On accidental explosions / F.A Abel.

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On Accidental Explosions.

THE winter of 1874–5 has been unusually prolific in so-called accidental explosions. On Christmas Eve a colliery explosion entailed the sacrifice of seventeen lives, and on one day last January the 'Times' published accounts of no less than six fatal explosions; two in collieries involving the loss of eleven lives; three boiler explosions, by one of which seven persons were killed and twenty injured; and one coal-gas explosion, by which two lives were lost. All these were of the class ordinarily termed accidental, but in every case the casualty was traced to a cause which could have been foreseen and guarded against.

The term "accident," applied in its strict sense to disasters caused by explosions, would imply that these were due to some circumstance, or combination of circumstances, entirely unforeseen, and that they were consequently unpreventable. An explosion which occurs during the preparation or investigation of a compound, the explosive nature of which is as yet unknown, may be purely accidental, but if, after the properties of the substance have been thoroughly ascertained and made known, an explosion occurs during its production, by some person who has not properly made himself acquainted with, or has neglected in some point or other, those conditions essential to its production with safety, the knowledge of which is within his reach, the term "accidental" can certainly not be properly applied to it, although in all probability it would be so designated popularly, and even by those entrusted on behalf of the public with the investigation of its origin and results. The explosion occasioned by a person employing a lighted candle to search for a gas-escape in a room where there is a powerful odour of gas, or a gunpowder explosion resulting from the dropping of a spark into an open powder-barrel from a candle which is held over it, should properly have as little claim to be called "accidental" as a boiler explosion occasioned by a person tying down the safety-valve. There may be criminal intent in the latter case which is entirely absent in the two former; but the probability of an explosion

could have been equally foretold in all three instances, and though ignorance may perhaps be pleaded as an excuse in the case of the gas-explosion, and carelessness made to account for that of the powder, those pleas cannot be accepted as grounds for regarding the resulting disasters as legitimate accidents. Indeed it is often impossible to forbear stigmatizing as criminal the carelessness or ignorance which gives rise to explosions of the kind popularly accepted as accidental.

In the present discourse it is proposed to accept the definition "accidental" in the loose sense in which it is popularly applied to explosions, with the object of examining into the nature and causes of such explosions, and, if possible, of indicating directions in which there may be hope of successful efforts being made for reducing the frequency of their occurrence.

The phenomena attendant upon an explosion are generally due to the sudden or very rapid expansion of matter, accompanied in most instances by its change of state from solid or liquid to gas or vapour. The most simple classes of explosions are those caused by the sudden yielding to force, exerted from within, of receptacles in which a gas is imprisoned in a highly compressed condition, or a liquid has been raised to a temperature greatly exceeding that at which its molecules have a tendency to fly asunder or to assume the state of vapour or gas. The strength or elasticity of the envelope which confines them suddenly yielding to pressure, the liquid passes with great rapidity into vapour, violently displacing by this sudden expansion the surrounding air and any other obstacles opposed to the expanding molecules.

Similar explosive effects less simple in their origin are brought about by the sudden development of chemical activity in mixtures of gases or vapours, of solids and gases, or of solids only, or in chemical compounds of unstable character, the result in all such instances being the development of intense heat and the sudden or very rapid and great expansion of matter.

Examples of the most simple class of explosions are the sudden failure in strength at some particular point, or generally, of the material composing a vessel in which a gas has either been liquefied or highly compressed. Accidental explosions of this character take place chiefly, and happily not very frequently, in the laboratory or lecture room, yet instances occasionally occur of disastrous explosions resulting from such causes in manufacturing operations, or in the practical application of compressed air or other gases. The most recent illustration of a serious accidental explosion of this kind is that which occurred in the Arsenal at Woolwich, in January, 1874, with the air-chamber of a Whitehead, or Fish-Torpedo, when one man lost his life and several were seriously injured. In this instance some part of the soft steel diaphragm closing the chamber in which the motive power of this self-propellant torpedo (air) was imprisoned under a pressure of about 800 lb. on the square inch, suddenly yielded to the efforts of the gas to return to its normal condition.

These air-chambers were invariably tested up to a pressure very considerably exceeding that to which they would be subjected in actual service, before they were allowed to form part of the torpedo; yet in this instance, some comparatively weak point in the plate in question, though it had successfully resisted the force exerted by the very highly compressed air for a short period, was eventually tried beyond the limits of its strength, by the continued strain exerted by the air confined at a lower pressure; the powers of cohesion of its particles were suddenly overcome, when the confined air, released at one point, expanded with irresistible rapidity, tearing asunder the splendid metal which composed the air-chamber, and consequently inflicting fearful injuries on the poor fellows who were preparing to launch the torpedo on its trial trip. Most careful steps have been taken to avoid the recurrence of an accident of this nature, the possibility of which, with the precautions already adopted, was quite unforeseen.

Other explosions of this class, which are of more than weekly occurrence, and but too frequently result not merely in destruction of property, but in more or less serious loss of life, are due to the bursting of boilers at factories, mines, and collieries, to say nothing of those which occur in buildings, in connection with heating appliances and with kitchen ranges, and bath- or other heating-arrangements. The explosion of a boiler may arise either from an exceptionally rapid development of steam, the pressure speedily exceeding that which the boiler, or some portion of it, can withstand; or from an absence, or failure in the proper operation, of appliances for relieving the pressure in a boiler, by permitting the escape of steam, and giving warning when the pressure begins to exceed the limit of safety. The suddenly tumultuous evolution of steam may either occur from the boiler becoming overheated in parts, in consequence of the shortness of water, or from the sudden cracking or peeling of a non-conducting incrustation, or fur, on some part of the boiler, whereupon the water comes into contact with the overheated metal beneath it. But by far the chief causes of boiler explosions are defects in their construction, or repair, and the reduction in thickness of the metal in parts by corrosion, or oxidation, internally and externally, from long use, and neglect of proper measures for periodically cleaning the boilers.

The accidents due directly to the deposits formed from water in boilers have been very greatly diminished of late years by the application of preparations, called boiler-compositions, of which there are many varieties, their general action being to prevent, more or less effectually, the carbonate and sulphate of calcium and other impurities in water, which are separated by its ebullition and evaporation, from producing hard impenetrable crusts or coatings upon the inner surfaces of the boiler. The judicious employment of a good anti-fouling preparation, and the thorough periodical cleansing of the interior of boilers, go far to guard against that source of danger, though, in adopting measures to diminish the formation of incrusta-

tions, care must also be taken to avoid promoting internal corrosion of the boiler by the agents used.

The operations of the Manchester Steam Users Association for the prevention of steam-boiler explosions, founded, mainly through the instrumentality of Sir William Fairbairn, twenty years ago, and of which Sir Joseph Whitworth has also been a warm supporter from its commencement, appear to have gradually succeeded in very importantly reducing the annual number of boiler explosions, by introducing among its members a system of periodical independent inspection, the efficiency of which is clearly demonstrated by the circumstance that no case of explosion has yet occurred with boilers under the regular inspection of the Association, while between six hundred and eight hundred boilers are examined monthly. The periodical reports prepared by the talented chief engineer of the Association, Mr. Lavington Fletcher, are full of interesting and valuable information, and throw great light upon the chief causes of boiler explosions, and the means by which they may be guarded against. The Association will not allow that the term "accidental," or mysterious, is applicable to steam-boiler explosions. Mysterious they certainly are not, as they are generally quite traceable to causes which may be obviated, such as inferior material or defective construction, or local injuries, gradually developing and increasing, which would certainly be discovered before they attained dangerous dimensions, by a proper inspection; it may therefore not be too harsh to maintain that boiler explosions are not accidental, as their prevention lies in the power of the steam users, though it is true the same view must equally apply to other classes of so-called accidental explosions which are referred to in this discourse.

The following statements, furnished to the speaker by the Steam Users Association, afford some idea of the number and nature of boiler explosions which have occurred in the last few years. The number of explosions recorded annually by the Association, from 1865 to 1874 inclusive, ranges from forty-eight to seventy-two; the average present annual number is fifty. The largest number of deaths recorded is eighty-seven, and the smallest thirty-two, the present average number being seventy-five. About double that number of persons are seriously injured annually. With respect to the causes of boiler explosions, 40 per cent. were due (from January, 1861, to June, 1870) to malconstruction of the boilers; 29 per cent. to "defective condition" of the boilers; 15 per cent. to the failure of seams of rivets at the bottom of externally fired boilers; 10 per cent. to overheating from shortness of water; and less than 3 per cent. to accumulation of incrustations.*

An examination into the particular nature of the services performed by boilers which have exploded shows that a con-

* These data are in part extracted from a Table submitted by Mr. Fletcher to the Select Committee on Boiler Explosions, in June, 1870, *vide* p. 118 of the Committee's Report.

siderable number of explosions have occurred at iron works, and a very large proportion at collieries, where plain cylindrical externally-fired boilers are much used. Many of the explosions of these particular boilers arise from places which remain for a time concealed in the overlaps of the seams of rivets, defying detection, but gradually extending from one rivet-hole to another, till some sudden strain causes them to extend throughout the entire seam, the boiler splitting in two. The particular description of boiler which gave rise to the largest number of fatal accidents during the year taken as illustration (1873) was the single-flued or Cornish boiler; and it was stated by Mr. Fletcher that all these explosions must have been the result of glaring neglect, as there is no boiler safer to use when well made and properly cared for. The simple precaution of strengthening, or giving internal support to the sides of the furnace-tube of these boilers, the importance of which was demonstrated many years ago by Sir W. Fairbairn, appears to be still greatly neglected, the result being the frequent collapse of the tube through weakness. This illustration will suffice to indicate the nature of the "defects of construction" which are fruitful of the so-called accidents with boilers. An examination of the details given in Mr. Fletcher's reports as to the cause of explosions reveals a really appalling state of things under the head of "defective condition" of the boilers. In one case the plates are described as having been reduced by corrosion in places to the thickness of paper; in another, they were "in some places not more than from one-thirty-second to one-sixtieth of an inch thick;" in another, they were reduced at the primary rent "to the thickness of a knife-edge;" in another, the plates were in some places "eaten into holes which were roughly patched by means of bolted cement patches," while many of the rivet-heads were eaten off. These are merely examples of many similar descriptions. Very few explosions in 1873 appear to have been due to the neglect of the attendants, but by far the greater number to that of the boiler owners or the makers. The ignorance or criminal neglect, or worse, which appears occasionally to be displayed in the sale, purchase, and use of second-hand boilers is illustrated by the following two examples: A boiler which burst in December, 1873, on a rag-puller and waste dealer's premises, scalding three persons to death and injuring five others, was found to have given way on its first trial by its then owners, simply from old age and decay. At the earliest period at which its history could be traced it was purchased second-hand, and worked for five years; it was then left exposed to the weather for five years and afterwards sold to a broker for 5*l.*, who re-sold it as old iron for 8*l.* It was then sold for 18*l.* to an engineer, who sold it to its last owners with the assurance that it was safe at a pressure of 60 or 70 lb. to the square inch. The jury at the coroner's inquest returned a verdict of "accidental death," but "desired to express their disapprobation of the conduct of the engineer who sold the boiler as in good working order when the flue-tubes were in some places less than one-sixteenth of an inch

thick." The other illustration is that of a large boiler which is graphically described in a professional journal of high standing as having been worked to within an inch of its life, being only removed from its seat because it would hardly hold water. On this boiler there was a patch, more than two feet long, covering a crack of the same length; the patch had only six bolts, three on each side, and was made tight with a piece of old carpet smeared with white lead. Had this boiler burst, the verdict would in all probability have been as in the other case "accidental death," though it was worked almost to the last to 35 lb. pressure.

The explosion early in January last of a boiler at North Shields, and of one at Sheffield, affords further illustration, if it were needed, of the fearful danger continually incurred, even by those well acquainted with the properties of iron and steel and the limits of their powers of resisting strain or pressure, in the employment of boilers long after they had ceased to be trustworthy. At Shields, at a large manufactory of chain cables and anchors, the boiler which exploded had been worked beyond a pressure of 35 lb., while it was unsound, over-patched, and quite unsafe at that pressure. Seven people were killed and about twenty others injured, and a vast amount of property was destroyed, the buildings within 500 yards appearing as though they had been bombarded. At Sheffield, where the explosion of a boiler not many days afterwards killed two persons, injuring several others, a leakage had been observed in the boiler some time before the explosion, but had not been repaired, and a plate fractured by the explosion had been greatly reduced in thickness by corrosion. This boiler appears to have been worked up to the day of the explosion at a pressure of from 40 to 50 lb., and the workmen employed are stated to have expressed fear at working in its vicinity.

The foregoing and other very numerous illustrations of the appalling display of ignorance, neglect, or recklessness in dealing with the application of steam-power, point strongly to the importance of legislation connected with this subject. A parliamentary committee of inquiry reported in July, 1870, that the introduction of compulsory independent inspection of boilers would interfere with the responsibility of the boiler owner; but it is somewhat difficult to realize where the responsibility lies, in the present condition of things. That a system of inspection may be made to work well has been demonstrated by the beneficial results of the now very widely applied labours of the Steam Users Association; and that Government realizes these benefits is demonstrated by the fact that the boilers at the manufacturing establishments of the War Department are subject to the inspection of the Association. There can be no reason why the responsibility of the proper condition of boilers, and steam apparatus generally, should not be thrown upon inspectors, just as the proper fencing of machinery in factories, and the proper condition of steam-boilers in a passenger steam-ship, are secured by a system of responsible official inspection.

The explosions which are often recorded as occurring in kitchen

ranges and in boilers used in connection with the heating of buildings are not unfrequently attended by fatal results. Much of what has been said with regard to boiler explosions, generally, applies to accidents of this class. Explosions in such boilers have repeatedly arisen from corrosion of the metal, and consequent great reduction of its thickness in places, due to the accumulation of hard incrustations or furs which in time exclude the water from contact with the metal, causing the latter to scale from overheating. The incrustations will crack or split from time to time, in consequence of inequality of expansion or contraction between them and the metal, and if the latter be heated at the time, pressure of steam may be suddenly generated which the worn boiler will not withstand unless provided with an efficient safety-valve.

As the water in kitchen boilers is often used for culinary and drinking purposes, the means employed in boilers used for steam-purposes only, to prevent the formation of hard deposits, cannot be resorted to; therefore the only means of guarding against accidents to domestic boilers from these causes consists in frequent and thorough cleaning out, which is especially necessary where the water-supply is hard.

Explosions also occur with household boilers of the ordinary circulating class, unprovided with safety-valves, through the stop-taps of the pipes which connect them with an overhead cistern being left closed by accident or negligence, in which case steam pressure must speedily accumulate to a dangerous extent, all outlets being closed. Accidents with such boilers are particularly liable to occur during severe frosts in consequence of the circulating pipes becoming plugged up with ice, whereby the outlet for steam pressure is as completely cut off as if the stop-taps were closed. Several accidents due to these two causes, some of them attended by fatal results, were recorded last year. The obvious and simple method of guarding effectually against such explosions is to have the boiler fitted with a reliable safety-valve, of the most simple form; a valve of pendulous dead weight construction is specially recommended for this purpose by the Steam Users Association as being inexpensive, certain of action, and free from any liability to get out of order. So simple a precaution for avoiding the possibility of a frightful accident surely only requires public attention being directed to it to secure its general adoption.

Explosions resulting from the ignition of mixtures of inflammable gas and air constitute even a more formidable class than that just described; for the number of explosions in coal mines which occur in a year is very considerably greater than that of boiler explosions, while the loss of life occasioned by the former is very considerable, and is occasionally appalling in its magnitude. Thus, in 1871, there were fifty-two fatal explosions, 268 men being killed, and 234 non-fatal explosions, by which it is estimated that 368 men were

injured; and, as examples of specially calamitous explosions, may be mentioned that at Risca Colliery in 1860, when 142 men were killed, and those at Oaks Colliery in 1866, and Ferndale Colliery in 1867, when 334 and 178 men were killed.

If marsh-gas, or light carburetted hydrogen, which exists imprisoned in coal-beds and escapes into the atmosphere in the pit-working, either gradually or sometimes under considerable pressure, becomes mixed with the air to such an extent that there are about eighteen volumes of the latter to one of the gas, the mixture burns with a pale blue flame, which will surround that of a candle contained in such an atmosphere; the appearance of such a "corpse light" round the flame of the pitman's candle or lamp-flame is a warning, too generally unheeded, of the presence of fire-damp in quantities likely to be dangerous; for if the proportion of marsh-gas increases much beyond that above specified, an explosive atmosphere will be formed, the violent character of which increases as the proportion of fire-damp approaches that of one volume to ten of air. Marsh-gas requires for its ignition to be brought into contact with a body raised to a white heat; fire-damp, or a mixture of marsh-gas and air, is therefore not inflamed by a spark or red-hot wire, but will explode if brought into contact with flame. The fact that this contact must be of some little duration to ensure the ignition of the fire-damp was applied by Stephenson in the construction of his safety-lamp; and a very philosophical application of the property possessed by good conducting bodies, such as copper or iron, of cooling down a flame below the igniting point of the gas, and thus extinguishing it, was made by Davy in the construction of his safety-lamp.

All the efforts of eminent scientific and practical men, for the better part of a century past, to diminish the number of coal-mine explosions, by improving the ventilation of the mines and providing the miner with comparatively safe means of illumination, appear to have had very little effect in reducing the number and disastrous nature of these accidents. Since the construction of safety miners' lamps by Davy, Stephenson, and Clanny, repeated and partially successful efforts have been made to reduce the loss of light consequent upon the necessary enclosure of the flame, and thus to lessen the temptation of the miner to employ a naked flame at his work in fiery mines. Yet investigations after mine explosions still frequently disclose instances of the employment of candles where they are undoubtedly dangerous; and the regulations which have been made law with the view of preventing accidents through the use of naked lights by miners, where there appears any likelihood of fire-damp escaping and lodging, are in many cases either habitually neglected or very carelessly carried out. One practice which appears to have become very general in mines where fire-damp is known to exist, that of sending *firemen* with safety-lamps to examine the mines, the men then proceeding to work with naked lights in all places marked as safe by those officials, is obviously a most dangerous

one, the lives of many being made absolutely dependent upon the vigilance and trustworthiness of one or two; yet it appears to be one almost forced upon the managers of collieries by the men themselves, who often absolutely refuse to go to work with safety-lamps. Of the three colliery accidents which occurred between December 23rd and January 7th last, by which twenty-eight men lost their lives, two afford sad illustrations of the fact that the overlookers and the miners themselves are chiefly to blame for the frequency of these accidents, and that the practice of employing "firemen" just referred to is a highly perilous one.

In the case of the explosion at Bignall Hill Colliery, North Staffordshire, the Government Inspector gave evidence to the effect that the explosion occurred in what was admitted to be *the most fiery seam in the North Staffordshire coal-field*, and in which *no naked light ought ever to be used*. The overlooker stated that, having found gas in the heading on the morning of the explosion, he told the men not to go to work there with naked lights; that "he had authority to order lamps, but *he had not done so*, because he had not seen any necessity for it. The explosion might have been avoided if the man whose light was believed to have fired the gas, had done his duty and used a lamp." Another witness "had found gas on the morning of the explosion, but not sufficient to lead him to suspect danger. He found gas in the place after the fireman said he had cleared it away; . . . . . the workings always were considered safe, and if he asked a man to use a lamp he would often be laughed at."

The Government Inspector deposed that "all the circumstances went to show that the fireman did not examine the place before the men went to work, and that one of the men walked into it with a naked candle and ignited the gas." At the second explosion (at the Aldwarke Main Colliery near Rotherham) the fire-trier appears to have made his customary inspection and found all safe at the place where the explosion occurred, and had left his usual sign to indicate to the men that all was right. The opinion of the engineer was that a considerable fall of roof (of the working) had occurred after he had left, and that, before the liberated gas had time to be carried away by the ventilating current, the men entered and met the gas, which immediately fired. "Had there been a delay . . . . . or *had the men been provided with safety-lamps* the accident would in all probability have been averted." In the Report of the accident it is stated that the men in that district will rather leave a colliery than be subject to the strict enforcement of the rules of the Act passed to ensure their safety, and that some such calamity was needed to enforce proper regulations for the safe working of the mine. There can be no question that the comparatively dim light afforded even by the best constructed lamps in general use, is a cause of great temptation to the men to use uncovered lights; it is therefore much to be hoped that continued efforts may be made to apply the electric light to the illumination of mine workings. Some approach to success in this direction

was already attained ten years ago, and one cannot but have great faith in the ultimate feasibility of some portable method of illumination by electric agency.

There are, however, causes other than the use of unprotected lights, which contribute to the production of coal-mine explosions. Efficient ventilation of workings, whether in use or not, whereby all dangerous accumulation of fire-damp is avoided and any sudden eruption of gas may be rapidly dealt with (the gas being largely diluted and swept away as speedily as possible) is indispensable to the safe working of the mine (without any reference to the health of the men) so long as there is any temptation for the use of naked lights. The original laying out of a working greatly affects the question of efficient ventilation, and explosions have been clearly traced to gas accumulations, which there was sufficient power of ventilation to reduce, if the nature of the working had admitted of its proper application. At the Bignall Hill Colliery where the fearful explosion occurred on Christmas Eve last, the ventilation had been reported imperfect about three weeks before the accident, and the Government Inspector stated that the deficient ventilation was due to the improper laying out of the work. In arranging for the efficient ventilation of a mine, ample provision for rapidly applying extra artificial ventilating power should be made; and, in connection with this, the interesting and useful series of observations should be borne in mind which have been made public in communications to the Royal Society and the Meteorological Society by Messrs. R. H. Scott and W. Galloway. Those gentlemen have clearly established a connection between the occurrence of meteorological changes and colliery explosions; they have shown that explosions frequently occur at the time of considerable barometric disturbances which must unquestionably affect the rate of diffusion of the fire-damp into air and the rapidity of air circulation in a mine. They also point out that when the external temperature rises very considerably, the natural ventilation, due to the higher temperature of the air in a mine, is liable to cease, by the external atmospheric temperature becoming equal to, or perhaps exceeding, that in the mine. They consider that of 233 explosions which occurred in 1872, 58 per cent. were due to disturbances of atmospheric pressure, and 16 per cent. to excessive heat of the weather, and they have similarly traced the proportion in which the same meteorological changes have contributed to bring about explosions in other years.*

* Reference must be made here to an ingenious application, made by Mr. Ansell, of the laws of diffusion and osmose for detecting the presence of fire-damp in coal-pits. Two or three forms have been given by Mr. Ansell to the detector apparatus; perhaps the most simple consists of a ball of thin india-rubber, filled with air and fixed upon a stand under a lever which slightly presses the upper surface of the ball. If from any cause the lever is raised it liberates a spring which sets a bell in vibration, or brings an electro-magnetic alarum arrangement into operation. If this apparatus is placed where fire-damp exists to an important extent, the light carburetted hydrogen passes through the pores of the india-rubber ball, and as the air in the latter passes outwards at a much lower rate, the ball

Since the employment of gunpowder as a means of rapidly removing coal, or overlying shale, has come into considerable use, there can be no question that an additional and a very serious source of danger has been imported into the working of collieries. That the explosion of a charge of powder in a blast-hole, or the "firing of a shot," has by no means unfrequently resulted in the production of a fire-damp explosion, has been clearly established by careful inquiry. This has been ascribed to two causes, one of them the direct ignition of the explosive gas-mixture by the flame from the shot, the other the dislodgment of fire-damp from cavities or disused workings by the concussion produced, and its ignition by some naked flame or defective lamp in the neighbourhood. If a shot takes effect properly (i.e. if the force is fully expended in breaking the coal or rock at the seat of the charge), there is seldom flame produced; but if the tamping which confines the charge in the blast-hole is simply blown out of the latter like a shot from a gun (which not unfrequently occurs when the rock is very hard or the tamping is not sufficiently firm, or when the charge of powder is excessive), the powder-gas issuing from the blast-hole will produce a flash of fire as obtained with a gun; and if the fire-damp were in the immediate neighbourhood, it would no doubt be ignited thereby. But this combination of conditions is not likely frequently to occur; the second cause above given is therefore more likely to be fruitful of accidents: but the existence of a third cause, to which the majority of explosions connected with blasting in collieries is most probably ascribable, has been very clearly established by the careful inquiries, sound reasoning, and ingenious experiments of Mr. W. Galloway, Inspector of Mines. The fact has long been known that if an explosive gas-mixture be driven, in a current of sufficient force, through the gauze of a safety-lamp at right angles to the lamp, flame may be forced through the meshes, and may thus ignite the explosive mixture outside the lamp; but Mr. Galloway conceived, and has clearly established by experiments in the laboratory and in coal-pits, that the sound-wave established by the firing of a shot (especially by the sharp explosion produced when the tamping is shot out of a hole) will by transmission, even to very considerable distances, have the effect of forcing flame through the meshes of the gauze of a safety-lamp, and will thus lead to the ignition of an explosive gas-mixture surrounding the latter. Safety-lamps may frequently be accidentally surrounded by (or purposely introduced, for purposes of inspection, into) an explosive atmosphere at the time that shots are fired in neighbouring workings; and the circumstantial evidence collected after the occurrence of some explosions has undoubtedly

soon distends, exerting sufficient pressure on the lever to bring into action the signalling arrangement, which, if electric, may be placed at any convenient distance from the fire-damp detector, being connected with the lever by means of conducting wires. It would appear as though a detector of this nature could be made of important service in fiery mines; but its employment does not seem as yet to have passed beyond the experimental stage.

indicated that this is the most probable explanation of the cause of the accident. It is probably not to be expected that even in fiery coal-pits miners will forego the advantages derivable from the employment of gunpowder, and it appears next to impossible to enforce prohibitory regulations with respect to such pits; but it may perhaps at any rate be hoped that the miner may be trained to a knowledge of the danger he incurs by the incautious use of gunpowder, although the persistent recklessness with which he sacrifices safety to comfort, in despising the use of the safety-lamp, forbids sanguine expectations in this direction.

Reference has not been made to another very possible source of accidents, due to the employment of gunpowder for blasting purposes, namely, carelessness in the keeping and handling of the explosive agent by the men. Personal observation by the speaker of the reckless manner in which powder is frequently dealt with in mines, leads him to believe that this contributes its quota as a cause of colliery explosions.

The accidents in collieries have their parallel in domestic life, in coal-gas explosions, which, though at first sight of comparatively small importance, if judged by the loss of life and property which they occasion, yet merit serious consideration on account of the great frequency of their occurrence, and the demonstration which they almost always afford of ignorance or culpable carelessness. Whether occasioned by defective gas-fittings or by want of care in dealing with the gas-supply, the escape of gas in a confined space, in any but very small quantities, must speedily result in the production of an explosive gas-mixture, by the rapidity with which the gas will diffuse itself through the atmospheric air surrounding the point of escape. The application of flame to such a mixture must inevitably result in an explosion, the destructive effect of which is regulated by the quantity of gas escaping, and the time which it has had to mix with the air.

The circumstance that the admixture of even minute quantities of coal-gas with air can be at once detected by the unmistakable odour of the gas, should serve as a safeguard against accidents; unfortunately, however, thoughtlessness or want of knowledge frequently causes this very fact to lead to the opposite result. Escapes of gas in comparatively small quantities often occur at the point of union (generally by a ball-and-socket joint) of a hanging burner or chandelier with the gas-pipe, or at the telescope-joint of such gas-fittings; the column of water required in the joints to confine the gas becoming very gradually reduced by evaporation. In such instances an explosive mixture will accumulate in the upper part of an apartment of which windows and doors are closed, while the air in the lower part will continue for a long time free from any dangerous admixture of gas; and instances are continually recorded in the public prints of the deliberate ignition of such explosive mixtures, by persons who, observing the smell of coal-gas upon entering

the room, proceed forthwith to search for the point of escape by means of a flame. It need scarcely be stated that such a test is a perfectly safe one in itself, and that if the acceptance of the warning given by the odour of gas in the lower part of the room were promptly followed by the simple precautionary operation of leaving open for some time all windows and doors, so as to afford ready ingress of fresh air, and thus speedily expel, or very largely dilute, the gas-mixture, the leakage could be looked for with no risk of accident.

Gas explosions, generally of a serious nature, do occasionally occur through no fault of those who are the direct agents in bringing them about, as by a person entering with a light a closed apartment in which there has been a very considerable escape of gas for some time, or a building into which gas has been entering from a leakage in the supply-pipe or the main. A very sad accident of the latter kind occurred in January last at Durham, resulting in the death of two persons. The occupants of a house had noticed on a Saturday afternoon a smell of gas, which was traced to a leakage in the main-pipe by the gas company's servants, who stated that it could not be repaired until the following Monday. The man, being satisfied that the gas-escape did not occur in his house, lighted a candle some time afterwards, with the result that a terrific explosion nearly wrecked the house, which had become to a very considerable extent filled with explosive gas-mixture. In another recent instance, the accidental ignition of an explosive coal-gas mixture issuing from a drain-pipe communicating to the sewer in which gas had leaked from the main, caused the demolition of one house and the partial demolition of another, the inmates, in both instances, escaping fortunately with bad injuries. The first of these accidents, at any rate, would not have occurred if prompt means had been taken for stopping the leakage when its source was discovered; and it may be confidently affirmed that a very large majority of the accidents resulting from coal-gas explosions might be avoided by the exercise of ordinary care and intelligence.

The employment of illuminating agents closely allied to coal-gas, namely, liquid carbo-hydrogen compounds obtained by the distillation of coal or shale, or derived as natural products from coal-bearing strata, gradually extended during the earlier part of the last quarter of a century until they became formidable rivals of mineral and vegetable oils and even of gas itself. Among the very earliest of these so-called mineral oils was paraffin oil, first obtained from a particular description of schist or coal, by Mr. Young; but some time before then, the most volatile products obtained by the distillation of coal-tar were employed in lamps without wicks, of such construction that the volatile liquid, flowing by gravitation from the reservoir to the source of heat, was converted into vapour as it reached the point where the jets of flame were produced. The great facility with which the more volatile portions of rock-oil or petroleum, and of the products of dis-

tillation from coal and schist, were applicable as brilliant illuminating agents in lamps of simple, cheap, and convenient construction, combined with the low price at which they could be retailed, consequent upon the great development of the petroleum industry in America, soon led to their extensive employment by the general public, and the importation of these volatile oils or spirits attained in a short time a scale of considerable magnitude.

The several varieties of so-called petroleum spirit which are known as naphtha, benzine, benzoline, gasoline, japanner's spirit, &c., yield vapour more or less freely on exposure to air at ordinary atmospheric temperatures, and even in some cases below 50° Fahr. Their low specific gravity and volatility permit of their employment in very simple and inexpensive lamps—the commonest form now extensively used by the poorer classes all over the country being the "sponge lamp" in which a small strip of sponge or coarsely plaited wick serves the purpose of drawing the spirit up from the reservoir to the orifice, where it is vaporized and burned. Although much the largest proportion of the petroleum spirit employed is probably used in lamps of some form or other, there are additional important uses to which it is applied in large quantities, e. g. as a detergent, by dyers, &c.; as a substitute for turpentine in paints and varnishes; as a means of imparting luminosity to non-luminous inflammable gas, or of rendering atmospheric air itself the vehicle for illumination by saturating it with benzoline vapour; as a solvent and purifying agent in connection with the manufacture of artificial alizarine, &c.

The statistics of the imports into London and Liverpool during the last three years show a very considerable increase in the consumption of petroleum spirit, as will be seen from the following numbers:

		1872.	1873.	1874.	
Barrels imported	..	33,693	45,889	58,687	London.
		26,871	27,394	47,200	Liverpool.

The imports of the less volatile and properly refined petroleum products, known generally as petroleum oil (also called kerosine, crystal oil, rock oil, astral oil, and, incorrectly, paraffin oil), which do not yield vapour below a temperature of 100° Fahr., have fluctuated considerably during the last six years, but have increased lately to about five-fold into London, and four-fold into Liverpool, of what they were in 1872, as shown by the following numbers:

		1872.	1873.	1874.	
Barrels imported	..	48,295	206,573	245,291	London.
		46,679	104,155	159,700	Liverpool.

The so-called paraffin- or petroleum-lamp *explosions*, of which in the earlier days of the employment of these illuminating agents there were so many recorded in the newspapers, and of which one still hears occasionally, were, with very few exceptions, not correctly designated as explosions, and when they were so, were not caused by

the employment of the volatile oils or petroleum spirit. As these vaporize very freely at the slightly elevated temperature which a reservoir of a lamp soon attains, air is either entirely expelled from the latter by the vapour, or so diluted by it, that the mixture is not explosive. If therefore flame can have access to vapour escaping from any opening in the reservoir near the wick, in a badly-constructed lamp, it will merely burn as it escapes. If a lamp charged with petroleum spirit be carried incautiously, or accidentally jerked so that the liquid is suddenly brought into contact with the warmer portion of the lamp, near the flame, a very rapid volatilization may thereby be caused, resulting in a considerable outburst of flame. In either case, a nervous person, holding the lamp at the time, may drop it in alarm, or the reservoir, if of glass, may be broken by the sudden burst of vapour and the resulting large flame; in such instances, the spirit will be scattered and at once inflamed, inflicting injuries more or less severe on the instigator of the accident, or setting fire to the premises.* A so-called petroleum-lamp explosion which occurred, quite recently, at Gloucester, resulting in the death, from burns, of a woman, was evidently brought about by the cause last described.

If a petroleum oil which has been imperfectly refined, and which therefore contains some proportion of the very volatile products, or spirit, be employed in a lamp, a slight explosion may be caused by its yielding up a small amount of vapour at the temperature to which the reservoir becomes heated, and thus producing a feebly explosive mixture with the air in the latter, which may become ignited by the flame of the lamp. An explosion thus produced is not at all of violent character, being generally merely a feeble puff; it may, however, cause the cracking of the reservoir, and the consequent spilling and inflaming of the oil, and may at any rate lead to accident as already described, by the alarm which it occasions to nervous or ignorant persons.

There is no doubt whatever that a very considerable proportion of the accidents which occur to persons using petroleum-lamps are really traceable to the erroneous belief, which is still so very prevalent, in the *explosive* character of these liquids. The fact that they and their vapours are simply inflammable, and that the latter require

* The Reports by Captain Shaw to the Metropolitan Board of Works of the causes of fires in London, show a generally steady increase in the number of fires caused by lamps: thus there were 20 in 1866, 30 in 1869, 49 in 1871, 56 in 1872, 47 in 1873, and 67 in 1874. These returns include fires from lamps of all kinds (many not defined); but it may be reasonably assumed that three-fourths of the totals noted were caused by petroleum-lamps. From one to seven fires annually are reported as caused by upsetting, "drawing off," or explosion of naphtha, paraffin, crystal oil, or petroleum. The proportion which fires from the above causes bear to fires caused by candles is small, but has been on the increase in the last few years. From 1866 to 1870 inclusive, the fires caused by candles were from seven to ten times more numerous than those caused by lamps; but in 1872 they were only about five times; in 1872 and 1873, four times; and in 1874 only little over three times more numerous.

to be mixed with a large volume of air before their ignition can be accompanied by explosive effects, is so slowly realized, that in public prints petroleum is still often spoken of as an explosive substance, although these very prints have recorded such events as the *burning*, in 1866, of warehouses at Bow containing 1000 barrels of petroleum, besides four barges laden with petroleum lying alongside the wharf, without any explosion; and the ignition at New Jersey (in August, 1874) of a petroleum tank in the Erie Railway Company's oil-yard, and the consequent *burning* of 70,000 barrels of petroleum. The popular belief in the explosiveness of these simply inflammable liquids contrasts strangely with the fact that many explosions have been brought about by the careless employment of candles or other naked flames in premises where the volatile varieties have been stored, or where the operation of transferring the liquid from one vessel to another for purposes of sale is carried on, the result being the ignition of the explosive mixture *produced* by the volatilization of the spirit and its diffusion through the air. This fact does indeed tend to discourage the hope that the proportion of accidental explosions of *gunpowder*, which are apparently due to ignorance, may become very greatly diminished by keeping its explosive properties before the minds of those using it.

Although those petroleum accidents which are the results of carelessness or ignorance are very difficult to attack, the community has unquestionably benefited very considerably in the matter of optional comparative security by the legislation of the last few years, in connection with the storage and sale of petroleum, imperfect though it still is. The prohibition of the sale of petroleum spirit of any kind, unless distinctly labelled so that the public may be alive to its specially dangerous nature as a very volatile liquid, and the limitation of its storage and sale, by properly licensed persons, to localities specially selected and inspected by responsible officials, have most certainly contributed greatly to the protection of the public against accidents entailed by the use of these materials. A still more important benefit which has resulted from legislation on this subject, aided by the zealous action of the Petroleum Association and of municipal authorities, is the almost complete exclusion from the market of such petroleum *oil* as yields inflammable vapour at temperatures considerably above the maximum atmospheric temperatures of Great Britain. The danger arising more especially from the transport and storage of oils bearing names which apply to the properly refined and therefore safe petroleum- or coal-oils which do not demand special precautions for their safe storage and use, and are consequently not subject to any restrictive or precautionary regulations, renders the application of the existing legal regulations to the inspection of petroleum *oils* imported into England of special importance. Such inspection, if efficiently conducted, must afford important protection to consumers and communities, by maintaining strictly the line of demarcation which it has been the object of legislation to establish between very

volatile and therefore highly inflammable petroleum-, or coal-products, and those liquid hydro-carbons of the same origin which are comparatively very safe illuminating materials, because they do not evolve vapour at any temperature below about 100° Fahr. A thoroughly trustworthy and sufficiently simple method of testing the oils is essential to the attainment of this result; and after much consideration and practical experience had been brought to bear on this subject, the so-called *flashing test*, described in the Act of Parliament, was adopted as the fairest and most reliable one which could be prescribed for general application; but there is no doubt that, when applied to oils which nearly approach in their flashing point the limit prescribed by the Act, the operation of the test is not sufficiently sharp, nor the prescribed method of conducting it sufficiently rigid, to preclude the possibility of its furnishing conflicting results in different hands, and thus leading to decisions, the justness of which may be legitimately open to dispute. It is therefore undoubtedly desirable, in the framing of any future Act, that this test should be carefully reconsidered, as well as the question whether some narrow limit below 100° Fahr. may not reasonably, and without incurring any increased risk, be fixed within which the flashing point of an oil (i. e. the temperature at which it evolves vapour) may range.*

Such accidents as the explosion of a mixture of petroleum vapour and air in a ship on the Thames (the 'Maria Lee'), laden with about 300 barrels of petroleum and with other inflammable materials (in June, 1873), followed by her complete destruction by fire, in somewhat alarming proximity to the Purfleet powder magazines, and a similar accident in Glasgow Harbour, demonstrate the importance of the regulations which are imposed by the local harbour authorities, as directed by the existing Act of Parliament, upon all ships carrying petroleum spirit, with respect to their mooring and the landing of their cargo. The Act also gives to the municipal and other licensing authorities the very important power of including, as conditions of the licences, regulations with regard to the quantity of petroleum spirit to be stored in a particular locality; the nature and situation of the store with reference to inhabited buildings; the mode of storage, and the nature of the other goods to be stored with it. Very efficient regulations have consequently been adopted by the Metropolitan Board of Works—and some other local governing authorities—with regard to the stores themselves, the exclusion of any source of fire or artificial light from them, the nature of the receptacles in which the petroleum is kept, &c. The latter is a point of the utmost importance, as specially affecting the risk of accident in storing and *transporting* petroleum spirit, and one which it is very necessary that legislation should deal

* As the law at present stands, an oil, the flashing point of which is declared to be 99° by the official inspector, must be condemned; but another operator may make the flashing point of the same oil to be slightly above 100°. Practically, an oil with a flashing point of 97° or 98° would be quite as safe as one which answers to the test at 100°, in the hands of the same operator.

with more specifically than is at present the case. The existing Act specifies that limited quantities, for sale or consumption, may be kept without a licence, provided they are contained in small vessels of glass, earthenware, or metal, but it is silent on the subject of the vessels in which larger quantities are to be stored, or with respect to any regulations conducive to safety in the transport of petroleum spirit. As regards the first point, it certainly gives ample power to licensing authorities; but that legislation is urgently needed in regard to the second, was demonstrated by the recent fearful catastrophe on the Grand Junction Canal.

The liability of oil or spirit to leak from casks or barrels even of the best construction, consequent upon the rough usage to which these are unavoidably subjected when transferred from store to ship or carriage, and the reverse, need scarcely be pointed out. But even in the absence of leakage from the openings of the barrels, or from any accidental point of escape, evaporation or diffusion of the volatile petroleum will occur through the wood itself of which they are constructed, especially in the warm holds of ships or in stores exposed to the sun, even though the precautionary measure is frequently adopted of rinsing the barrel out before use with a solution of glue. It is evident that the object of imparting an impervious coating to the interior of the barrel can thus be only very imperfectly attained, and that, even if it were, the alternations of temperature to which the barrels must be exposed must in course of time open up places for escape by leakage or evaporation.

It is stated, on the authority of the manager of the extensive depôt for petroleum oil and spirit of the London Wharfing and Warehousing Company, at Plaistow, on the Thames, that in spite of the adoption of special arrangements for keeping down the temperature of the petroleum-spirit stores, whereby it is made not to exceed 62° Fahr. in the very hottest weather, the loss of spirit by leakage and evaporation is very considerable, amounting to an average of 18 per cent. As the loss on petroleum *oil* from leakage at the same establishment amounts to about 9 per cent., it is evident that the limpidity and volatility of the spirit give rise to a loss as great again as that which is simply due to leakage from imperfectly closed vents or defects developed by rough usage.

The dangers resulting from the escape of petroleum spirit or its vapour from receptacles in which it is kept, in confined spaces, where little or no ventilation exists, has been but too frequently exemplified by explosions more or less violent, followed by fires, in localities where it is stored or handled, or in the holds of vessels in which it is transported. Accidents of such kinds have been due either to carelessness in transferring petroleum from one vessel to another, in a shop or store in which a light has been burning at the time, or to a light being carried into or a match struck in a store where vapour has been escaping until it has formed an explosive mixture with the air. The explosion which occurred in a sewer at Greenwich last January,

and was productive of much damage, was clearly traced to the entrance into the sewer of certain petroleum products (from a patent gas factory in the neighbourhood); the vapour from these had formed an explosive mixture with the air, which had become accidentally lighted, perhaps by the dropping of an inflamed pipe-light through one of the sewer-gratings. The speaker has a vivid recollection of an accident of this kind which he witnessed at the Royal College of Chemistry in 1847. Mr. C. B. Mansfield, who was then engaged in his important researches on the composition of coal-tar naphtha, which led a few years afterwards to his sad untimely death, was engaged at one extremity of a low room (38 feet long, about 30 feet wide, and 10 feet high) in converting one of the most important of these products—benzol—(which boils at 176° F.) into nitrobenzol in a capacious retort, which suddenly cracked, and, yielding to the pressure of its contents, allowed the warm liquid hydro-carbon to flow over the operating table. There was a gas-flame burning at the other extremity of the laboratory and no other source of fire. Within a very few minutes after the fracture of the vessel a sheet of flame flashed from the gas-flame along the upper part of the room and communicated to the table upon which the liquid had been spilled.

The firing of the ship 'Maria Lee' just now referred to was clearly proved to have been preceded by the explosion of a mixture of air and petroleum-vapour, produced by leakage or evaporation from the barrels stored in the hold of the vessel. The weather was very hot at the time, and, there having been a heavy thunderstorm the night before the fire, the hatches had been kept closed and covered over with tarpaulin, so that there was no possibility of ventilation. The vapour gradually diffused itself through the air in the ship during the night until the explosive mixture extended to the cabin at the after part. As the captain entered this cabin quite early in the morning (the *immediate* source of the fire was not clearly traced) a loud explosion occurred, and flame was immediately observed issuing from the fore part of the ship.

A similar explosion of petroleum-vapour and air occurred not long since in a ship at Glasgow; and lastly it was established by a sound chain of circumstantial evidence, that the explosion of the powder-laden barge in the Regent's Park must have been caused by the ignition, in the cabin of the barge, of an explosive mixture of air and of the vapour of petroleum, derived from the leakage of certain packages of the spirit which were packed along with the powder. The description given by an eye-witness, on board a barge in front of the ill-fated 'Tilbury,' of a bluish flash of flame, emanating from the cabin of the barge within a very brief period of the explosion, corresponds with the result produced when flame is applied to a mixture of hydro-carbon vapour with a large proportion of air. The manner in which the freight of the barge was enclosed by tarpaulins precluded ventilation, and was most favourable to the gradual diffusion of inflammable vapour, from even slight leakages in the barrels,

through the confined air, until an explosive mixture extended to the opening in the bulk-head or partition, which in these barges separates the cabin from the hold.

It is impossible to protect heavy packages from rough usage, in the processes of unloading ships or other vehicles of conveyance; it is therefore most important that means should be adopted of thoroughly closing the vents of receptacles of petroleum spirit, by such means as are capable of sustaining ordinary rough usage without any injury to their efficiency, and that the improvement of the nature and construction of the receptacles themselves should be seriously considered with the view of reducing the liability to accidents resulting from the escape of the spirit or its vapours, and the consequent creation of danger connected with the transport and storage of these valuable illuminating materials.

The fact that combustible, and especially inflammable solid substances, if of sufficiently low specific gravity, and reduced to a sufficiently fine state of division to allow of their becoming and remaining for a time suspended in air, may furnish mixtures with the latter which partake of explosive character, scarcely needs to be pointed out. The ignition of a particle of such a substance, surrounded by atmospheric oxygen, will, under these conditions, at once communicate to others immediately adjacent to it; and if the particles of suspended solid matter be sufficiently numerous and finely divided, the ignition will spread throughout the mixture with a rapidity approaching that of a mixture of inflammable vapour and air, the development of gaseous products and heat being sufficiently rapid and considerable to produce explosive effects, which may even be of violent character, their violence being regulated by the nature and *inflammability* of the solid substance, the proportion and state of division in which it is distributed through the air, the quantity of the mixture, and the extent of its confinement.

Explosions of an accidental nature produced in this way are believed to have occurred in connection with operations in the chemical laboratory; but it was scarcely to be expected that the first clearly authenticated cases of any importance should have arisen out of the apparently harmless operation of grinding corn.

That a mixture of very fine flour and air will ignite with a flash when light is applied to it, and produce in a very mild form the species of explosion observed on applying a light to lycopodium suspended in air, is not very difficult of demonstration; but it is not easy to realize the possibility of the production of violent explosive effects by the ignition of such a mixture even upon a very large scale, though the rapidity of its ignition be accidentally favoured by the warmth of the atmosphere. Cotton mills have been known to be rapidly fired by the ignition of cotton particles suspended in the air; but, compared with flour, cotton is very combustible. Flour when absolutely dry would contain only about half its weight of

carbon, and about 6 per cent. of hydrogen, the remainder consisting of nitrogen and mineral substances; constituents which, by absorbing heat instead of contributing to its development, must tend to reduce the rapid combustibility of the substance. Yet the possibility of very serious calamities arising out of the accidental ignition of a mixture of flour-dust and air has been but too conclusively demonstrated.

On the 9th July, 1872, the inhabitants of Glasgow were startled by an explosion which was heard to a considerable distance, and occurred in some very extensive steam flour-mills, of which the front and back walls were blown out, while the interior was reduced to ruins, and speedily enveloped in flame, destroying the remainder of the extensive buildings. Several persons were killed, and a number of others were severely burned, or injured by the fall of masonry. That the explosion was not occasioned by the steam-boilers employed as motive power in the mill was soon made clear; and by the evidence of persons employed in the mill at the time of the explosion, its origin was conclusively traced to the striking of fire by a pair of mill-stones, through the stopping of the "feed," or supply of grain to them, and the consequent friction of their bare surfaces against each other, the result being the ignition of the mixture of air and fine flour-dust surrounding the mill-stones.

This ignition alone would not suffice to develop any violent explosive effects; such ignitions, though occasionally observed in small mills, being caused either by the striking of fire by the stones, or by the incautious application of a light near the mill-stones, or the meal-spout attached thereto, have not in these instances been attended by any serious results. But in an extensive mill, where many pairs of stones may be at work at one time, each pair has a conduit attached to it, which leads to a common receptacle called an exhaust-box; into this the mixture of air and very fine flour-dust which surrounds the mill-stones is drawn by means of an exhaust-fan, sometimes aided by a system of air-blowers. The fine flour is allowed to deposit partially in this chamber or exhaust-box, and the air then passes into a second chamber, called a stive room, where a further quantity of dust is deposited. It follows that when the mill is at work, these chambers and the channels or spouts connecting them with the atmosphere immediately surrounding each mill-stone, are all filled with an inflammable mixture of the finest flour-dust and air, and that consequently the application of a light to any one of those channels, or the striking of fire by any one of the mill-stones, by igniting some portion of the inflammable mixture, will result in the exceedingly rapid spread of flame throughout the confined spaces which are charged with it, and will thus develop an explosion. The violence of such explosions depends much upon details of construction of the exhaust-boxes and stive rooms, and upon the dimensions of the channels of communication; it must obviously be regulated by the volume of inflammable mixture through which fire rapidly spreads,

and upon the extent of its confinement. In the case of the catastrophe at Glasgow, the production of a blaze at a pair of mill-stones was observed to be followed by a crackling noise as the flame rapidly spread through the conduits leading to the exhaust-box upon an upper floor, and a loud report from that direction was almost immediately heard. Professors Rankine and Macadam, who carefully investigated the cause of this accident, report that other flour-mill explosions which they have inquired into had been observed to be attended by a similar succession of phenomena to those noticed upon this occasion. The bursting open of the exhaust-box by a similar though less violent explosion, attended by injury of workmen, the blowing out of windows and loosening of tiles, appears to have taken place on a previous occasion at these particular mills. In the last accident, however, the more violent explosion appears to have been followed by others, the flame having spread with great rapidity to distant parts of the mills through the many channels of communication in which the air was charged with inflammable dust, resulting from the cleansing and sifting operations carried on in different parts of the building, and rapidly diffused through the air by the shock and blast of the first explosion.

The subject of flour-mill explosions, though it has attracted little if any attention in this country previous to the Tradeston explosion, is discussed in Continental treatises on flour-mills, and the results of Messrs. Rankine and Macadam's inquiries have demonstrated that accidents of this kind are actually of ordinary occurrence in mills, especially since the introduction of the exhaust arrangements. Those gentlemen point out that it appears scarcely possible to guard against such accidents altogether, although the frequency of their occurrence may probably be much reduced by adopting efficient precautions to prevent, as far as possible, a stoppage of the "feed" to the mill-stones or the accidental introduction of nails between them together with the grain, and by prohibiting the employment of naked lights in the vicinity of the mills and the dust passages. In order to reduce as far as possible the damage and risk of sacrifice of life resulting from such explosions, it is important that all receptacles into which the dust-laden air is drawn from the mills, should be fixed outside the buildings, and constructed so as to offer as little resistance as possible to the sudden expansion resulting from the ignition of the inflammable mixture. The conduits leading from the mills to the exhaust-chambers should, moreover, be of small dimensions, and there should be no other communication between the interior of the building and the dust receptacles, which must not be opened while the mill is at work. By adopting precautions of this kind, the mill-owner may succeed, at any rate, in reducing the mischief resulting from an accidental ignition of flour-dust at the mill-stones to such limits that the mill itself and the lives of those engaged in it will not be endangered.

The production of explosions by mixtures of air with marsh-gas, coal-gas, petroleum vapours, or a finely divided inflammable solid, such as flour, has been shown to be due to the application of sufficient heat to some portion of the mixture to cause the atmospheric oxygen to combine with the combustible constituents of the gas, vapour or solid, the results being the development of chemical action, the formation of gaseous products, and their expansion by the heat developed. It need scarcely be said that the same explanation applies to the production of explosions by that class of so-called explosive agents which is prepared by intimately mixing combustible or inflammable solids with a solid oxidizing agent (i. e. an oxygen-compound which readily yields up a part or the whole of that gas under the influence of heat, and with the co-operation of chemical force, to carbon, hydrogen, or other readily oxidizable elements). Distinct from these explosive mixtures as regards their nature, but quite analogous to them in their behaviour and the effects they produce when subjected to heat or other disturbing influences, are explosive *compounds*. The majority of these contain carbon, hydrogen, and oxygen as the most important components; they are more or less susceptible of sudden or extremely rapid transformation into gases or vapours, attended by development of great heat, in consequence either of their resolution into their elementary constituents or, generally, of the rearrangement of these into comparatively simple forms of combination. Some of these explosive compounds are of such unstable character, that they are liable to undergo change from very slight inciting causes, such as the existence in them of minute quantities of foreign substances of active chemical character; or they may even be prone to absolutely spontaneous change. In such substances decomposition may be in the first instance established only to a very minute extent: but this decomposition, by the products to which it gives rise, and by the attendant development of heat, however small, may speedily promote further and more rapid change in the mass of the substance, so that eventually decomposition of violent nature may be established, and the principal portion of the compound may suddenly undergo the same transformation into gases or vapours, attended by the same development of heat, as though any one of the agencies (i. e. fire, friction, or percussion) ordinarily employed to determine the explosion of these bodies had been applied. Cases of so-called spontaneous explosion thus brought about are more familiar to scientific and manufacturing chemists than to the general public; but accidental explosions of very alarming and, in a few instances, of very calamitous character, are on record, which, though not actually of spontaneous nature, in the strict application of the term, have been brought about without any apparent application of external inciting agencies, and have hence, from a practical point of view, not been incorrectly classed as spontaneous explosions.

A few substances, well known to chemists, are so very unstable in character, or are so very difficult to prepare in a condition approach-

ing purity, that they either begin to undergo change as soon as they have been produced, or very shortly afterwards, such change proceeding sometimes gradually and quietly until the substance has been transformed into non-explosive bodies, or occurring, in other instances, with a rapidity speedily resulting in the violent decomposition or explosion of the substance. Injuries more or less severe have been inflicted upon the discoverers or investigators of substances of this kind, or upon those who prepare them and exhibit their properties for instructional purposes; and such accidents occasionally occur, even though all possible or reasonable precautions appear to have been taken to guard against them. It has occasionally also happened that serious accidents have resulted from attempts to apply to practical purposes the explosive power of such substances (as, for example, the chloride of nitrogen and iodide of nitrogen,) by persons imperfectly acquainted with their properties or those of explosive substances generally. The great danger in which want of knowledge may involve experimenters in this direction is too obvious to need being dwelt upon.*

The risk of accident resulting from the liability of explosive compounds to so-called spontaneous decomposition has been on several occasions exemplified in the past history of the two most important of these compounds, guncotton and nitroglycerine. Until within the last few years it was believed that both these substances were in themselves so prone to change, that their preservation for any length of time without undergoing spontaneous decomposition, resulting most probably in explosion, was regarded as, at best, a great uncertainty. They acquired this character for instability partly from the

* The great danger incurred in experimenting with, or attempting the manufacture upon a large scale, of substances of unstable and explosive nature, the properties of which are imperfectly understood, has been exemplified by repeated accidents with a liquid called methylic nitrate, the vapour of which is highly explosive. In 1872 a young English chemist of great promise lost his life by a very violent explosion which occurred in a laboratory in Germany, where he had been engaged in preparing large quantities of this substance with a view to its employment as a substitute for nitroglycerine preparations. No conjecture could be formed of the immediate cause of the explosion. Some time after a German manufacturing chemist of eminence lost the sight of one eye by the violent explosion of a very small quantity of the same substance while he was heating it in a glass tube; and in November last a very violent explosion occurred at the works of a manufactory of dyes at St. Denis, in a building where very considerable quantities of the methylic nitrate were being prepared and purified for colour-making purposes. Two men were killed, and a number seriously injured. In this case the accident was clearly traced to an act of recklessness of one of the workmen. The use of lights was prohibited in the building where the purification of the substance was carried on, in consequence of the inflammable vapour evolved and the danger of explosion from its ignition. But on this occasion, a man not only brought a lamp into the room, but actually lowered it into a large boiler from which the liquid was being decanted with a siphon, his object being to see how much remained. The vapour in the boiler was at once fired, and a violent explosion occurred almost immediately, followed by a second, there being upwards of 1000 lb. of the material in an adjoining store.

imperfect purification of specimens prepared from time to time for scientific or instructional purposes, and partly from repeated attempts to utilize their explosive properties, and therefore to produce them in considerable quantities, while their nature and properties were still very imperfectly understood (this being specially the case with guncotton). The liquid nature and some other peculiar properties of nitroglycerine delayed any important attempts at its application for many years; on the other hand, guncotton presented to the superficial experimenter so many alluring advantages as an explosive agent that its discovery was very soon followed by its manufacture and storage upon a large scale, which speedily resulted in such serious disasters that the material acquired, within a very brief period of its discovery, an unmerited, but for a long time completely damnatory, reputation for utter untrustworthiness. The stability of properly purified guncotton, as well as that of nitroglycerine, has, however, now been for some time past fully established, and no difficulty exists in carrying on with safety their manufacture on such a scale as to satisfy the continually increasing demand for efficient preparations of these violent explosive agents. At the same time, the experience of the last few years has afforded repeated illustrations of the terrible risks and responsibilities incurred by manufacturers of these substances by the slightest departure from conditions essential to perfection and safety of manufacture, or by a relaxation of the strictest supervision in the production, purification, and storage of the materials. The calamitous explosion at Stowmarket in 1871, and many serious explosions at nitroglycerine (or dynamite) factories during the last few years, in different parts of the Continent, have demonstrated the liability of these substances to so-called spontaneous explosion, if the acids employed in their production are allowed to remain in contact with them for protracted periods, even in very small quantities. Any negligence whatever, therefore, in the production and purification of these substances, or the introduction, by accident or otherwise, of acid impurity into the finished materials, must in all probability prove destructive of their stability, and may lead to most serious disasters.

In these respects the utilization of explosive compounds of this class involves special risks not attendant upon the manufacture of gunpowder and modifications of that substance; in others, however, it presents important elements of comparative safety. Thus, with proper precautions, the conversion of glycerine into nitroglycerine may be carried on with safety; the purification of the substance is not attended by any danger, and the manipulations attendant upon its conversion into suitable preparations for use (e. g. dynamite) are also in themselves perfectly safe operations. Again, the manufacture and purification of guncotton, and its conversion into the compressed or granulated substance, are absolutely safe operations, the material being wet throughout the entire course, and therefore quite uninflammable, until, when completed, it is dried by long exposure to air, or by artificial heat. On the other hand, gunpowder, and all preparations

of similar nature, are explosive from the very commencement of their manufacture; the roughly mixed ingredients already furnish a material which deflagrates violently when a spark reaches it, and the subsequent operations of intimate mixture or incorporation, compression, granulation, &c., which are necessarily carried out with the nearly dry material, are all of a highly dangerous character, demanding for their safe performance the strictest attention to precautions which have been dictated by practical experience and knowledge of the sources of danger to be guarded against.

Accidents at gunpowder factories are very frequent, and though they may not often involve considerable loss of life or destruction of property, the fact that their occurrence must in most instances be caused by partial, occasional, or complete and persistent neglect of precautions absolutely essential to the safety of the people employed in the works, or to a reduction of the risks of accident to the minimum, points to the necessity for improved legislation connected with manufactories of gunpowder and other explosive preparations, whereby the proper attention to regulations and precautions for safety may be rendered compulsory, and seconded by an efficient system of inspection. The absolute exclusion of lucifer matches from such works; the adoption of every possible precaution for excluding grit from all buildings in which the explosive substance is submitted to any kind of operation, by proper construction and closing of the buildings; the employment of special shoes and other external clothing for use in the buildings only; the total exclusion of iron, in any form, from the works; the proper separation from each other of the buildings in which the several operations are carried on, and their construction with a view to divert the force of a possible explosion into comparatively harmless directions; the reduction within particular limits of the quantity of explosive allowed to remain in any one building; the provision of efficient lightning conductors; —such are some of the principal precautionary measures which go far to reduce the possibility of accident in works of this kind (or the mischief accruing from such accidents when they do arise), and the adoption of which does not present any serious difficulty. And lastly, though properly first in importance, the manufacturers of gunpowder and other explosive agents should not only themselves possess some scientific as well as a practical knowledge of the nature and properties of the substances in the manufacture of which the lives of their workmen are at stake, but they also should ascertain and insist that at any rate the persons who act as managers and foremen in their factories should not be deficient in the elementary knowledge indispensable to a proper performance of their duties.

Major Majendie, the Government Inspector of Gunpowder Works, &c., has reported officially that he was "much struck, in the course of his inspections, with the extraordinary ignorance of even the most elementary dangers, and the precautions necessary for avoiding them, which prevails among persons in charge of important factories and

magazines," and that there can be no doubt that to the ignorance and incompetence of such persons a large number of the accidents which occur are indirectly due. Surely it is in the interest of employers to adopt measures for securing that the management of their works is in the hands of competent men, experienced in the details of the manufacture, and possessing adequate general education and technical knowledge to fit them for posts of such responsibility. The obvious mode of securing this is to render it compulsory for such men to obtain certificates of competency before they can hold responsible appointments in manufactories of gunpowder and other explosive agents.

The manufacture of fireworks, ammunition, percussion caps, and other articles involving the application of explosive agents is, it need scarcely be stated, attended by liability to accidents similar to, and sometimes even greater than that existing in manufactories of gunpowder and materials of similar nature, and necessitates the adoption of precautions of the same nature as apply to these works.

Such necessity has, however, been very much disregarded in the arrangement and management of factories of this kind; and many very sad casualties have resulted either from utterly inadequate arrangements for localizing explosions and reducing them to small proportions, by regulating the quantities of material dealt with in one building, and sufficiently separating and subdividing the manufacturing operations, or from neglect of simple regulations for excluding sources of fire from the buildings. Thus, in inquiries following on explosions at ammunition or firework factories, it has been found in some instances a common practice for the men to wear their ordinary clothing when in the factory, and to carry lucifer matches about them. Again, at an ammunition factory, at Birmingham, where an explosion, not long since, resulted in the deaths of fifty-three women, it was brought to light during the inquest that there were open stoves, not even provided with fenders, in the middle of the sheds in which the powder-work was carried on; at these stoves the women used to cook their dinners, and they were also in the habit of shaking the grains of powder off their aprons into the stoves.

Other and special sources of danger exist sometimes in connection with this branch of the industry of explosive substances. Great stress has been laid upon the dangers which may arise in the manufacture of guncotton, and nitroglycerine preparations, from the liability of those substances to spontaneous change in consequence of the readiness with which their stability may be affected by imperfections in their manufacture. But there are several important instances of accidental explosions on record, which have occurred in the manufacture of pyrotechnic compositions and other articles of explosive nature in consequence of a liability to the establishment of chemical activity between the ingredients of such preparations by even very slight inciting causes. Thus, certain descriptions of coloured fires are readily susceptible of so-called spontaneous ignition

or explosion, either simply from the unstable nature of one or other of their ingredients, or from so apparently trifling a cause as the absorption of a small amount of moisture, or the employment of a small quantity of an easily oxidizable oil or fat in connection with their application to pyrotechnic purposes. Two remarkable instances of unforeseen danger in dealing with materials of this kind, even when their stability, under normal conditions, is beyond question, have come under the notice of the speaker. In one case, an explosive mixture, prepared for use in percussion caps, was preserved in a moist condition with the view of storing it in a non-explosive form, but this very precaution gave rise to a serious explosion; chemical activity became established between the components of the mixture, through the agency of the water, attended by development of heat and the speedy production of violent chemical change, a result which would certainly not have occurred had the mixture been kept dry. In the other instance, some signal-lights, composed of a mixture of ingredients which long experience had shown to be in every way as permanent as those of gunpowder, were found to be undergoing decomposition to an extent which, had it not been noticed in time, must have resulted in serious consequences. The cause of this change baffled inquiry for some time, but ultimately it was clearly established that a very minute quantity of free acid contained in the paper linings of the cases in which the composition was confined (and derived from the antichlore used in the manufacture of the paper) had set up an action between the saltpetre and the orpiment composing this material, which spread gradually but with increasing rapidity through the highly compressed mass, being of course accelerated by the heat developed. Such occurrences afford instructive illustrations of the dangers which surround the manufacture and application of explosive substances, and of the necessity for combining continued study with untiring vigilance in dealing with these branches of manufacture.

Many of the most distressing accidents connected with firework-manufacture have occurred in dwelling houses of the lower class, situated in crowded districts, in which not unfrequently several families reside, and where people, generally in very poor circumstances, have carried on the manufacture of squibs, crackers, or pin-wheels, which they have either retailed, or generally supplied to more extensive firework makers or sellers. This production of fireworks has almost always been carried on illegally, i. e. without the maker having obtained the licence necessary, under an existing Act of Parliament, to enable him to manufacture fireworks; hence work of this kind has mostly been conducted as secretly as possible, other dwellers in the same house being often unaware of the dangerous operations carried on in the house itself, or sometimes in small sheds or out-houses. It can only be matter of surprise that firework accidents have not been more numerous, when it is remembered that the processes of mixing the firework compositions, ramming them into cases, &c., have frequently been carried on by these illegal makers in the

common dwelling room, the several members of the family old and young taking part in the work, while cooking and even smoking may have been going on in the same room, and the work continued by candlelight in busy seasons, the powder or finished fireworks being placed in a cupboard in the room, or perhaps even in places affording less protection. This illegal firework making has been greatly checked of late by vigilance on behalf of the Government officials, and it is to be hoped that it will disappear almost entirely when new regulations are introduced which will facilitate the profitable employment of these small firework makers upon sufficiently extensive and properly organized premises of large manufactories, thus reducing the temptations which have hitherto existed for large vendors to purchase cheap fireworks of the poor people who carry on the manufacture illegally, and for the latter to convert their dwellings into sources of danger to themselves and their neighbours.

The fearful recklessness with which gunpowder and other explosive agents are handled and used by uneducated persons, such as these small firework makers, of which there are large numbers in the mining and manufacturing districts, and by the most extensive consumers of powder, namely, the miners and quarrymen, can scarcely be realized by anyone who has not had opportunity to acquire by personal observation a knowledge of the state of things. A miner may be seen with his naked lamp or tallow candle fixed in his hat or plastered against the rock close to the blast-hole he is about to load, pouring the powder into his rough measure, or his cartridge case, from the flask produced from a pocket which is often also the receptacle of lucifer matches, and at times of a half-finished pipe of tobacco (if he has not the pipe actually alight in his mouth). Having inserted the charge into the hole, he will proceed with the operation of *tamping*, which consists in ramming débris of the rock into the hole as tightly as possible by means of a heavy iron tool and a hammer. Grains of powder lying upon the sides of the hole, and sometimes forming a train to the charge at the bottom, are thus frequently submitted to most violent friction, and it is wonderful that accidents in this process of loading are not more frequent; but when, in spite of oft-repeated cautioning, the miner proceeds to submit to the same, and sometimes even to more violent, treatment a cartridge of guncotton, dynamite, or other explosive agent ignited more readily than gunpowder by friction (and which is tightly confined in the blast-hole by the act of ramming with a heavy tool), it is not a matter of surprise that fatal accidents should occur during the employment of these substances by the miner, although he is exposed to less danger with them when carrying them about his person or handling them for actual use, because they are not violently explosive in small quantities when unconfined.

It is, however, more particularly from the fact that there are no regulations forbidding or restricting the making up, in dwelling

houses, of blasting cartridges, mining fuzes and the so-called powder-straws used in blasting, that the chief liability to accidental explosions in mining districts arises. Miners are constantly in the habit of keeping considerable quantities of powder in their dwelling rooms, and making up their cartridges or fuzes (straws) at night. In a recent official report the Head Constable of Middlesborough stated, "In one case, at Eston, the roof of a house was blown off, and on inquiries being made respecting it the man . . . . stated that he was tallowing the end of the straw, when he put it too near the candle flame, which ignited the straw; he threw the straw away and it fell into the barrel of powder, which exploded." The Head Constable of Richmond in Yorkshire reported as follows: "I have seen miners with a quarter cask (25 lb.) making their charges by the fire frequently, and they generally keep it under the bed or in the pantry, where their children have access to it." At Wigan a collier was filling cartridges from a can of powder, when a spark from the candle fell into the can and produced a serious explosion. In another instance a boy was left alone in a house where an open barrel containing 7 lb. of powder, with a piece of wood simply placed over the head, was in the bedroom. A box of matches was known to be in the room, and it is supposed that the boy, who died from injuries received, exploded the powder by means of them.

Numerous illustrations such as these could be quoted of the fearfully careless manner in which powder is very generally dealt with in manufacturing districts. It naturally follows that other explosive agents, such as dynamite and guncotton, should be treated with similar and perhaps even greater recklessness. The apparently less dangerous nature of such materials when unconfined tends to render the miner even more regardless of precautions, and hence it is unquestionably wrong to foster the notion of the safety of these materials in the hands of the miner, especially as it frequently occurs that the men who use these materials are unable to read the printed instructions which are supplied by the manufacturers with the cartridges for the purpose of guarding against accident. Thus several frightful accidents have occurred through direct exposure to the fire of frozen cartridges of dynamite for the purpose of thawing them,* and the apparently harmless nature of dynamite and compressed guncotton has on more than one occasion caused the miner, when a charge has become jammed in a blast-hole, to endeavour to drive it home with his rammer, with all the force at his command, with what result need

* The necessity for thawing dynamite cartridges before use in cold weather, and the disregard of instructions furnished by the makers for doing this with safety, constitute one of the chief causes of accidents with this material. Fatal explosions have resulted from the placing of cartridges in front of a fierce fire or upon a stove. Quite recently a pit sinker, at Mountain Ash, placed some dynamite in the oven of the fireplace in his house and sat down to breakfast. Before the meal was ended the dynamite exploded, killing the man and injuring two others.

scarcely be stated.* The wholesome effect of stringent regulations which keep constantly before the minds of the ordinary operative the dangerous nature of gunpowder and all operations connected with it and with other explosives, is well exemplified by the care and caution which generally become developed as characteristics in the men employed in Government factories of this class; and although there is but little hope of the possibility of enforcing even the mildest precautionary measures with the miners themselves, it can hardly be doubted that their minds must become to some extent influenced by example, and that, by constantly witnessing the strict enforcement of precautions at the stores to which they resort to obtain their supplies, they must in time become impressed with the necessity for the exercise of some amount of care in handling explosive substances.

It does not admit of dispute, however, that the recklessness of the miner has actually been fostered hitherto by the utter disregard of all ordinary precautions which they must but too frequently witness at the stores where the powder is sold or issued to them. The practices of small dealers in gunpowder present illustrations of ignorance and recklessness if anything even more appalling than those which the habits of the miners furnish. The manner in which powder is often dealt with by those in charge of the stores or magazines in quarries or mines, and who have to issue supplies to the men, may be illustrated by one or two examples from a report to the Home Office by Major Majendie. At a quarry in Scotland he was conducted by the man in charge to a magazine containing about 6 cwt. of powder. For this purpose the man lit a naked candle; as they entered the door it was blown out by the draught, but the man produced some matches from his pocket and rekindled it. When asked how he issued the powder to the men, he held the candle with his left hand, and ladled the powder out with the other hand. The practice of smashing in the head of a powder barrel with an iron crow-bar is stated to be a very common one, or else a large stone is used, or a hole is bored into the head with a steel bit; and as an extreme instance of recklessness the case of a man is quoted who was in the habit of boring into the barrels with a red-hot poker; on one occasion, the lid of the barrel being thinner than usual, the heated iron was thrust into the contents of the barrel, and the man fell a victim to his very original mode of dealing with packages of gunpowder.

In some mining districts it has been customary to pay no regard whatever to the suitability, in point of safety, of the localities selected for the storage of powder. It has not unfrequently been kept in large quantities (e.g. 500 lb.) in ordinary buildings, quite close to dwelling houses. An instance is quoted in an official report by a

* A fatal accident occurred quite recently at Ebbw Vale in consequence of a man using great force in ramming a dynamite charge into a blast-hole with a wooden rammer. The printed instructions distinctly laid down that the cartridges were never to be rammed. It came out at the inquest that the partner of the man killed could not read.

chief constable, of about 3 cwt. of powder being kept in a colliery lodge constantly used by workmen, and in which a fire was regularly kept. Even where magazines have been provided, in connection with extensive mines and quarries, many instances are on record of gross ignorance or carelessness in regard to the precautions essential to the safe handling of gunpowder. The men who go to the magazines for supplies of powder, and even the man who is in charge, are allowed to enter the building in their iron-shod dirt-covered boots, often coming to the store smoking, the pipe being merely put into the waistcoat pocket when they get close to the building; the barrels containing loose powder are often left unheaded, and powder grains lie upon the floor; the door of the magazine in some instances opens inwards, scraping the floor as it is pushed open. A magazine in which this utter want of precautions was observed in the most extreme degree contained several tons of gunpowder. In illustration of the way in which explosions occur at such stores, it may be mentioned that some children saw some loose powder outside a store (in Cornwall), and set fire to it; the contents of the building were thus exploded, there being a train of powder grains leading under the door to the stock of powder in the building.

The strenuous exertions of the Government inspectors during the last few years have already resulted in a considerable amelioration of this lamentable condition of things, although the existing state of the law affords them little power to enforce simple regulations which are vital to the safety of the people employed, and often of the neighbourhood, but scant regard being but too frequently paid to the position of even extensive stores or magazines with reference to contiguous habitations.

The fearful explosion which occurred at a gunpowder merchant's magazines at Erith, containing 51 tons of powder, in October, 1864, and the explosion at Liverpool, in the same year, of the ship 'Lottie Sleigh,' laden with 11½ tons of powder (through the accidental spilling and ignition of some paraffin oil), directed public attention at that time to the existing laws relating to explosives just as forcibly as did the recent explosion in London, and their very defective condition was then, as now, apparent. No steps have been taken since that time, in the way of legislation, to afford the public greater protection from dangers arising out of the storage and transport of gunpowder, or to bring the doings of powder makers and consumers more under legal control, although the Government did in 1865 contemplate for a time the enactment of new laws relating to explosives.

Very considerable alarm was felt then, as lately again, at the possibility of most calamitous disasters arising out of the collection of very large stores of gunpowder, by powder merchants as well as by the Government, in particular localities, some of them in close proximity to populous districts. In some instances representations to the Home Office, which were followed by efficient inspection, made at the instance of Government by Colonel Boxer, led to the closing of extensive

merchants' magazines existing in objectionable positions, or to a considerable reduction in the amount of powder stored in them; but it does not appear that any substantial improvement occurred in the extent to which precautions, vital to the safety of the magazines, were observed or attempted to be carried out by persons in charge of them.

The subdivision of the reserves of gunpowder, which it is the duty of the Government to maintain to as great an extent as is compatible with efficient arrangements of inspection, and with the exigencies of the service in time of war, is unquestionably most advisable. It is admitted to be desirable that the magnitude of depôts of powder at some of the principal establishments should be reduced in extent, and in some instances extensive depôts which existed in close proximity to towns have been removed or reduced to insignificant proportions. It must be borne in mind, however, that the possibility of the explosion of magazines, where powder is simply stored as a reserve, emanates almost exclusively from causes external to the depôts themselves; and that as long as these are situated at such distances from habitations as will secure them against fire reaching any part, the precautions adopted by Government to guard against accidents from electric discharges, and against the possibility of any danger arising within the establishments themselves, render such depôts quite safe, provided operations connected with gunpowder (such as the making up or breaking up of cartridges) are not carried on at or in close proximity to such magazines. It is only in conducting manipulations with gunpowder that danger may arise (from any causes excepting fire or electric discharges); and therefore any operations with powder, such as the making up of cartridges, or any transactions involving the frequent issue and receipt of powder, or the opening or repacking of powder packages, should be imperatively conducted in establishments distinct from those simply devoted to the preservation of reserve supplies.

The recent powder explosion revived the discussion which arose some years ago as to the probable advantages to be derived, in point of safety, from a dilution of gunpowder, for purposes of storage and transport, with some incombustible, non-conducting material, which, by isolating the grains from each other, would prevent the transmission of fire from one to those surrounding it. Although quantities of gunpowder may thus be rendered practically non-explosive, there can be no doubt that the possibilities of accident must be considerably increased by the additional manipulations to which the powder must be subjected in the application of such a safeguard. If, as in the case of compressed guncotton, gunpowder could be preserved in a sufficiently wet condition to be perfectly uninflammable, the drying, as a final manufacturing operation, being simply deferred until the material was required for use, the protection afforded by a diluent could be secured without the introduction of any extra operations involving, by their adoption, the usual risks invariably attendant upon manipula-

tions with an explosive. The impracticability of such a course need however be hardly pointed out; in this particular respect, therefore, guncotton possesses a decided superiority over gunpowder, especially as for almost every purpose to which it can be advantageously applied it may be employed in the wet perfectly uninflammable condition as effectively as if perfectly dry, by the adoption of very simple modes of exploding it.* Supplies of guncotton in the condition in which it can actually be used without further preparation may therefore be stored without the precautionary measures indispensable in the case of gunpowder.

Experiments on a considerable scale made by the late Government Committee on guncotton, &c., demonstrated conclusively that when stored in *small* quantities (two or three hundred pounds) dynamite and dry guncotton are unquestionably much less dangerous in their character than gunpowder. Such quantities, even if confined in strong boxes and contained in buildings filled with inflammable matter, may burn away entirely, when these are set on fire, without developing explosion; but the burning of 5 to 6 cwt. of these materials under similar conditions may terminate in an explosion, unless they be less strongly confined; and there is no doubt that very considerably larger quantities, if set fire to, will not even need other confinement, to develop an explosion, than that to which the interior of the mass of explosive is subjected by the external portions, and by the pressure of gas developed by the fierce burning of the substance. The degree of comparative safety with which explosive materials of this description may be stored is therefore regulated by the quantity and the extent of confinement, and hence great caution must be exercised in relaxing in their favour the precautions and restrictions applied to gunpowder. Indeed, the prudence of relaxing them at all is questionable, as the result may be the fostering a sense of security in those who have to use these substances, which, by encouraging negligence and forgetfulness as to the properties of the materials dealt with, may be productive of disastrous results.

A regulation of the quantity of an explosive stored in one place, and of the mode of storage, by the nature of the particular material, and the circumstances which may tend to develop its violent explosion, would involve a combination of complex rules with an impractically comprehensive system of supervision; and it is therefore obviously not only wise but also necessary to deal with the storage, upon an extensive scale, of all explosive substances upon the broad general basis of their being susceptible of violent explosion from accidental causes; any relaxation in favour of the comparatively safe materials being suffered only to apply to small quantities.

* In experiments recently conducted by the late Guncotton Committee at Eastbourne, two separate tons of compressed guncotton, in the wet condition in which it is now stored by Government, were exposed to fierce fires in strong magazines, the guncotton being confined in stout boxes and in wooden tanks. No explosion occurred; the guncotton was slowly converted into gases and vapour.

The safe *transport* of gunpowder and other explosive agents demands the application not only of many of the precautionary measures which should be observed in their manufacture and storage, but also of certain others of special character, to meet the liability to casualties arising out of the ordinary accidents of locomotion, and out of the more or less unavoidable exposure of the explosive agents during transport to treatment and conditions involving risk of accident. Thus the submission of packages of gunpowder and many other explosive substances to the continued concussion unavoidable in transit by road or rail necessitates the employment of strong and thoroughly sound or tight receptacles, so as to prevent the escape of fine particles or dust from the packages into the conveyances, and the possibilities of accident resulting therefrom. Again, the transmission of both large and small quantities of explosives by land or water must be governed by well-defined rules regarding the extent and manner which the transport of such materials should be kept distinct from that of other goods, the nature and construction of the conveyances specially devoted to, or occasionally selected for, their transport, and the conditions generally under which such transport shall be accomplished.

The utter inadequacy of the existing regulations as to the conveyance of powder, &c., by land or water, and the flagrant manner in which even these defective regulations are but too frequently disregarded, are matters to which public attention has been much directed since the explosion in October last, and which are but in harmony with the negligence and ignorance displayed to so alarming an extent in connection with the handling and storage of gunpowder. Thus, the packages (barrels, &c.) in which powder is transmitted to distant places are often so imperfectly constructed that the grains escape into the cart, or the hold of a vessel in which the powder is stowed, where they may become mixed up with grit and be eventually trampled upon. As regards the vehicles in which the powder is transported, some regulations exist with respect to the employment of covered or uncovered carts with reference to quantities of powder exceeding considerable limits; but there is no law requiring carts or barges to be specially constructed or employed so as to exclude sources of danger (such as grit, employment of iron fastenings, &c.). In the mining districts and even in towns powder is constantly conveyed in dangerous quantities in ordinary carts, which may have been used for carrying stones, coal, or road rubbish. It may be and frequently is conveyed in carts with other goods, such even as lucifer matches and petroleum; there is no regulation to prevent the person in charge from smoking while in his cart, or stopping at a public house, leaving the powder standing at the door, and Major Majendie reports that such occurrences are frequent.

Public conveyances often carry packages of powder, without any precautions, other than perhaps a caution to a passenger who may unwittingly be exposing himself and companions to immediate danger. Thus there is a case officially recorded of a man who, on getting on to an

omnibus at Wigan, was requested to put out his pipe, as the passenger next to him had 100 lb. of powder in a barrel beside him. The conveyance of large quantities of gunpowder in a number of wagons passing close together through towns has been no uncommon occurrence; thus Major Majendie discovered that it was a practice in Edinburgh to convey as much as twenty tons and upwards of powder at one time through the streets, the public having thereby incurred the greatest possible risks, through smoking going on while the carts have been standing in crowded places. A similarly extensive conveyance of powder through the most populous districts of London for transfer to ships at wharves has often taken place; and as one of many instances mentioned by the police authorities may be quoted that of a train of fifteen vehicles loaded with about twenty tons of gunpowder passing from Camden Town to Blackwall Stairs (a densely populated place) to be shipped off, the whole of the loaded vans being detained in the street for some time for the arrival of the barge to which the consignment was to be transferred. Railway companies as a rule adopt comparatively efficient precautions with respect to the transport of powder and explosives. The former is conveyed, when in sufficient quantities, in vans specially constructed, and more or less well adapted to the purpose, or, when the quantities are comparatively small, in barrels separately packed in specially constructed metal cylinders. With regard to the conveyance of other explosives and of small packages of fireworks, the regulations and charges adopted are in most instances so restrictive, that they lead to much surreptitious carriage of such goods, whereby passenger and goods trains are often exposed to great risk.

The carriage of powder and other explosives by water should be the safest mode of conveyance, if proper regulations could be enforced; but here again the Regent's Park catastrophe has afforded a terrible example of the danger to which the public has been continually exposed, by the profound oblivion which appears to have reigned in the minds of those engaged in the transport of powder by water-traffic as to the explosive nature of this material. The arrangements made by Government for the transfer of gunpowder by barges from the factory to the depôts, illustrate the nature of the precautions which are regarded as indispensably necessary by those who have well considered the subject. No iron whatever is allowed to enter into the construction of the barges; the men engaged in stowing the powder wear special shoes and clothing; every particle of grit or dust is most scrupulously removed before the powder packages are introduced, and these are very carefully and securely covered in. The bargemen are strictly prohibited from smoking and carrying lucifer matches either about them or in any part of the vessel; no fire is permitted on board during the loading, carriage, and unloading of the powder, and the strictest regulations exist with regard to the manner in which the journeys are to be performed. The barges are, moreover, provided with valve-arrangements by means of which they may be sunk in a

very short space of time, should danger of fire arise from neighbouring barges or other sources.

In other vessels used occasionally for the transport of powder by Government the foregoing precautions are carried out as far as possible; the vessels are not specially constructed, but, in order to exclude all iron fastenings and accidental grit from contact with the powder barrels, hides and thick woollen covers are spread over the bottom and sides of the vessel. Although the barges of canal owners and others are subjected to this practice when carrying powder for Government, it has not been so with regard to the freights of powder carried for merchants; and regulations respecting abstinence from smoking, or exclusion of fires or matches, have been avowedly of the most lax description, or have even become a dead letter, although the existing law is thus set at defiance. The practice of carrying lucifer matches about the person, and of smoking, has unquestionably been among the most prolific sources of accidents connected with gunpowder, and it need scarcely be stated that they are almost the most important dangers to be guarded against in the transport of powder in barges. During the inquest which followed the great explosion at Erith in 1864, it transpired that lucifer matches were allowed, as a rule, on board the barges and vessels carrying merchants' gunpowder; and while one powder barge was unloading, another empty one by its side was seen to have a fire on board. The falling of a match from a man's pocket while he was engaged, in a stooping attitude, in moving the powder packages from the barge to the magazine was considered by Colonel Boxer, after careful investigation, to have been the most probable cause of that explosion.

Another source of danger, which, viewed in conjunction with the non-exclusion of sources of fire, is of a most alarming nature (and which has evidently been of common occurrence), is the carriage of gunpowder in barges as part of a miscellaneous cargo. There are obviously many goods which may be transported together with powder without danger to the latter, although the special care which gunpowder should always receive renders its isolation from other goods desirable under all circumstances. Recent experience has, however, demonstrated that it has not been the custom to exercise any discrimination in the stowage of packages of gunpowder with other goods, when the former was insufficient in quantity to constitute a barge load. It is scarcely to be realized that the indifference with which gunpowder has been treated by those who undertake its transport by water could have attained such an extreme that powder packages could be stored in the hold of a barge side by side with casks of petroleum spirit, by persons whose experience must have made them cognizant of the liability to leakage of petroleum from such casks. Such leakage (occasioned perhaps by rough handling in placing it on board) must inevitably furnish in course of time an explosive atmosphere by the diffusion of inflammable vapour through the air confined in the barge-hold (which is closely covered in); the

extension of this explosive mixture to the small opening which these barges contain in the bulkhead separating the hold from the small cabin, or its penetration through crevices in the bulkhead, is but an affair of time; and then, whichever of the several sources of fire provided on board the barge, i. e. the stove, lamp, or lucifer matches, happens to come within reach of the quickmatch which the explosive atmosphere constitutes, completes the arrangement for inflaming any small quantity of petroleum which may have leaked out on, or in close proximity to, a powder barrel. But for the fact that a concurrence of several conditions is essential to the communication of fire to gunpowder, through the agency of a leakage from a petroleum cask in a confined space, it can scarcely be doubted that the rude awakening which the public recently received, to the danger they were frequently exposed to in the vicinity of canals where powder traffic goes on, must have occurred long since. The simple flash produced by the ignition of a mixture of hydro-carbon vapour and air would probably not suffice to ignite powder grains exposed to it; but any small quantity of the liquid itself which, leaking from a cask, has furnished the vapour, may be in close proximity to a few grains of loose powder, or upon a powder barrel which is not securely closed, or some other simple conditions resulting in the conveyance of the fire to the powder may be fulfilled, and then explosion must ensue.

The imperative necessity for better legislation in reference to the transport of powder has been so convincingly demonstrated by the Regent's Park disaster, that the long-contemplated revision of the law relating to explosive agents would, there is little doubt, have been hastened thereby had the serious attention of the Government not already been devoted to this subject. During the first two years which succeeded the appointment of Government Inspectors of Gunpowder Factories and Magazines, the unceasing labours of Major Majendie resulted in so convincing a demonstration of the utter inadequacy of the existing laws relating to the manufacture, storage, transport, and use of gunpowder, and other explosive agents, to afford protection to the public and to those dealing with these substances, that the intention (already entertained by the Government in 1865) of framing a bill to amend the Gunpowder Act was actively pursued by the late Ministry in 1873. Although the submission to Parliament of new measures was delayed by the change of Government, this delay has been productive of benefit, inasmuch as the present Government has secured most important aid in the preparation of the comprehensive bill which has recently been submitted to Parliament, from the labours of a Select Committee, appointed last session, to inquire into the working of the existing laws, and the directions which fresh legislation should take.

The rapid development which has taken place in the manufacture and use of other valuable explosive agents has considerably increased the necessity for comprehensive measures regulating these important branches of industry. When the introduction of nitroglycerine into

this country, a few years ago, was speedily followed by numerous deplorable disasters, the protection of the public demanded the imposition for a time of severe restrictions in dealing with an explosive agent of most violent character, the nature of which was still very imperfectly understood. A measure was therefore made law in 1869, whereby the employment of nitroglycerine itself and of its preparations was placed entirely under the control of the Government. Although this arrangement involved great labour on the part of the Government officials, and placed what now certainly appear to be unduly severe restrictions upon the manufacture and employment of dynamite, its necessity and beneficial operation as a temporary measure have been fully admitted by those chiefly interested in the progress of nitroglycerine preparations; and there is no question that it importantly promoted the *wholesome* development of the application of dynamite in Great Britain, where it has during the last three years secured a firm footing as a material indispensable to mining industry. The existing laws relating to nitroglycerine preparations can now be modified with great advantage, and no important difficulty should be experienced in including in a general Act the measures necessary for developing and regulating, with proper security to the public, the production of this and other valuable substitutes for gunpowder, in such a manner as not to hamper the powder industry with undue restrictions. Other long-established branches of manufacture connected with explosive materials, which are quite as dangerous as many of new creation, but have enjoyed comparative immunity from restrictions, will also be brought under the operation of that systematic supervision which the security of the public demands.

It is obvious that to attempt to deal in detail in one, or more than one Act of Parliament with the various modifications of regulations specially applying to gunpowder, which the peculiarities of other explosive agents, or of branches of manufacture involving risk of explosions, necessitate, would be to overburden the law with an unwieldy mass of measures which, however circumstantial in their nature, would certainly fail to embrace all conditions and contingencies likely to arise. Hence the wisdom (which has been so clearly demonstrated by the Nitroglycerine Act) of entrusting the Government with discretionary powers, under the operation of a comparatively simple but sufficiently comprehensive Act of Parliament, can scarcely admit of question.

The beneficial results attainable by a systematic and thoroughly authoritative supervision, by Government inspectors, of factories and stores of explosive agents, if conducted with intelligence and discretion, have been most convincingly demonstrated by the great good which it is admitted on all sides that the inspectors have already succeeded in accomplishing, even with the very insufficient powers which the present state of the law affords them. The favourite argument of some, that Government inspection must operate mischievously, by diminishing private responsibility, has certainly received no support

from the results of inspection, so far as the experiment has been tried. It will scarcely be asserted that a manufacturer or store-holder who may have willingly adopted, as suggestions which the inspector has no power to enforce, measures conducive to the safety of life and property, would be careless in the application of those measures because their adoption was no longer optional, or because the responsibility for their due observance was to some extent shared by the inspector. This very system of inspection cannot fail to benefit those interested in different branches of the industry of explosives by reducing the necessity for hard and fast rules with respect to the arrangement and conduct of works, which might in many instances entail hardship or inconvenience without any real necessity, and by strengthening the hands of factory owners, and thus rendering comparatively easy the proper observance and enforcement of regulations for the safety of the men and the works. It is, however, especially in connection with the storage, transport, and employment of gunpowder and other explosives in mining districts that efficient inspection, supported by the reasonable power which a well-considered Act of Parliament cannot fail to afford, may be confidently expected to produce important beneficial results, not the least of which will probably be the wholesome influence exercised indirectly, by the force of example, upon the miner or pitman, whose ignorance has fostered the indifference with which long habit has led him to regard the possibility of danger.

But although improved legislation, and the beneficial regulations thus supplied, may be confidently hoped to effect an important reduction in the number and magnitude of the disasters now recorded as accidental explosions, it would obviously be worse than shortsighted to encourage a reliance upon legislation alone as a safeguard against the evils which lead to casualties of this kind. Punishments inflicted for transgression of the law may engender caution, but the disasters which arise from ignorance are not likely to be importantly reduced in number by legislative enactments alone.

It is to the general promotion of education among the people, and to the spread of scientific and technical knowledge, if even of the most elementary kind, among employers and employed, that we must look for a substantial diminution of these casualties which the uneducated mind is but too prone to attribute to accident, and the prevention of which rests, at any rate to a large extent, with those who are at present tacitly content to regard them as inevitable.

[F. A. A.]