarket gun-cotton works, the cause of which had been clearly established to possess no bearing upon the stability of gun-cotton, had more than its parallel in numerous disastrous explosions at dynamite works in Germany and America, and in the succession of explosions at gunpowder works.

It was remarkable that, notwithstanding the numerous and deplorable accidents with gunpowder, it appeared to be exempted,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 338.

by special privilege, from condemnation, while the obviously unreasonable expectation appeared to be generally entertained that the manufacture and use of the violent explosives should be unattended by occasional accident. That their extensive employment, with reasonable precautions, would have the effect of greatly diminishing the accidents resulting from explosions, had already been conclusively demonstrated.