## XIX. "Experiments with Safety-Lamps." By William Galloway, Inspector of Mines. Communicated by R. H. Scott, F.R.S. Received May 4, 1874.

After the occurrence of a great colliery-explosion it is usually very difficult, and sometimes impossible, to arrive at a satisfactory conclusion as to what were the causes which probably led to the catastrophe, and when safety-lamps have been exclusively used by the workmen its origin seems to be shrouded in mystery. The explosions which happened at Risca, Morfa, Cethin, High Brooks, and Pelton Collieries between the 1st of March, 1860, and the 21st of October, 1866, appeared to be altogether inexplicable; and, in the last two cases, when all the safety-lamps were found locked after the accident, no attempts were made to explain the phenomena.

On the 12th of December, 1866, however, the great explosion took place at the Oaks Colliery, and fortunately several of the men who survived could give an account of some of the circumstances which immediately preceded it. A stone drift had been cut from near the bottom of the downcast-shafts to within a few feet of one of the intake-airways, and shortly before the accident a shot-hole was drilled at its inner end, and charged with a considerable quantity* of gunpowder; the men who were about the pit-bottom were warned into a sheltered place; the shot was fired, and in a few seconds afterwards the shock of the explosion was felt. It was ascertained subsequently that a part of the rock at the bottom of the shot-hole had been blown into the intake-airway, leaving the tamping intact, so that the concussion of the air would be almost as great as if the tamping alone had been blown out.

A coincidence so remarkable as this attracted considerable attention, and after every great explosion which has happened since the Oaks' a search has evidently been made for some evidence of recent shot-firing. The following Table will give an idea of the magnitude of the important explosions which have happened within recent years, and of some of the circumstances under which they occurred.

Synopsis of great explosions since 1860.

| Date of Explosion. | Name of Colliery. | Number of men killed. | Remarks. |
|---|---|---|---|
| 1860. | | | |
| March 1 | Burradon | 76 | Naked lights. Deficient ventilation. |
| December 1 | Risca | 142 | Safety-lamps. Several explosions simultaneous with the principal one? |
| 1862. | | | |
| February 19 | Cethin | 47 | Naked lights and safety-lamps. Deficient ventilation. |
| 1863. | | | |
| March 6 | Coxlodge | 26 | Naked lights and safety-lamps. Gas from the goaves came upon the naked lights. |

* $1\frac{1}{2}$ to 6 lbs. Reports of the Inspectors of Mines for the year 1866, p. 43.

| Date of Explosion. | Name of Colliery. | Number of men killed. | Remarks. |
|---|---|---|---|
| 1863. | | | |
| October 17...... | Morfa............... | 39 | Safety-lamps; all were found in good order. Cause unknown. |
| 1865. | | | |
| June 16......... | Bedwelty ......... | 26 | Lamps? Gas accumulated in an unventilated heading. |
| December 20... | Cethin ........... | 34 | Locked safety-lamps; shot-firing carried on. Cause unknown. |
| 1866. | | | |
| January 23 ... | High Brooks...... | 30 | Locked safety-lamps; all were found locked. Cause unknown. |
| June 14......... | Dukinfield......... | 38 | Naked lights and safety-lamps. Deficient ventilation. |
| October 21...... | Pelton ........... | 24 | Locked safety-lamps; all were found locked; shot-firing carried on. Cause unknown. |
| December 12... | Oaks ............... | 334 | Safety-lamps. A heavily charged shot was fired in pure air a few seconds before the explosion. |
| December 13... | Talk o' th' Hill... | 91 | Safety-lamps; shot-firing carried on. Deficient ventilation. |
| 1867. | | | |
| August 20...... | Garswood Park... | 14 | Safety-lamps. A shot had blown out the tamping. |
| November 8 ... | Ferndale ......... | 178 | Safety-lamps; shot-firing carried on. Two distinct explosions took place simultaneously in districts communicating only by two passages, and ventilated by different air-currents. |
| 1868. | | | |
| November 25... | Hindley Green ... | 62 | Safety-lamps. A shot had blown out the tamping. |
| December 26... | Haydock ........ | 26 | Safety-lamps. A shot had blown out the tamping. |
| 1869. | | | |
| April 1 ......... | High Brooks...... | 37 | Safety-lamps. A shot had blown out the tamping. |
| June 10......... | Ferndale ......... | 53 | Cause unknown. |
| July 21 ......... | Haydock ......... | 59 | Safety-lamps? An empty shot-hole was found from which it was supposed the tamping had been blown; two or more explosions took place simultaneously in distant parts of the mine. |
| November 15... | Low Hall ......... | 27 | Safety-lamps. A shot had blown out the tamping; there appear to have been two simultaneous and very violent explosions. |
| 1870. | | | |
| February 4 ... | Pendleton ......... | 9 | Safety-lamps? A shot had blown out the tamping. |
| February 14... | Morfa............... | 30 | Gas from a barred-off goaf ignited at a naked light. |
| July 7 ......... | Silverdale ......... | 19 | Lamps? Cause unknown. |
| July 23........ | Charles Pit ...... | 19 | Naked lights. |
| August 19...... | Brynn Hall ...... | 20 | Safety-lamps? A shot had blown out the tamping. |
| 1871. | | | |
| January 10 ... | Renishaw Park... | 26 | Safety-lamps. A shot was fired with an overcharge of gunpowder; two explosions? |
| February 2 ... | Pentre ........... | 38 | Locked safety-lamps; shot-firing carried on. A blower is supposed to have made the return air so explosive that it ignited at the ventilating-furnace. |
| March 2 ........ | Victoria Pit, Monmouth. | 19 | Gas in a stall worked with a safety-lamp; it is assumed that a naked light was carried into it. |

| Date of Explosion. | Name of Colliery. | Number of men killed. | Remarks. |
|---|---|---|---|
| 1871. | | | |
| September 6... | Moss Pits ......... | 70 | Safety-lamps. An empty shot-hole discovered after the pits were reopened. Cause unknown. |
| October 25...... | Seaham ............ | 26 | Safety-lamps. A shot was fired in pure air: one explosion of firedamp was simultaneous with the shot; another followed after a short interval? |
| 1872. | | | |
| February 11 ... | Oakwood ......... | 11 | Safety-lamps. A shot was fired. |
| March 28 ...... | Lover's Lane...... | 27 | Safety-lamps? A shot had blown out the tamping. |
| October 7 ...... | Morley Main...... | 34 | Safety-lamps; shot-firing carried on. Cause unknown. |

It will be seen from the data given above that shot-firing was carried on in 17 of the 22 collieries at which important explosions took place after the 12th of December, 1866; safety-lamps were certainly used in 12, and probably also in the 5 which are marked doubtful; in 8 cases it was ascertained that a shot had blown out the tamping at or about the time of the explosion; in 2 an empty shot-hole was found, from which the tamping is supposed to have been blown; and in 3 a shot had been fired bringing down the coal or rock; finally, at Risca, Ferndale (1867), Haydock (1869), Low Hall, Renishaw Park, and Seaham, two or more explosions appear to have taken place simultaneously in different parts of the mine unconnected by a train of explosive gas. The Seaham explosion is a remarkable one: a heavily charged shot was fired in pure air in one of the intake-aircourses, and, according to the statement of three men who survived, the explosion of firedamp followed the shot immediately; one of the men further asserted that, in several minutes more, he heard the distinct report of another explosion.

Two methods of accounting for the simultaneousness of the explosion of firedamp with the firing of the shot have been suggested in the Reports of the Inspectors of Mines: one of them supposes that the firedamp is ignited directly by the shot; the other, that the concussion of the air caused by the explosion of gunpowder dislodges gas from cavities in the roof and from goaves, and that this gas, passing along in the air-currents, is ignited at the lamps of the workmen. In some instances, when it has been known to be highly improbable that any gas existed nearer to the shot-hole than 10, 20, or even 40 feet, the advocates of the former hypothesis have taken it for granted that the gases issuing from the shot-hole were projected through the air as far as the accumulation of firedamp, retaining a sufficiently high temperature to ignite it on their arrival. On the other hand, the advocates of the latter hypothesis have not attempted to show how the gas, which they assumed could be dislodged in quantity by a sound-wave and its reflections, could be ignited

in those cases in which safety-lamps only were used. It is no doubt highly probable, however, that when once an explosion of firedamp has been initiated in one way or another, and large bodies of air are driven through the passages of a mine with great velocity, explosive accumulations will be dislodged from cavities and goaves, and pressed through the safety-lamps with the velocity requisite to pass the flame.

In the beginning of the year 1872, when I was giving attention to this subject, it appeared to me to be probable that the sound-wave originated by a blown-out shot, in passing through a safety-lamp burning in an explosive mixture, would carry the flame through the meshes of the wire gauze, in virtue of the vibration of the molecules of the explosive gas. It had long been known *, indeed, that if an explosive current were made to impinge upon a lighted safety-lamp in a direction perpendicular to its axis, and with a velocity of 8 to 14 feet per second, the flame would pass through the meshes after a short time, and ignite the explosive mixture on the outside; but it does not seem to have been suspected that the same result might be produced by the passage of an intense sound-wave through a safety-lamp burning quietly in an explosive mixture. The explosion at Cethin Colliery in 1865 is a good example of one that may have been caused in this way, by the firing of a shot. Several days after the explosion the safety-lamp of the overman was found, securely locked and uninjured, lying at the distance of a few yards, within an abandoned stall which was known to have contained firedamp: shot-firing was carried on in this mine, and it is not improbable that a sound-wave from an overcharged or blown-out shot had passed through this lamp and ignited the explosive mixture shortly after the overman had entered it: moreover the Inspector of Mines says † he has no hesitation in stating that, in his opinion, the gas in this stall had been ignited, and was therefore the origin of the explosion; but he is unable to state by what means it was fired.

It is certain that, in every fiery mine, safety-lamps are placed in an explosive mixture from time to time, either by accident (as when men retire hurriedly, perhaps into disused places, after the fuse of a shot has been ignited) or by design to test the quality of the air, as the overman at Cethin Colliery may have been doing; and it is equally certain that shots are fired, occasionally, which blow out the tamping and cause a violent concussion of the air. If, therefore, the explanation which is brought forward in this paper to account for the relation between explosions and shot-firing be the true one, then the question as to how often explosions of this kind are likely to occur would resolve itself into one of probability as to how often an ordinary Davy or Clanny lamp, burning in an explosive mixture, would be traversed by a sound-wave of a certain amplitude of vibration.

* Transactions of North of England Institute of Mining Engineers, vols. i. & xvii.

† Reports of the Inspectors of Mines, 1865, p. 118.

On the 16th of January, 1872, I made the first experiment in connexion with this subject in the Physical Laboratory of University College, London: Professor G. C. Foster was present and co-operated with me. A sheet of wire gauze, 1 foot square, was inclined at an angle of 70°, and a slow current of gas and air from a Bunsen burner was directed against its under surface. Part of the explosive mixture thus formed passed through the meshes, and, when ignited, produced a flat flame on the upper surface 3 in. long by 1 in. wide, and symmetrically situated in regard to the sides of the sheet. A glass tube, 3 ft. 4 in. long by $3\frac{1}{2}$ in. diameter, was placed with one end at a distance of $1\frac{1}{2}$ in. from the upper surface, of the sheet of wire gauze; its axis was horizontal, passed through the middle point of the flat flame, and was at right angles to the line of intersection of a horizontal plane with the sheet. At the end of the tube furthest from the wire gauze, a vessel, $3\frac{1}{4}$ in. diameter, containing a solution of soap in water was placed; the point at which the axis of the tube cut the perpendicular from the centre of the liquid was $2\frac{1}{2}$ in. from the end of the tube, and at the same distance above the surface of the liquid. An explosive mixture of coal-gas and oxygen was forced into the solution of soap until bubbles containing about 2 cub. inches had formed on the surface. A light was then applied to the gas at the upper surface of the wire gauze, and immediately afterwards to the bubbles; and after the explosion it was found that the flame had vanished from the upper surface, and that the gas issuing from the Bunsen burner was on fire.

In December 1872, I made a number of experiments similar to the foregoing in the Laboratory of the Royal College of Chemistry, when I was much indebted to Dr. Frankland for his valuable suggestions. The glass tube of the first experiment was replaced by two tin-plate tubes, each 2 in. diameter (one 10 ft. 11 in., the other 9 ft. 7 in. long); they were joined to form a continuous tube 20 ft. 6 in. long. The vessel containing the solution of soap was small enough to be placed just inside of one end of the tube, and the sheet of wire gauze was at a distance of 1 in. from the other end. The same explosive mixtures were again employed, and the same result was obtained as before. A diaphragm, consisting of four sheets of brown paper of ordinary thickness, was now inserted at the junction of the two tubes; the centre of the diaphragm was bulged to a distance of about half an inch towards the origin of disturbance. After the passage of the sound-wave, it was found that the flame had shifted to the opposite side of the wire gauze, and the diaphragm was bulged to about the same extent, but in the opposite direction. A quantity of loose cotton-wool, sufficient to fill the end of the tube completely for a length of three inches, was then pushed into the end of the one furthest from the wire gauze, at its junction with the other. After the sound-wave had passed, the flame was again found to have removed to the opposite side of the wire gauze, and the

cylinder of cotton-wool was one inch further from the origin of disturbance.

Two sets of apparatus (figs. 1 & 2, Plate VI.) were now constructed: in both the sound-wave of a pistol-shot is conveyed through tin-plate tubes to a distance of 20 feet; then it passes through a safety-lamp, which can be surrounded by an explosive mixture of gas and air.

In the apparatus represented in fig. 1 there are two tubes, each 10 feet long by 3 inches in diameter. At the end *o* a disk of wood, $\frac{3}{4}$ in. thick, with a hole in the centre large enough to receive the muzzle of the pistol, is fitted into the tube *a*; at *c* a sheet of india-rubber, $\frac{1}{16}$ in. thick, is tied over the end of the tube *b*, and a tubular ring, one end of which is covered with a network of wire $\frac{1}{16}$ in. thick, with meshes $\frac{3}{16}$ in. square, is drawn over the fastening till the network is close to the diaphragm. The part of the apparatus which is surmounted by the safety-lamp is of the following construction:—A round sheet-iron plate, *g*, of 6 in. diameter, rests on four short legs: above this, and joined to it, is a circular chamber, *f*, formed of two concentric tubular rings and two flat rings; its exterior diameter is $2\frac{1}{4}$ in., its interior diameter is $1\frac{3}{4}$ in., and in the top ring there are twenty-four small equidistant holes, whose locus is a circle of 2 in. diameter. The screw which receives the lower ring of the wire gauze is carried upon projections inwards from the upper flat ring of the chamber *f*. The wire gauze of an ordinary Davy lamp, held between two rings in the usual manner, incloses a space in which a small gas-jet occupies the position of the wick in the oil-lamp, when screwed into its place above the chamber *f*: the three stout wires joining the upper and lower rings are omitted in the figure. A rod, *l*, screwed into the plate *g*, carries a short narrow plate at its top, bent to the curve of the tube *b* which rests on it; there is a strip of iron fastened to the tube, on each side of this support, to prevent it from altering its position relatively to the lamp. The part of the tube *b* opposite to the wire gauze is cut out, so as to leave a clear space of half an inch all round for the passage of the explosive mixture. The pipe *h* conveys gas to the chamber *f*, and the pipe *k* supplies the jet in the inside of the wire gauze; the quantity is regulated by screw-clips on the india-rubber tubes.

The experiment is made in the following way:—A pistol, of which the barrel is $\frac{1}{2}$ in. bore and 5 in. long, is loaded with ·205 gramme of gunpowder, and several pieces of paper are rammed down well upon the charge; the firing is done by a cap. The gas-jet of the lamp having been lighted and the wire gauze screwed into its place, gas is made to pass into the chamber *f*, and escaping by the holes in the top, it mixes with the air and forms an explosive mixture, which surrounds the lamp: part of the explosive mixture passes into the interior, where it is ignited; the remainder passes up on the outside. The muzzle of the pistol is then placed in the hole in the wooden disk, and as soon as the shot is fired along the axis of the tube, a large flame leaps up, and continues to burn

Fig. 1.

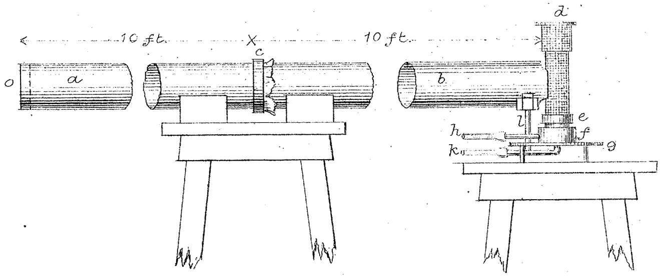



Fig. 2.

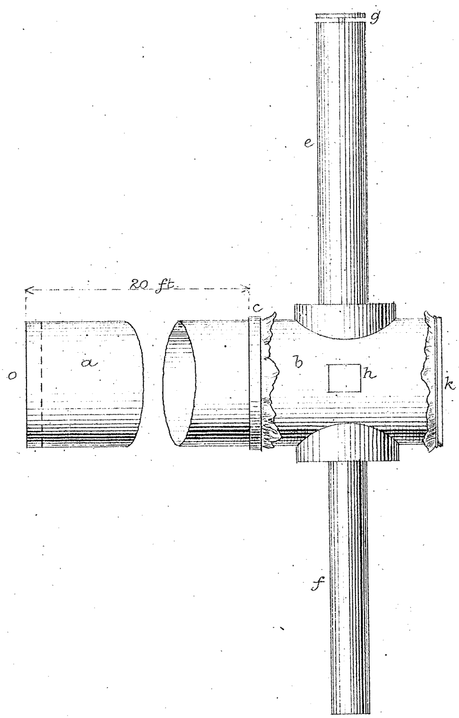
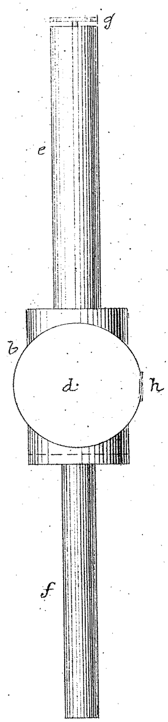



Fig. 3




Scale 1 in = 1 foot.

W. H. Wesley. lith. W. West & C° imp.

Fig. 4.

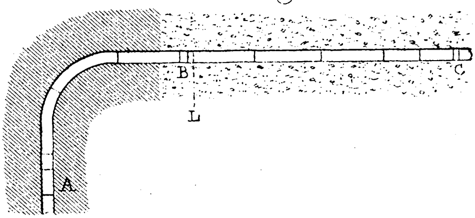



Fig. 5.

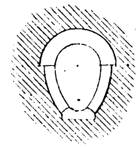
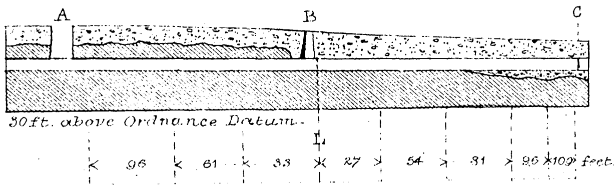


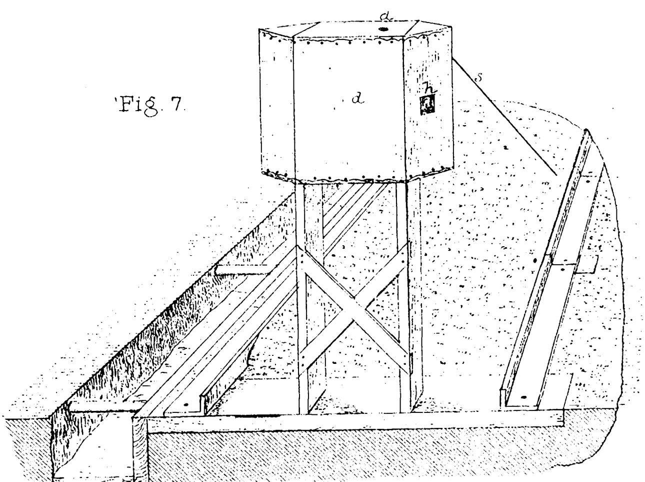
Fig. 6.




*Scales.*

*Figs. 4 & 6, 1 in = 80 ft. Fig 5. 1 in = 16 ft.*

Fig. 7.




*Scale $\frac{5}{8}$ inch = 1 foot.*

on the outside of the lamp*. If the charge of gunpowder be increased to ·272 gramme, or be decreased to ·136 gramme, the experiment does not succeed; and if the wire gauze has become smoked by the flame of the inner jet being too large, the flame cannot be passed through.

In the apparatus represented in fig. 2, there are again two tin-plate tubes, each 10 ft. long by 8 in. diameter, but they are joined to form one continuous tube 20 feet long. At the end *o* there is a disk of wood, $\frac{3}{4}$ in. thick, with a hole in the centre for the muzzle of the pistol. The tube *b* (figs. 2 & 3), of tin plate, 12 in. long, has its interior isolated by an india-rubber sheet tied over the end *c*, and a sheet of paper tied over the end *k*. A ring, with a network of wires $\frac{1}{8}$ in. thick, and with meshes $\frac{1}{4}$ in. square, is drawn over the diaphragm in the same way as in the apparatus already described. Two short tubes, of 6 in. diameter, are joined to *b* to form a chamber large enough to receive a safety-lamp; they are closed by flat ends, with the exception of a hole 3 in. diameter in the upper one, opening into a chimney *e*, and an opening of 2 in. diameter into the tube *f* in the lower one. The upper end of the tube *f* opens into a flat round chamber, with holes $\frac{1}{2}$ in. diameter and $\frac{1}{2}$ in. apart round about its outside; its position is indicated by the dotted line in fig. 3. At the top of the chimney *e* there is a draught regulator, *g*, which can be raised or lowered by means of the screwed spindle which supports it. The safety-lamp to be tested is placed on the discoid chamber, with its top projecting into the chimney if it is so long. Gas is supplied by a Bunsen burner at the bottom of the tube *f*, and, mixing with air, it flows upwards through the discoid chamber into the isolated space around the lamp. The products of combustion pass upwards through the chimney.

The experiment is made thus:—The pistol is loaded with ·41 gramme† of gunpowder in the same way as before: an ordinary Davy or Clanny lamp is lighted and put into the space *d*, which is afterwards closed at the ends. Gas is then made to flow into the tube *f*; the lamp is observed through the window *h*, and as soon as it is seen that the atmosphere in the space *d* is explosive, the shot is fired at *o*. The paper at *k* is blown out and set on fire; and the flame of the explosive mixture, passing backwards down the tube *f*, ignites the gas escaping from the Bunsen burner.

The lamps which were tested with this apparatus are those known as the Davy, Clanny, Stephenson, Mueseler, and Eloin. The flame was easily passed through the Davy lamp, with rather more difficulty through the Clanny, and not at all through any of the others.

The first experiments with firedamp were made in No. 7 Pit, Barleith, near Glasgow. A wooden plug, with a small pipe through it, was driven

* This experiment was shown by Mr. Spottiswoode at the Royal Institution on the evening of the 17th of January, 1873, with the apparatus I have described. The same apparatus was afterwards used at one of the Cantor Lectures of the Society of Arts.

† If the charge be made greater or less than this by ·15 gramme the experiment does not usually succeed.

into a horizontal borehole which had struck a blower, and the firedamp was conducted in tubes to a collecting vessel at a short distance. I soon found that this firedamp was very impure, as a mixture of one part of it with thirteen parts of air was not explosive; however, I made a number of experiments in the mine with both sets of apparatus (figs. 1 & 2, Plate VI.), but did not succeed in passing the flame, except perhaps in one doubtful instance with the larger apparatus, when the gas issuing from the Bunsen burner was not set on fire.

The next experiments with firedamp were made in the C Pit, Hebburn Colliery, near Newcastle-on-Tyne. The gas, which issued from a bore-hole similar to that in the Barleith Pit, was collected in the same way, and conveyed in the collecting vessel to a convenient place near the stables, where naked lights could be used. The experiments with both sets of apparatus were quite successful, the quantity of gunpowder required being, in each case, the same as when coal-gas was used. The Davy lamp employed in the experiments with the larger apparatus belonged to the colliery, and was in constant use below ground. At the fifth trial (when I had ascertained the quantity of gunpowder required) the flame passed through the wire gauze, set fire to the paper tied over the end *k*, and passing backwards down the tube *f*, kindled the gas issuing from the Bunsen burner. My brother, Mr. R. L. Galloway, who was the resident viewer of the colliery at that time, was observing the lamp through the window *h* when the shot by which the flame was passed was fired. The flame of the wick, which was of ordinary dimensions before it was surrounded by the explosive mixture, had sent up a long smoky point to near the top of the gauze, which showed that the explosive mixture was composed of about 1 part of firedamp to 12 or 13 parts of air. The lamp was carefully examined after the trial, and was found to be in good order.

The Directors of the Company to whom the colliery belongs were unwilling to allow any further experiments to be made in the mine, so that this series had to be abandoned before any more results had been obtained.

Following are the analyses of the firedamp used in the foregoing experiments. The sample of gas from the Barleith blower was collected by myself at the time the experiments were being made, and analyzed by Dr. T. E. Thorpe, of Glasgow; that from the Hebburn blower was collected by my brother several weeks before the experiments, and was analyzed by Dr. Wright, of St. Mary's Hospital, London.

| | Barleith. | Hebburn. | |
|---|---|---|---|
| Light carburetted hydrogen | 75·86 | 85·22 | |
| Carbonic acid | 1·31 | 3·27 | |
| Olefiant gas | .. | traces | |
| Carbonic oxide | .. | 1·36 | |
| Oxygen | .. | 2·17 | } 1·51 |
| Nitrogen | 22·83 | 7·98 | |
| | 100·00 | 100·00 | |

The next experiments were on a larger scale. Through the kindness of Mr. Carrick, the City Architect of Glasgow, part of a new sewer in North Woodside Road was placed at my disposal; and Mr. Foulis, the manager of the Corporation Gas-Works, caused a pipe to be led into it, and provided a liberal supply of gas. Figs. 4, 5, & 6, Plate VII., are sections of the part of the sewer in which the experiments were made: fig. 4 is a plan section through the widest part, fig. 5 is a vertical cross section showing the dimensions of the sewer (6 ft. × 4 ft. are the greatest measurements), and fig. 6 is a vertical longitudinal section through the highest part. Part of the sewer is a tunnel in solid rock (the diagonal shading in fig. 6 shows the position of the rock), and part of it is built in brickwork through the surface-drift. The length that was available for the experiments is comprised between the point A, where there was a wide shaft to the surface, and the point C, where I caused a wooden partition to be set up to prevent the draught of air from affecting the lamp. B is a manhole, 3 ft. 6 in. × 3 ft. 9 in. at the bottom, and 23 in. square at the top; it was covered by two stones, each about 2 in. thick, with a space about 1 in. wide between them across the middle of the top of the manhole. The safety-lamp part of the apparatus (fig. 1, Plate VI.) was set upon a board fixed across the sewer at the point L, at a height of 2 ft. 8 in. from the deepest point.

I made a large number of experiments here, but it will be sufficient to give only the principal results. The shots were fired from the same pistol that was employed in the former experiments at the distances from the lamp indicated by the figures below fig. 6, Plate VII.; they were nearly all fired towards the position of the manhole B. Each measure of gunpowder weighed ·273 gramme (= 4·213 grains). The number of measures given below, corresponding to the distances from the lamp at which the shots were fired, are those by which the flame was passed; and it is to be understood that at each distance a charge containing one measure less was generally insufficient to effect the purpose.

(1) Between C and L:—

| | | | | | |
|---|---|---|---|---|---|
| At | 27 ft. | 5 measures | = | 1·365 | gramme |
| | 54 ft. | 8 ,, | = | 2·184 | grammes |
| | 81 ft. | 10 ,, | = | 2·730 | ,, |
| | 96 ft. | 12 ,, | = | 3·276 | ,, |
| | 109 ft. | 14 ,, | = | 3·822 | ,, |

One experiment was made with the pistol pointing towards the roof at an angle of 70° to the axis of the sewer; the distance was 109 ft., the charge 20 measures, = 5·460 grammes; the muzzle of the pistol was 1 ft. 6 in. from the floor, and the firing was effected by drawing a cord. The flame passed through the wire gauze, and ignited the gas on the outside.

(2) Between A and L:—

| | | |
|---|---|---|
| At 33 ft. | 8 measures | = 2·184 grammes |
| 61 ft. | 8 ,, | = 2·184 ,, |
| 96 ft. | 8 ,, | = 2·184 ,, |

It is remarkable that, in these latter experiments, it was not necessary to increase the quantity of gunpowder as the distance from the lamp was increased. The large charge required at the first station seems to have been owing to the presence of the manhole between the lamp and the point at which the shot was fired; but this waste of energy having been provided for, no further addition to the charge was required. It would seem as if part of the energy of the sound-wave was expended in the space C L in shaking the brickwork and a narrow wooden gangway supported on cross-pieces at a height of 1 ft. 5 in. from the sole; whereas in the space A L, in which no gangway had been laid down, it was conveyed through the tunnel in the solid rock without much loss of intensity.

The temperature of the air in the sewer was 55°–56° Fahrenheit; and there was generally a current travelling in the direction C to A at the rate of 5 to 10 ft. per minute.

These are the last experiments from which important results have been obtained; they were concluded in November 1873.

After this I made some experiments with firedamp in a stone-mine in No. 2 Pit, Douglas, near Glasgow. I filled a sheet-iron box of 18 cub. ft. capacity with firedamp at the borehole in the C Pit of Hebburn Colliery, and brought it to this mine. As the gas appeared to have become mixed with air through leakage during the transport, and would not burn satisfactorily in the lamp of the apparatus (fig. 1, Plate VI.), the apparatus shown in fig. 7, Plate VII., was constructed. Two boards, each $\frac{5}{8}$ of an inch thick, and of the shape and dimensions of the top of the apparatus, are joined together by iron rods $\frac{3}{8}$ of an inch in diameter, one at each angle. A sheet of india-rubber, $\frac{1}{32}$ of an inch thick, is then fastened round the frame thus formed by nailing it to the boards, and an isolated space of the form *d*, fig. 7, is obtained. An opening, $1\frac{5}{8}$ inch in diameter, in the upper board serves as an outlet for the products of combustion; and a similar opening in the lower board serves as an inlet for fresh air and the firedamp from a Bunsen burner. This apparatus is placed on two legs fastened to one of the sleepers in the roadway, and it is stayed tightly before and behind by four stout wires in positions analogous to *s*, the only one that can be seen in the figure.

A Davy lamp was lighted and placed in the inside of *d*, on a block of wood 3 inches high by 3 inches in diameter, so as to have its wire gauze as near as possible to the centre of the space; firedamp was then admitted at the lower opening, and the draught was regulated at *a*. The appearances presented by the lamp were observed through a glass window, *h*, fastened in the sheet of india-rubber; and as soon as the flame showed

that the mixture surrounding it was explosive, shots were fired from a gun at a distance of 30 yards. The barrel of the gun which was used is $\frac{13}{16}$ of an inch in diameter, and it is rifled for a length of 3 ft. with seven grooves; the breech which received the charge is smooth-bored, and $4\frac{1}{8}$ inches long. Each measure of gunpowder weighed 3·822 grammes (=59 grains), and the charges fired ranged between 1 and 9 measures; paper tamping was rammed down tightly, and the charge was fired by a cap.

The gun was tied to a prop in the middle of the mine, with its barrel at an angle of about 35° upwards, pointing towards the apparatus; the muzzle was 18 inches from the floor. At the part where the experiments were made, the sizes of the mine are:—width at top, 4 ft.; width at bottom, 6 ft.; height, 5 ft. 6 in.

The sound-wave from a shot of two measures extinguished the flame of the Davy lamp when it was placed on the outside of the apparatus; but when it was placed in the inside of *d*, the flame could not be extinguished nor passed through the meshes, even when the quantity of gunpowder was raised to nine measures. However, after the lamp had been allowed to burn in the isolated space for a few minutes (the supply of fresh air not being very good), its flame could be extinguished by the sound-wave from a shot of four measures. The whole quantity of fire-damp was so small that there was no opportunity for enlarging or varying the apparatus.

These experiments, and one which I made formerly in the sewer with the *b* tube of the apparatus, fig. 2, Plate VI., show that a very slight obstacle will interfere with the action of the sound-wave. They were concluded in March 1874.

I would add, in concluding, that the liberal grant of money which I received from the Government-Grant Committee of this Society has been of great value in enabling me to carry out these experiments.

I have also been much indebted for assistance to each of the following gentlemen:—Mr. Robert H. Scott, F.R.S.; Professor A. C. Ramsay, F.R.S.; Professor W. W. Smyth, F.R.S.; Professor Marreco, of the College of Physical Science, Newcastle-on-Tyne; Mr. John Galloway, of Barleith and Dollars Collieries; Mr. J. B. Simpson, of Newcastle-on-Tyne; Mr. Charles Shute, of Hebburn Colliery; and to Mr. William Kirkwood, of the Inkerman Mines, near Glasgow.

## XX. "On the Adiabatics and Isothermals of Water." By A. W. RÜCKER, M.A., Fellow of Brasenose College, Oxford. Communicated by R. B. CLIFTON, M.A., F.R.S., Professor of Experimental Philosophy in the University of Oxford. Received June 4, 1874.

M. Verdet, in his work on Thermodynamics ('Œuvres,' vol. vii. p. 184), enunciates the proposition "Deux courbes de nulle transmission ne peu-

Fig. 1.

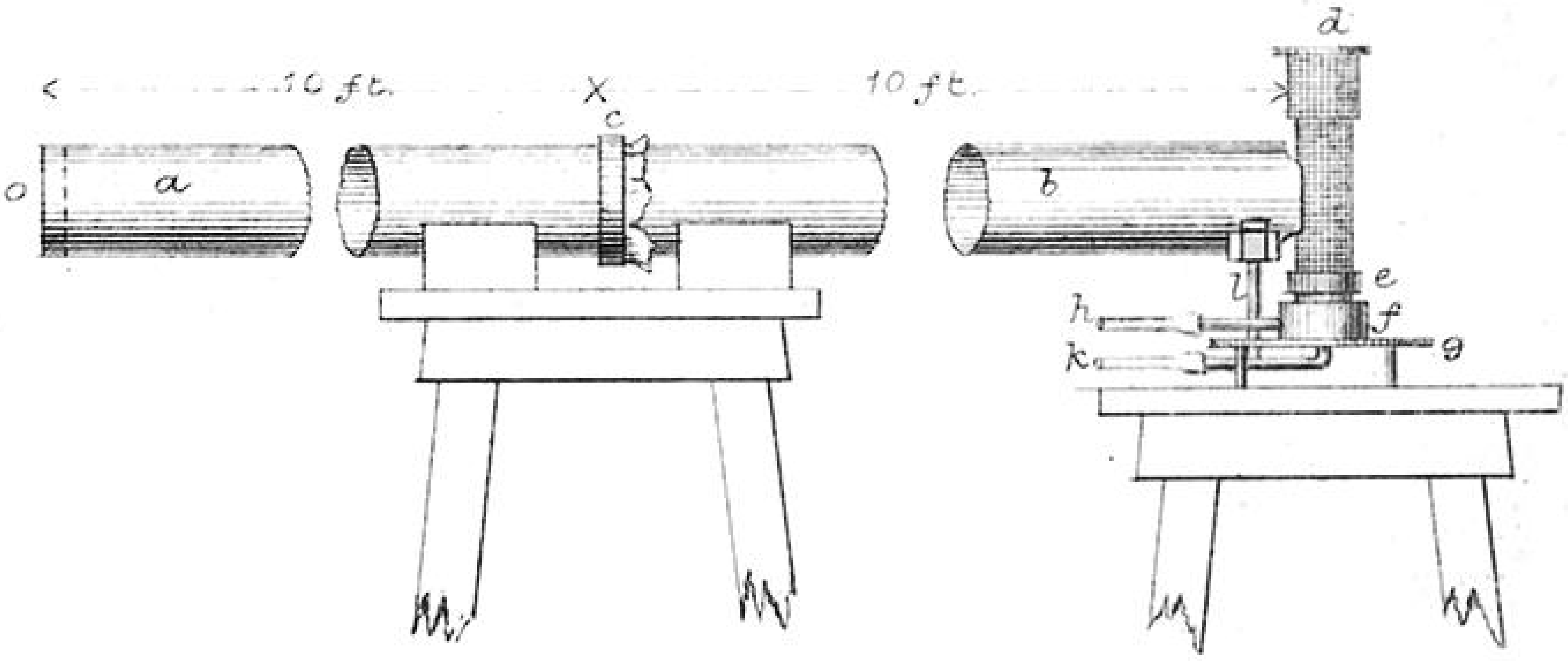



Fig. 2.

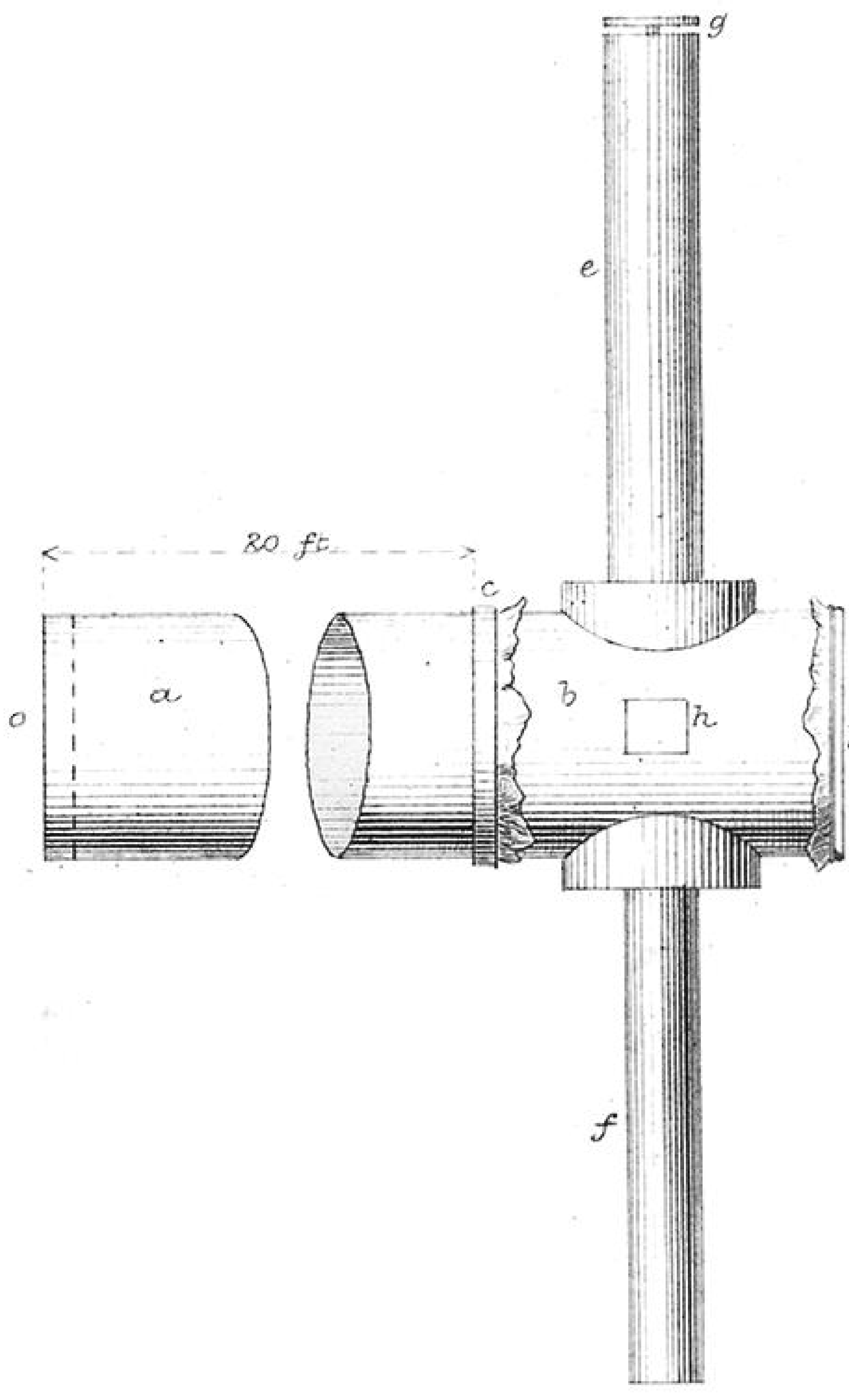
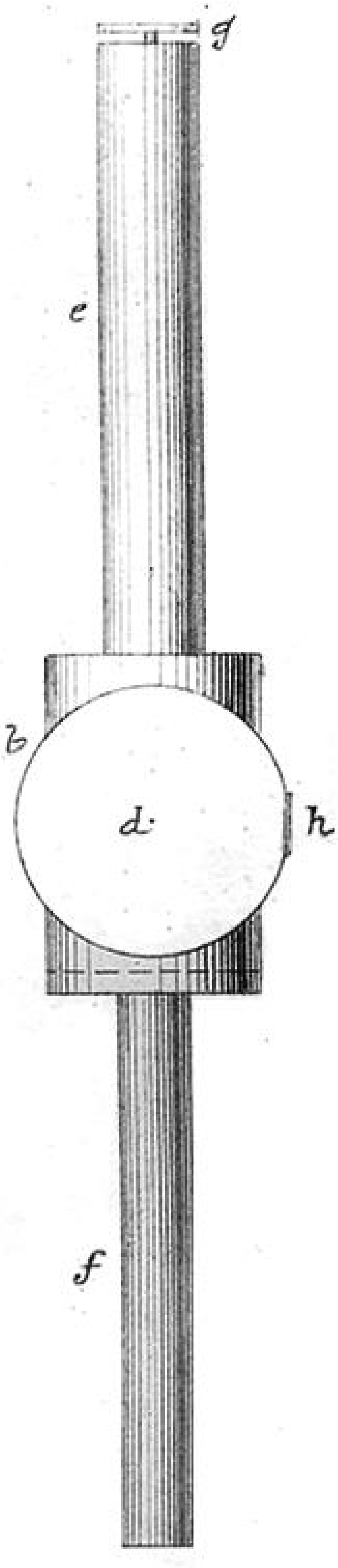



Fig. 3.




Scale 1 in = 1 foot.

Fig. 4.

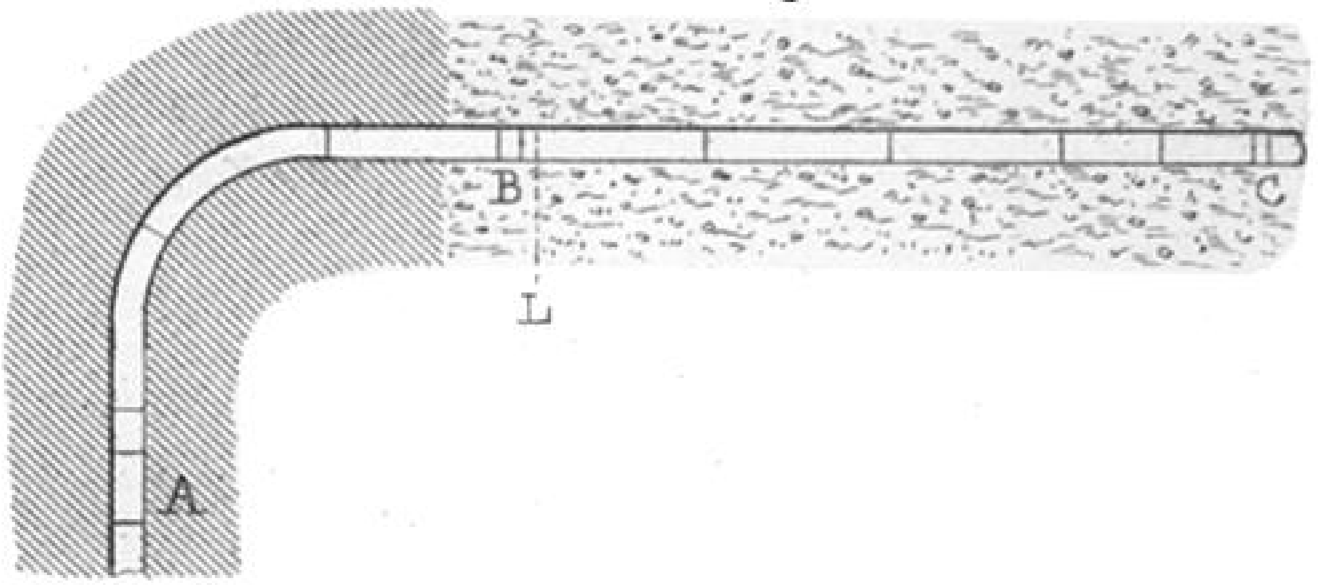



Fig. 5.

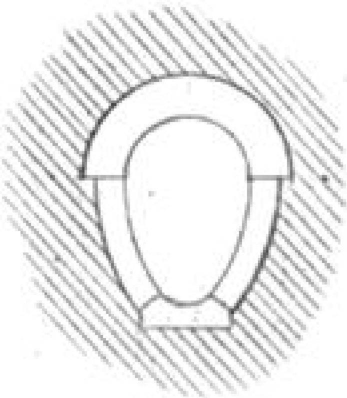
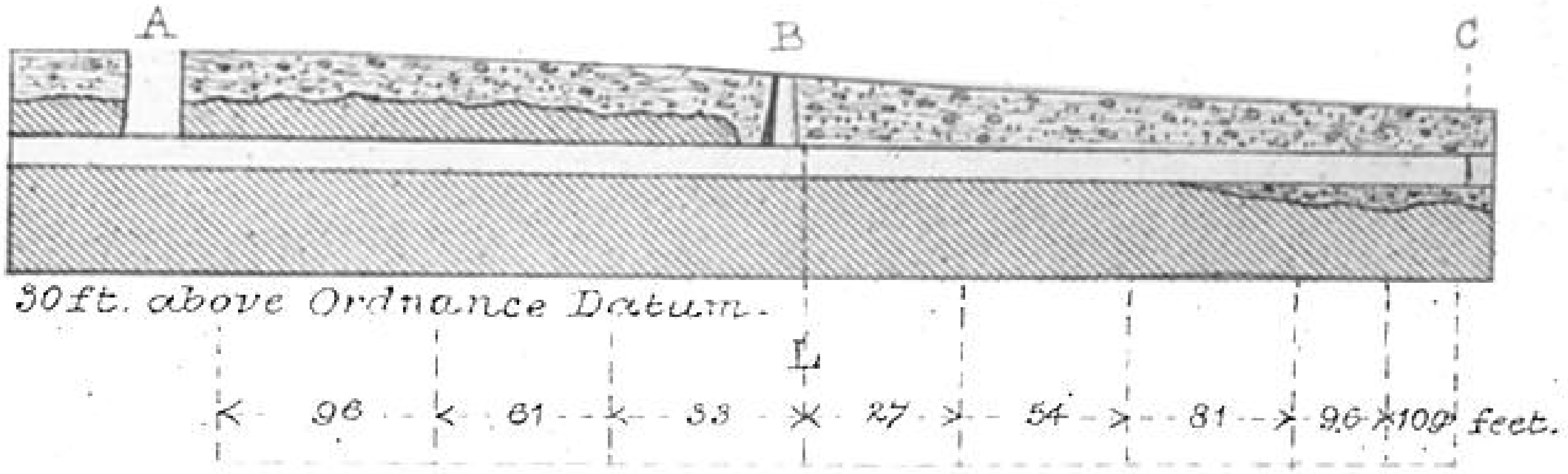


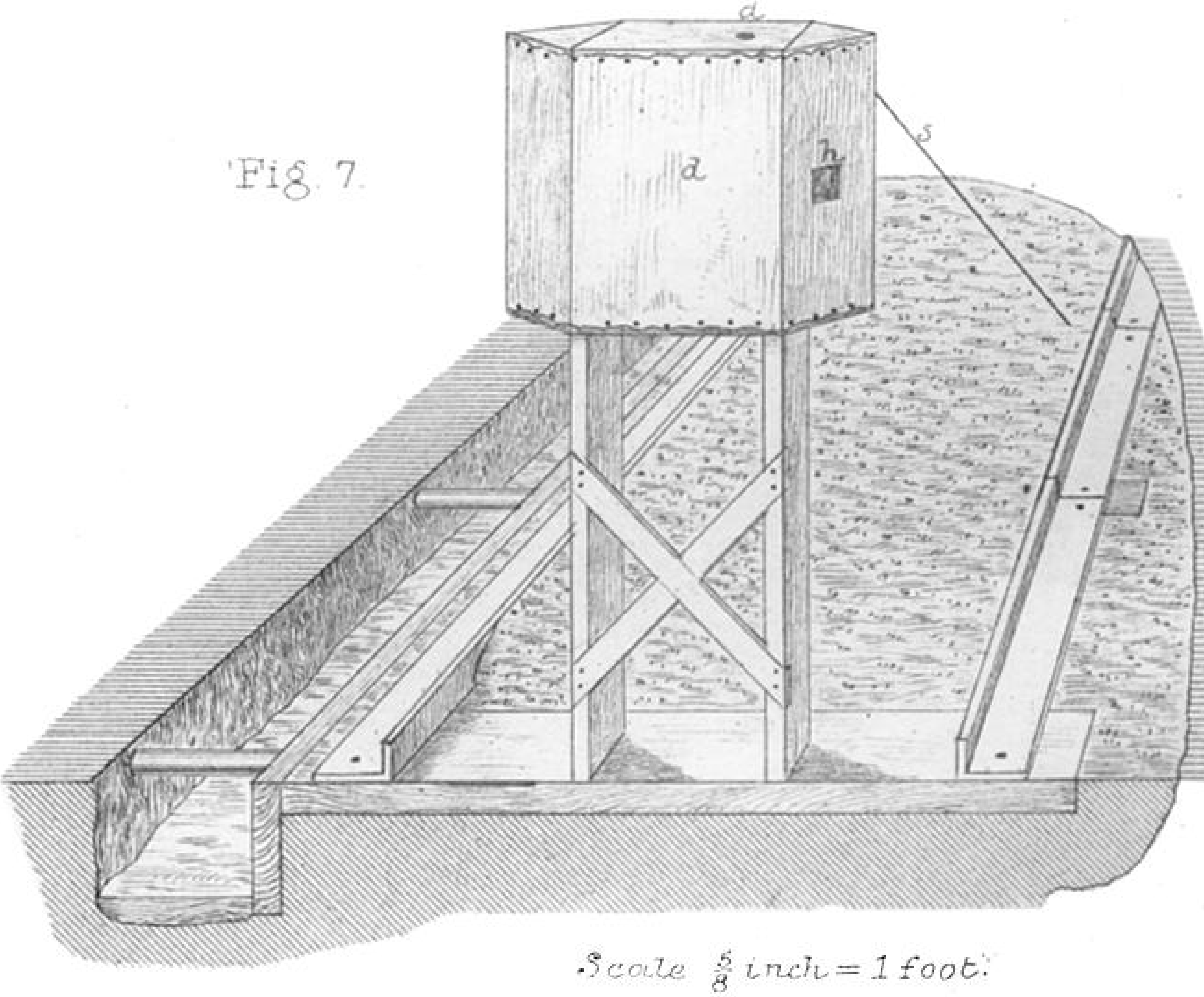
Fig. 6.




Scales.

*Figs. 4 & 6, 1 in = 80 ft. Fig. 5. 1 in = 16 ft.*

Fig. 7.




*Scale $\frac{5}{8}$ inch = 1 foot.*