ON SAFETY LAMPS. BY ARNOLD LUPTON, ESQ., C.E., F.G.S.,
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An unusual amount of attention has been given to safety lamps during the last two years, not only by mining engineers, lamp makers, and other inventors, but by the general public; and, as a consequence of public interest, by the Government through the Inspectors of Mines, and the Accidents Commission; it occurred to me that some brief summary of the results of the experience gained in reference to safety lamps by general usage, by mining institutes, by Royal Commissions, and by individual investigations might not be uninteresting and might possibly afford some instruction. Few things are more striking in engineering history than the occurrence of great inventions just at the moment when the progress in other departments of the arts and manufactures makes such an invention of prime importance, and then the invention, once made, it seems to be complete, and as if no further inventions could supersede it. This is the case with regard to the safety lamp. It was just when the war with France was ended, and we directed the whole of our national energies to the pursuits of peace, when the improvements in the steam engine, and the development of the factory system and the resulting increase of trade and population called for a large production of coal for iron-making, manufacturing, and domestic purposes, and this large production of coal could only be obtained at a terrible risk and great sacrifice of human life; then it was that the safety lamp was invented and first practically used, just 70 years ago, in 1816. The lamp invented by Sir Humphrey Davy remains to-day in large and general use; thousands of clever men have spent time and money since then in the endeavour to invent a novel safety lamp, but with two exceptions, to which I shall afterwards refer, not one has succeeded; and of these two exceptions, one is only fit for occasional use, and the other has not yet received a practical trial. Many improvements have been made, but these have been in matters of detail, and there is not one single lamp in practical use which is not

Fig. 1. Davy Lamp, $\frac{1}{4}$.

Fig. 2. Clanny Lamp, $\frac{1}{4}$.

Fig. 3. Stephenson Lamp, $\frac{1}{4}$.

Fig. 4. Mueseler Lamp, $\frac{1}{4}$.

in effect a Davy lamp, though it may be with improvements added to it.

I do not wish it to be supposed that I ignore the invention of George Stephenson, who invented a safety lamp at the same time that Davy invented his. Stephenson's invention had merit, but the merit was not equal to Davy's, because whilst the Davy lamp is and has been generally used, and is by some, even at the present day, considered to be unsurpassed for general utility, the Stephenson invention has never been practically used, except when put inside a Davy lamp. I will now briefly describe the Davy lamp, as a foundation for the description I propose to give of the various modifications and improvements, to which the time at my disposal will permit me to refer:—The Davy (see fig. 1) is an oil lamp, of which the flame is covered with a wire gauze cylinder; under ordinary conditions flame will not pass through this gauze, it is made of woven wires, the wires about 1-50th of an inch in diameter, and 28 of these wires are laid paralld in an inch of warp, and the same number in the weft. This gauze constitutes a metallic case with perforations, and the case might be made of plate iron perforated with holes, this would make a lamp as safe as wire gauze when in good order, but it would be more easily broken; it would be more costly, and give less light. When flame is brought into contact with the gauze the gas passes through the apertures, but is cooled by the contact with the wires below the point of ignition, so that the flame does not pass; hence a flame inside the lamp does not pass through and ignite gas on the outside; and even when the gauze is very hot the same effect is produced, because the heat of a flame is so intense that very hot wire is cool by comparison. A lamp covered with this wire gauze may be safely carried through a mine filled with an explosive mixture, and may be used to detect the presence of inflammable gas, without danger to the fire-trier. When put into a place containing two per cent. of gas, if the flame is drawn down, a blue cap may be seen over the lamp flame, and the more the gas the bigger the blue cap; but if there is eight per cent. of gas it will explode inside the lamp, but no harm ensues. The lamp has been used by hundreds of thousands of miners without accident, in other cases accidents have occurred.

I will now describe some of the modifications of the Davy, and the first of these is the Clanny lamps (see fig. 2), called, like most other lamps, by the name of the inventor. This only differs from the Davy in having a glass cylinder substituted for the lower part of the gauze cylinder. There are two great advantages gained by this improvement, great increase of light, taking the light of a sperm candle as 100, the Clanny will give 47 and the Davy only 18 (according to Marsaut). The second advantage is that it is easily carried in a strong current of air which would extinguish a Davy lamp. These great advantages have caused the Clanny to be largely used. There are, however, three disadvantages as compared with the Davy: The glass may be cracked and broken if it is heated by holding the lamp on one side or by water falling on to it; it is more complicated and it is an easy matter to put the parts together in such a way that it is unsafe, and yet this may not be detected; 3rd, it is possible to cause an explosion with this lamp if the flame is drawn down for gas trying, and it is raised into an explosive mixture and rapidly withdrawn, an explosion may take place inside which will pass through the gauze and fire the gas outside; this is owing to the glass cylinder holding a charge of explosive gas which is shot out with great violence against the gauze. Such an accident cannot take place with a full flame, because the products of combustion partly fill the lamp and diminish the force of any explosion that may occur; therefore in using a Clanny a full flame should be in the lamp when testing gas.

The Stephenson Lamp (see fig. 3) is constructed by taking a Davy lamp of large diameter, and putting inside it, a glass chimney, on the top of the chimney is a copper cap perforated with small holes; the air for the flame enters the lamp through an external brass ring below the glass, in this ring are perforated small holes, which regulate the current of air entering the lamp, the air then passes through the gauze and under the glass; the amount of air entering the lamp is thus regulated by the openings above and below to the amount required for combustion. If gas enters the lamp it uses up all the oxygen and the lamp is extinguished. This lamp may therefore be put into an explosive mixture and will, under ordinary

Fig. 5. Davy in Case, $\frac{1}{4}$.

Fig. 6. Section of Patent "Protector" Mueseler with Shield, $\frac{1}{4}$.

Fig. 7. Marsaut, Section, $\frac{1}{4}$.

Fig. 8. Marsaut, Two gauze Lamp, with Shield, $\frac{1}{4}$.

conditions, be certainly extinguished ; and it has happened that all the lamps in a large colliery have been extinguished by a sudden blower of gas filling the mine with an explosive mixture. This is an element of safety which the Davy lamp does not possess, and in consequence the Stephenson lamp has been very largely used ; it gives, however, a worse light than the Davy.

The Mueseler (see fig. 4) or Belgian lamp resembles a Clanny and differs from it only in having a metal chimney and flat gauze diaphragm at the top of the glass. This lamp has two advantages over the Clanny, it is safer, because the horizontal gauze and the chimney constitute minor lines of defence ; the chimney is a defence, because it is filled with the products of combustion through which a flame will not pass under ordinary circumstances. The second advantage is that the lamp is extinguished when put into an explosive mixture, so that in the case of a blower all the lamps in a large mine have been extinguished. The Mueseler lamp has only one fault in the eyes of the workman, and that is that it goes out if held a little crooked. The Mueseler has come into very extensive use because it combines the safety of a Stephenson lamp with the good light of a Clanny. This lamp then seems *prima facie* to satisfy our requirements, and we will pause to enquire as to what are the circumstances under which it is not safe. The lamp is not safe to use with a reduced flame when testing for gas, as it might cause an explosion, the same as the Clanny, but it is safe for fire-trying with a full flame.

Some of the lamps which I have named are safe in a rapid current of an explosive mixture. Thus if a Davy is in a current of 400 feet per minute, it will explode the gas. A Clanny, a Stephenson, and a Mueseler may explode the gas if the speed is 600 feet per minute. It very rarely happens that an explosive mixture travels through a mine at the speed of 400 or 600 feet per minute, but it often happens that a lamp is carried or moved at a very much greater speed, and therefore it is desirable to have a lamp that is safe at any speed. A man may travel as fast as a mile in ten minutes or 500 feet per minute, and he may meet a current going at an equal speed, the current would, therefore, strike the lamp with a velocity of 1000

feet; if we take a very extreme case, the man might travel on a good road 750 feet per minute, and meet a current of 1500 feet, making a total speed of 2250 feet; to be perfectly safe, therefore, a lamp should be capable of resisting this velocity for some time, but if, in addition to running against the wind, the man should swing his lamp violently, it would be brought against the air at a very much greater velocity. It is difficult to say at what speed a lamp might be swung. I find that I can give a three pound lamp 120 swings of five feet in a minute, making an average speed of 600 feet a minute, and it is probable that the maximum speed of swing exceeds this by half, making a speed of 900 feet, this 900 feet added to the previous velocity of 2,250 feet, makes a total of 3,150 feet. But this is only instantaneous, say a third of a second, because the backward swing of the lamp reduces the speed of current, so that a lamp ought to resist 3,150 feet for a third of a second, and 2,250 feet for a long period, say seven minutes. It must be remembered that the swing of the lamp might happen after it had been exposed for a long time to a rapid current. It may be worth while to consider if the conditions often occur in which a lamp is subjected to a rapid current of an explosive mixture; the history of our coal mines gives a negative reply, it can only happen under one of three circumstances, as follows:—

1. A very badly ventilated mine, where the return air course was foul to the explosive point, a condition of things almost, if not quite unknown in the last twenty years.
2. A sudden issue of gas from stalls between pillars, caused by a large fall of roof; a species of accident of exceedingly rare occurrence.
3. A sudden outburst of gas from the roof or floor of the mine, so powerful as to foul the main air courses to the explosive point; this is also not a frequent occurrence, but is a more frequent cause, taking the last twenty years, of the fouling of a colliery than any other. I do not know the number of such outbursts, but probably in Yorkshire alone there is more than one every year, and perhaps two or three. If such an outburst happens and there is any exposed light on the return air side of it, an explosion will happen; sometimes the intake is also fouled.

It may be taken that the Stephenson or the Mueseler lamp, if well constructed, are safe enough for the general conditions of a mine, and that extra precautions are only required when there is danger of a great outburst. It is, however, difficult to say where this danger does not exist, if we except those mines mostly near the outcrop where firedamp is hardly ever seen; in all the collieries where firedamp abounds in the coal and in the strata there is a possibility of an outburst, and it is to guard against this possibility that the recent inventions have been directed. Having found that the source of danger is the velocity of the air-current, the most obvious cure is to put the lamp behind some shelter,—this is done by putting a Davy lamp into a tin can with a glass plate in front (see fig. 5),—with this protection the Davy lamp from being the least safe becomes one of the safest of all lamps. It has been exploded with a velocity of 2800 feet; it has frequently resisted a velocity of 3100 feet.

The Royal Commissioners consider that it may be implicitly trusted in a current of 2000 feet. But some forms of the tin-can lamp explode at 1200 feet a minute. But this is not satisfactory if we are to be perfectly safe. The next step then is to take the safest of the unshielded lamps, the Mueseler, and to put it in a case that will protect it from an air-current. (See fig. 6.) If this case is properly constructed it makes a lamp that will resist a current of 2400 feet a minute with certainty, and will generally resist a current of over 3000 feet, and if the chimney is very carefully proportioned, and the bonnet also, it is possible that this lamp will resist a velocity of over 5000 feet a minute, and it is in fact absolutely safe. Mr. C. E. Rhodes says that the lamp is safe at 52 feet a second, but I consider Mr. Rhodes' 52 feet is really 104 feet, owing to the contraction of the air-passage by the lamp. There are a variety of modifications of the form of shield, of the chimney, and of the gauze, for some of which is claimed a greater degree of safety, in fact that no velocity will explode them. There is a practical difficulty in testing lamps at high velocities; a considerable force is required to produce the air-current, and large gas-holders. And also, some of the lamps are blown out in the testing-tube before the gas reaches them. In considering how to make a safety lamp, it is natural to reflect that if

one gauze will make a lamp safe, two gauzes would make it safer, and three gauzes safer still. It was this form of reasoning which led M. Marsaut to improve the Clanny lamp, by putting two gauzes instead of one (see figs. 7, 8) and also three gauzes. By this arrangement the lamp is made perfectly safe for fire-trying, but a shield is necessary to make it safe in a rapid current. With a well-constructed shield and two gauzes the lamp is probably safe at 1500 feet, with three gauzes it has resisted trials at a velocity of 3000 feet, and, I believe, 5000 feet.

In choosing a safety lamp the great weight of authority is in favour of having one that gives a good light, and that is, therefore, the first consideration. Therefore it is necessary to have:—(1) glass lamps, and (2) in order that the lamp may be always in good order, the inlet air should not pass through gauze or perforations on a level with the oil-pot, therefore the air must enter the lamp above the glass. Gauze or perforations at the oil-pot level are sure to get clogged and dirty. (3) The colliers and deputies ought to be able to see that all the essential parts of the lamp are in their proper place before it goes into the mine, and for that reason the shield should be removed after using, and before the lamp is given out again it should be examined by the collier and a deputy before the shield is attached. It has always been considered essential in using safety lamps, that they should be examined by the collier and by the fire-man or deputy, and any departure from this rule involves greater risks by far than those now incurred by the use of the common Davy. (4) The lamp should be so designed that when it is put together for use, it cannot be partially opened, without undoing the lock; a great many of the glass lamps in common use are so made that the glass can be loosened so as to entirely destroy the safety of the lamp, and this may be done inadvertently.

Before proceeding further, it may be well to consider the electric light, and it must be admitted that if we are seeking a perfect lamp in order to avoid a risk that may not occur in any mine for thirty years, we must at once regard as inadmissible any light in a mine that causes additional risk. No gas lamp, or any other lamp than the best safety lamp should go below the pit bank, or be within reach

of the mine-air issuing from the upcast top. Therefore the incandescent electric lamp for lighting the porch of the downcast bottom and the upcast pit top, if coal is wound at the upcast, is a great improvement upon gas or paraffin lamps, because the light is in a perfectly air-tight case and no gas can touch it.

The incandescent electric lamp fulfils all the conditions of a perfect lamp; it is destroyed the instant it ceases to be perfect. Perfect as the lamp is, there is a sensible risk in taking it a yard beyond the arching of the porch, because the wires that connect it with the dynamo are a source of danger. If a wire breaks there is a spark, and this would ignite the gas if there was any; and it is doubtful if there is any advantage in the electric light in the porch to compensate for the risk incurred through the conducting wires.

For lighting the working-places of a coal mine a portable lamp only is permissible, several of these have been made varying from 3lbs. to 6lbs. in weight. The 6lb. lamp made by Swan is charged by a dynamo on the bank for a small cost, and it is probable that the only practical objection to some such lamp is the weight; for a collier who stops all day in one place this is not serious, but for deputies, managers, and horse drivers, it is a serious objection, and one that will prevent the general adoption of the 6lb. lamp. The 3lb. lamp has not yet been made to work cheaply, a cost of chemicals alone amounting to one penny a shift is a prohibitory charge. The inventors, however, promise to work it for one farthing a shift. For the present, therefore, the portable electric lamp is only in the experimental stage, and the colliery manager of to-day must use a different lamp. To-morrow, or next year, the portable electric lamp may be perfected.

As soon as we depart from the older types of lamp we encounter new risks; with a Davy lamp we know where we are, we can see if the lamp is in proper condition or not, and if it is well made it is perfectly safe, except under conditions which very rarely arise, but with the new lamps unless a man has seen it put together he cannot tell what he is carrying; it might be a lamp without a gauze, it might be no safety lamp at all, and the man who enters the most dangerous parts of the mine may be trusting entirely to the memory,

care and skill, of some lamp cleaner who has very little experience. For my part I would sooner carry an old Davy lamp than take a shielded lamp which I had not seen put together myself unless I had the assurance of some pitman that he had seen it put together. It has been suggested that safety can be insured by testing the lamps in an explosive mixture every day as they are given out. When I gave evidence to the Royal Commissioners about six years ago, I told them that I did not consider such a system of tests was practicable, and I have seen no reason to alter my opinion. When an imperfect lamp is put in an explosive mixture it may ignite the gas or or it may not; the ignition proves the lamp to be bad, but the failure to ignite it does not prove the lamp to be good. A means of rapidly applying a really searching test, such as a rapid current of explosive gas, in a rapid and practical manner, has not yet been adopted, and if it is ever adopted it will be a rather costly operation. The more common tests of putting the lamp for a few seconds into a box filled with an explosive mixture, or passing it through a ring of gas jets, are absolutely worthless, and the plan recommended by the Commission is very little better. They recommend a vertical tube about eight inches in diameter and two feet long open at both ends, and gas jets at the bottom, so that there may be a constantly ascending current of explosive gas. (See fig. 13.) An imperfect lamp put into such a tube may or may not explode the gas; if it does not explode nothing is proved at all. To illustrate this I have prepared a few experiments:—

1. I take a Clanny lamp with a hole in the gauze $\frac{1}{4}$ inch in diameter, manifestly a very unsafe lamp; I put it into the hole which contains an explosive mixture; the lamp is at once extinguished.
2. I take a Stephenson lamp with a hole about $\frac{3}{8}$ inch diameter, punched through the copper cap of the glass and through the gauze cap, that too is extinguished.
3. I take a Stephenson lamp and remove the glass, leaving it a large Davy, then I punch a hole $\frac{1}{8}$ inch diameter in the side of the gauze, that too is extinguished.
4. Then I take a Shield lamp and omit one of the gauzes, so that there is a straight opening entirely unprotected, and put that into the explosive mixture, that too goes out.

By the test all these lamps are safe, as a matter of fact, they are all exceedingly dangerous. It is an elementary proposition that an experiment with a negative result proves nothing until it has been repeated a great number of times. One experiment is enough to prove beyond the possibility of doubt that a lamp will explode the gas; it takes a hundred experiments to establish an even *prima facie* case, or a probability that it will not fire the gas. There is only one mode in which we can make reasonably sure that all the lamps in the mine are safe; and it is this, to adopt a lamp which has successfully passed the heaviest test a thousand times; to make every lamp an exact and perfect copy of this tested lamp; to discard every lamp that is damaged; and every time after a lamp has been used, it must be examined by a competent person to see that it has not been damaged, and every time that the separated parts of a lamp are put together it must be done by a competent person, and the operation must be watched by two other persons, one of whom should be the collier who is going to use it, and the other an experienced deputy or fireman. This involves some loss of time and some expense, on which I remark that the time is only a minute spent by the collier to preserve his own life; that the expense is an insurance by the owner of the safety of his mine. But I submit to all reasonable men, that when in our anxious search after the perfect lamp, we discard those lamps that for two generations have served us fairly well, we must not blindly rush into far greater and more constant danger than these from which we seek to escape; yet this is what there is likely to happen under cover of a permanently fixed shield, imperfect lamps may be given out and returned undetected, until some day there is an accident of which the cause will remain a mystery.

I now describe a few of the lamps. The Marsaut (see figs. 7 and 8), here we notice there is no ring below the glass, the glass is fixed by the oil-pot, this is the same in the Belgian-made Mueseler and in the Wolf lamp. This is in some respects a disadvantage, because it involves re-fixing the glass every time the lamp is cleaned—but in other respects it is a very great advantage, because it secures the glass in its position; whereas in those lamps where the glass is fixed

by a ring, the ring may be unscrewed by turning the glass, and thus the lamp may inadvertently be made unsafe.

Wolf Lamp. This can be re-lighted without opening. This relieves the collier from the temptation to open his lamp to re-light it, but it is a question, whether, if re-lighted in an explosive mixture, the flame might pass the gauze and cause an accident.

The Morgan Lamp (see figs. 9 and 10) is a safe lamp if the glass is locked and it gives a good light, like all lamps with the Mueseler chimney it is easily put out accidentally which is annoying. It has successfully resisted all trials up to 3200 feet per minute, but it can be exploded with very high velocities.

The Evan Evans Lamp (see fig. 11), is so made that it extinguishes itself when hot; the heat melts a soldered joint and then a spring is liberated which causes a cap to descend and close the air-holes.

The Protector Lamp (see fig. 6) cannot be opened without putting out the light, and the spirit they burn gives a good light with no trouble because the wick does not char; in using the spirit precautions must be taken and a specially arranged lamp-room made, because, if carelessly used it is sure to set fire to the lamp-room; as far as the lamp itself is concerned, when once it is locked the spirit is as safe to use as Colza oil and much cleaner.

The Clifford Lamp (see fig. 12) has several ingenious novelties. The double bonnet is so designed as to equalise the pressure of the air current on a lamp at the inlet and outlet so as to prevent it taking effect upon the light, in fact to make a perfect shield. In place of wire gauze there is a perforated plate made up of a copper and lead plate superposed so that if the lamp gets hot the lead will melt, the intention is to close up the air holes in the copper and put out the flame. The lower end of the chimney terminates in a bell of glass covering the flame; this diminishes the light, but by the means of this bell the lamp can be tilted without being upset. Mr. Clifford claims that his lamp will resist any velocity and that it has resisted a speed of 12000 feet or over two miles a minute. I saw it tested at a pressure of 1·4 inch of W. G. and it got red-hot but extinguished

itself in five minutes; under the same pressure the Morgan Lamp exploded in two minutes thirty-eight seconds.

Fleuss. This lamp is only for exploring mines full of gas. It is enclosed in a glass case, it burns spirit, and oxygen is supplied under pressure. The products of combustion escape through water. Unless it is broken it is quite safe.

The Mackinless Lamp has perforated brass plates instead of gauze, and has a Mueseler chimney.

In conclusion, let me sum up the results of our enquires:—

The lamp of the future will be one of the following:—

- (1.) Electric Secondary Battery (Swan's).
- (2.) „ Primary „
- (3.) Bonnetted Three Gauze (Marsaut).
- (4.) „ „ „ (Mueseler).
- (5.) Inorgan Three Gauge (Mueseler).
- (6.) Clifford, if it stands official tests as well as Mr. Clifford claims for it.
- (7.) I understand the Mackinless lamp has not been exploded.

These lamps give light, which is what we want, and they are, so far as testing can prove them, safe (except the last, which is new, and for which I only give the inventor's authority).

All lamp cabins must be on the surface, and have enough delivering windows for the delivery of lamps to the men at a rate not exceeding 120 lamps per hour at each window, so that each man may see his lamp put together. The diagram shows a sketch plan of such a cabin. (See fig. 14.)

Without some such careful arrangement of lamp rooms the new lamps will prove worse than the old, but with due care they will prove much better.

I have said enough, however, to show how very carefully changes must be made, to prove how blind all legislation is likely to be. Lamps will be improved, but not by law. In these days of invention a law on mechanical questions is always antiquated by the time it is passed, and it hampers and discourages invention.