XIV. *On the Application of Hydrogen Gas to produce a moving Power in Machinery; with a Description of an Engine which is moved by the Pressure of the Atmosphere upon a Vacuum caused by Explosions of Hydrogen Gas and Atmospheric Air.*

BY THE REV. W. CECIL, M. A.

FELLOW OF MAGDALEN COLLEGE,

AND OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY.

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THERE is scarcely any uniform operation in the Arts which might not be performed with advantage by machinery, if convenient and economical methods could be found for setting such machinery in motion. The extensive application of machinery, therefore, depends much upon the number and various capabilities of the engines which can be employed to produce moving force. Even the most perfect engines at present employed for this purpose, are not capable of being applied universally; but each has a province peculiar to itself, beyond which the use of it cannot be extended with profit or convenience.

Two of the principal moving forces employed in the Arts are Water and Steam. Water has the singular advantage, that it can be made to act at any moment of time without preparation; but can be used only where it is naturally abundant. A steam-engine, on the contrary, may be constructed, at greater or less expense, in almost any place; but the convenience of it is much diminished by the tedious and laborious preparation which is necessary to bring it into action. A small steam-engine, not exceeding the power of one man, cannot be brought into action in less than half an hour: and a four-horse steam-engine cannot be used under two hours preparation.

These limitations exclude the use of water and steam, as moving forces, in all works which are much interrupted and discontinued at considerable intervals, and subject to a change of place.

The engine, in which hydrogen gas is employed to produce moving force, was intended to unite two principal advantages of water and steam; so as to be capable of acting in any place, without the delay and labour of preparation. It may be inferior, in some respects, to many engines at present employed; yet it will not be wholly useless, if, together with its own defects, it should be found to possess advantages also peculiar to itself.

The general principle of this engine is founded upon the property, which hydrogen gas mixed with atmospheric air possesses, of exploding upon ignition, so as to produce a large imperfect vacuum. If two and a half measures by bulk of atmospheric air be mixed with one measure of hydrogen, and a flame be applied, the mixed gas will expand into a space rather greater than three times its original bulk. The products of the explosion are, a globule of water, formed by the union of the hydrogen with the oxygen of the atmospheric air, and a quantity of azote, which, in its natural state, (or density 1), constituted .556 of the bulk of the mixed gas. The same quantity of azote is now expanded into a space somewhat greater than three times the original bulk of the mixed gas; that is, into about six times the space which it before occupied: its density therefore is about $\frac{1}{6}$th, that of the atmosphere being unity.

If the external air be prevented, by a proper apparatus, from returning into this imperfect vacuum, the pressure of the atmosphere may be employed as a moving force, nearly in the same manner as in the common steam-engine: the difference consists chiefly in the manner of forming the vacuum.

We will now estimate the power resulting from such a vacuum, by comparing the effects of equal bulks of steam and hydrogen.

Let the line *AB* (Fig. 1.) represent any space: this may be formed into a perfect vacuum, by filling it with steam, and condensing: in which case, the steam produces a vacuum nearly perfect, and equal to its own bulk. The same space may be formed into an imperfect vacuum, by exploding in it a mixture of hydrogen and atmospheric air: the bulk of the mixed gas being about one third of the vacuum required, and consequently the bulk of the hydrogen about one tenth. The effect of this imperfect vacuum may be represented, geometrically, by drawing a square *ABCD* upon *AB;* taking *AE, CF*, each equal to one sixth of the side of the square;* and drawing a common hyperbola, through the points *E, F,* with asymptotes *BA, BC*. The ordinate *GH* varies inversely as the abscissa *GB*, and may therefore represent the density and elasticity of a given quantity of azote confined in the variable space *GB;* the elastic force of the atmosphere being represented by *AD*, the side of the square. Therefore *HK* will represent the excess of the atmospheric pressure above the elasticity of the azote; and the whole effect of the atmospheric pressure upon the imperfect vacuum will be represented by the external hyperbolic area, *EHFD*. And the effect of a perfect vacuum, over the same space *AB*, is represented by

* The bulk of the azote is .556 of the mixed gas; and the gas by the explosion expands to about 3.4 of the original space; hence the imperfect vacuum thus produced is about six times the space which the azote occupies when reduced to the elasticity of the atmosphere. That is, when the azote occupies a space *BI*, its elasticity is represented by *IF*.

the square *ABCD*. But the effects of equal bulks of steam and hydrogen, to produce moving force, are proportional to the fraction, whose numerator is the effect produced, and the denominator, the quantity employed in producing it. Hence the effect of a given bulk of steam, is to the effect of the same bulk of hydrogen, as the area of the square divided by unity, is to the external hyperbolic area divided by the fraction $\frac{1}{10}$; which ratio is as $3 : 5 \times \{5 - \text{hyp. log. } (6)\} :: 3 : 16$, nearly*.

Thus it appears by calculation, that any quantity of pure hydrogen gas will produce more than five times the effect of the

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* Let *BD* be the diameter of the square, which is also the axis of the hyperbola, *ML* perpendicular to *AB*, and therefore equal to *LB*;

$$\text{Then } GH \times GB = LM \times LB = LM^2.$$

$$\text{Let } GH = y, \quad GB = x, \quad LM = a,$$

$$\therefore y = \frac{a^2}{x}, \text{ and } y\dot{x} = \frac{a^2\dot{x}}{x},$$

$$\therefore \text{the fluent of } y\dot{x} = a^2 \text{ hyp. log. } x \pm \text{a constant quantity;}$$

$$\therefore \text{area corresponding to ordinate } GH = a^2 \text{ hyp. log. } x \pm \text{a constant quantity;}$$

$$\text{———————— } LM = a^2 \text{ hyp. log. } a \pm \text{a constant quantity;}$$

$$\therefore \text{area between ordinates } GH \text{ and } LM = a^2 \text{ hyp. log. } x - a^2 \text{ hyp. log. } a$$

$$= a^2 \text{ hyp. log. } \frac{x}{a};$$

$$\therefore \text{area } AEML = a^2 \text{ hyp. log. } \frac{AB}{a}, \text{ but } AB \times \frac{AB}{6} = a^2;$$

$$\therefore \text{area } AEML = a^2 \text{ hyp. log. } \frac{a\sqrt{6}}{a} = \frac{a^2}{2} \text{ hyp. log. } 6;$$

$$\therefore \text{whole hyperbolic area} = a^2 + \frac{a^2}{2} \text{ hyp. log. } 6 + \frac{a^2}{2} \text{ hyp. log. } 6,$$

$$= a^2 . (1 + \text{hyp. log. } 6);$$

$$\therefore \text{external area } DEMF = AB^2 - a^2 (1 + \text{hyp. log. } 6) = 6a^2 - a^2 (1 + \text{hyp. log. } 6)$$

$$= a^2 . (5 - \text{hyp. log. } 6);$$

$$\therefore \text{whole square : external hyperbolic area } DEMF :: 6a^2 : a^2 (5 - \text{hyp log. } 6)$$

$$:: 6 : 5 - \text{hyp. log. } 6;$$

$$\therefore \text{the ratio required is } \frac{6}{1} : \frac{5 - \text{hyp. log. } 6}{\frac{1}{10}} :: 3 : 5\ (5 - \text{hyp. log. } 6)$$

$$:: 3 : 16, \text{ nearly.}$$

same bulk of steam: and in practice the disproportion of their effects is still greater. It is here supposed, that steam produces by condensation a perfect vacuum equal to its own bulk; but this is far from being the case: much of the power is lost by needless condensation, by the escape of steam through the piston, besides a considerable deduction for working an air pump, and two water pumps, which are necessary to a steam-engine.*

It may be worth while to add in this place an experiment, calculated to obviate any objection arising from the apprehension of danger, as connected with the explosion. If a close cylinder, ten inches long, and two inches diameter, be made of thin tin, seamed up one side, and soft soldered, the ends being well secured, it will easily sustain, without bursting, the whole force of the exploding mixture. The internal pressure against the sides of the vessel, in this case, is about 180 pounds on the square inch; or twelve atmospheres nearly.† From this experiment an idea may be formed, how little strength is necessary for such parts of a gas-engine as are exposed to the pressure of the expanding fluid; a pressure which, as will hereafter appear, bears a very small proportion to the initial exploding force, which is twelve atmospheres.

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* The loss of power, from friction, &c. in a condensing steam-engine, even when working with a double stroke, is estimated by practical mechanics at about one-third of the gross power.

† The greatest expansive force was ascertained by filling with mixed gas the cylinder just described, one end being entirely solid, the other being closed with a cork bung, accurately fitted, and confined by several strings, parallel to the axis of the cylinder, and so arranged that the tension might be equally distributed. It was observed how many strings the explosion was able to break, by pressing on a surface of three square inches. The same strings were then transferred to a common steelyard; and it was observed how much weight they would sustain. The results of several trials, differing but little from each other, indicated a pressure of five hundred pounds upon three square inches. If to this be added 45 pounds for the atmospheric pressure on the same surface, the whole being divided by three, gives 180 pounds nearly, for the pressure upon every square inch.

It is already stated, that if hydrogen gas and atmospheric air, mixed in the most explosive proportion, be ignited by an electric spark in a close vessel, the internal pressure upon the sides of the vessel is about twelve atmospheres. But if the mixture be allowed to expand into a space rather more than three times its original bulk, (suppose 3.4,) the initial force is reduced to one atmosphere, or fifteen pounds on the square inch: for the expansion is here at an end; that is, it just balances the elastic force of the atmosphere. This experiment agrees with the hypothesis, that the exploding force varies, during the expansion, inversely as the square of the space occupied by the expanding fluid, and not in the simple inverse ratio of that space;

$$\text{for } \sqrt{12} : \sqrt{1} :: 3.4 : 1, \text{ nearly.}$$

If this law be general, the initial force of any exploding mixture may be known, by observing its greatest expansion.

In large vessels containing hydrogen gas, there is little or no danger to be apprehended, from the unavoidable admixture of atmospheric air in small quantities. In mixtures of hydrogen gas and atmospheric air, if the hydrogen be in excess, the exploding force is very small; but if the atmospheric air be in excess, the exploding force is considerable. If the atmospheric air be only one fifth part of the whole, the explosion, if any, is not sensible; but if the hydrogen be one fifth of the mixture, it will explode with considerable force. The gas-engine about to be described, was found to work very freely when the hydrogen did not exceed one fifth of the mixed gas: but the greatest power was obtained, when the hydrogen was $\frac{2}{7}$ of the mixture. Yet, for the purpose of economy, or that a given quantity of hydrogen may produce a maximum of moving force, it is conjectured that a less proportion of hydrogen would be preferable.

A gas-engine admits of various constructions, but we shall explain at length that model only which is represented in Fig. 2:—

first describing the several parts of it, and then shewing how the motion is continued. The drawings are adapted to a peculiar kind of orthographic projection, digested by Professor Farish into an easy and convenient system of perspective, called the Isometrical Perspective, which is already before the Society. The representation of the central cube *ABF′*, formed by joining the angular points of an equilateral and equiangular hexagon with the centre of the inscribed circle, will serve as a key to the proportion and direction of the other lines in the picture. The dotted lines represent such parts as are not visible, except on the supposition that all other parts are transparent.

ABF′ (Fig. 2.) is a cube, having three cylinders, of equal capacity, attached to its sides at right angles. The vertical cylinder is separated from the narrow horizontal ones, by a moveable key or plug *abcd* in the cube. This plug is hollow, and open at the bottom: it has also two large apertures opposite to each other, one inch wide, and an inch and a half deep; by which, upon turning the handle *ef*, it causes a free communication from the vertical cylinder *ABCD*, to each of the narrow horizontal cylinders *FG*, *F′G′*. In the lower part of this plug, and below the level of the large apertures just mentioned, are two small apertures, in the same horizontal plane, and situated eighty degrees apart from each other. One of these *c*, which is about one tenth of an inch diameter, corresponds with a similar hole *c′* in the face of the cube *ABF′*, upon turning the handle *ef* to the left; and by continuing this motion to the left, the aperture *c* is again closed. If the position of the plug be reversed, by turning the handle *ef* to the right, as represented in the picture, the other aperture *d*, which is about half an inch diameter, will be brought to coincide with *d′*, the mouth of the pipe *no*, which enters nearly at the bottom of the cube, on the side opposite to that which has the small hole *c′*. Near *F* is a small hole, one quarter of an inch diameter, which, by means of a trench excavated in the solid side of the plug, admits the atmospheric air freely into the narrow cylinder *FG*, and restores it to an equilibrium with the atmosphere, after the vacuum has performed its office. There is another hole F' on the opposite side of the cube, corresponding to *F*, by which the equilibrium is at the same time restored in the cylinder $F'G'$. Hence the plug *abcd* commands six apertures, three of which, namely, the mouth of the pipe *no*, and the two holes *F*, F', all being small apertures, are opened at the instant when the lever *ef* is completing its motion to the *right*. The other three, namely, the two large apertures and the touch-hole *c*, are opened by turning the lever *ef* to the *left;* and of these the small touch-hole *c* is opened just at the *end* of this motion, and immediately shut again. Fig. 3. is a vertical section, at full size, of the cube *AAAA*, the plug *OOOO* in it, and a cap *BB*, which screws into the top of the cube. Through the cap *BB* is a cylindrical hole *DD*, to admit the axis which turns the plug; and in the small cube *CCCC* is a stuffing box and collar of leathers, by which the hole *DD* may be made air tight if required.

The vertical cylinder *ABCD* (Fig. 2.) is closed at the bottom by a cap *CD*, but not so as to exclude the external air: it has also a piston *ghk* connected with a parallel motion *LK*, $L'K'$, causing the piston rod to move in a vertical straight line, nearly.*

* As this parallel motion is not exactly similar to any of those in common use, and produces a very near approximation to a rectilineal motion, a further explanation of it is here added.

Fig. 4. *A* and *C* are fixed centres, about which the levers *AB*, *CD* are moveable. *B* and *D* are moveable joints; also $\frac{AB}{CD} = \frac{DE}{BE}$. Then the locus of *E* is nearly rectilineal.

When *AB* is parallel to *CD*, *DBE* is at right angles to each of them; and is therefore a common tangent to the circles described by the points *B* and *D*. That the point *E* may continue in the same straight line *FG*, for every position of the point *B*, the deflection of the point

On the top of the piston is a solid conical frustrum, to occupy the hollow of the plug, when the piston is at the top of the cylinder. The horizontal frame ***LHN*** is connected with a crank on the axle ***PQ***, by an upright rod ***NO***, jointed at its extremities. A fly-wheel, three feet in diameter, and weighing half an hundred weight, is placed upon one extremity, ***P***, of the axle ***PQ***, and at the other extremity ***Q***, is a crank or handle, situated about ten degrees in advance of the crank ***O***, causing the rod *wx*, which slides through a fixed hole at *x*, to oscillate in a vertical plane, parallel to the axis of the cylinder ***FG***. When the rod *wx* is vertical, it touches the point *s* of the horizontal lever *qs;* and its angular velocity is then the greatest; and the horizontal levers *qs*, *ef* are moved by it, through a considerable angle, with a motion nearly instantaneous, so as to reach their furthest point to the right, at the instant when the piston becomes stationary at the top of the cylinder. The rod *wx* having passed the shoulder *z*, slides along the bar *zv*, which is at that time parallel to the plane of the rod's motion; and upon its return strikes against the shoulder *y*, causing a rapid motion of the levers *qs*, *ef*, to the left; the motion, which is nearly instantaneous, being ***completed*** at the instant when the piston

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point D from the common tangent, must be greater than the deflection of the point B, in the proportion of $DE : BE$; but the deflections, for small arcs of the same length, in different circles, are inversely as the radii;

$$\therefore \text{rad. } AB : \text{rad. } CD :: \text{deflection at } D : \text{deflection at } B :: DE : BE, \text{ or } \frac{AB}{CD} = \frac{DE}{BE}.$$

The arcs described by the points D and B have the same lineal magnitude *ipso motus initio:* but if D describe a finite arc, it will be greater than the corresponding arc described by the point B; owing to the increasing obliquity of the line DBE. This will occasion the point E to continue in the straight line FG for a much longer space than might be expected from the preceding theory: and hence it appears, that the correctness of the parallel depends in some measure upon the ratio of AB to DE. The best proportion of AB to DE is that which makes the *chords* of the arcs BB', DD', to maintain most nearly a ratio of equality.

The straight line AC produced passes through the point G, and the curve is symmetrical on each side of the line ACG. The point E may in practice be made to trace out the whole double curve, by inverting the angle D.

becomes stationary at the bottom of the cylinder. After this the rod *wx* slides along the bar *yt*, which is now parallel to the plane of its motion. The angular motion of the plug *abcd* is about 90°.*

The apparatus situated upon the pipe *no*, for mixing the pure hydrogen with any required proportion of atmospheric air, comes next to be described.

UV, *WV*, are two small cylinders, closed at both ends, and separated from each other by a plate of metal between the flanges by which the cylinders are connected at *V*. In this partition is an air-tight metallic valve opening upwards, and moveable by a wire passing through a stuffing box at *U*, and connected with the lever *XY*, whose centre of motion is *X*. At *W* there is another valve, similar to the former, and opening upwards *spontaneously*, as often as there is any rarefaction of the air in the cylinder *VW*. That this valve may open more easily, its weight is partly taken off by a lever parallel to *XY*. This lever also prevents, by its inertia, a rapid saltatory motion of the valve, arising from its conical form, and which retards in some measure the descent of the piston. Into the upper cylinder enters a pipe *lm*, from a gazometer or reservoir containing pure hydrogen gas: and from the lower cylinder, a pipe *no* goes to the engine, and enters at the back of the cube *ABF′* exactly opposite to the small touch-hole *c′*. The lever *XY*, and with

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* If the crank at *Q* were placed exactly parallel to the crank at *O*, or exactly opposite, that is, 180° in advance of it, the motion of the plug *abcd* would take place while the piston continued nearly stationary at the top and bottom of the cylinder, but it is here required that the motion of the plug may be *completed* at the instant when the piston arrives at its stationary points; for which reason, the crank at *Q* is placed a little further (about 10°) in *advance*. The crank at *Q* may also be placed about 170° before the crank at *O*. In this case the engine will move in the contrary direction; and this latter construction is to be preferred.

it the hydrogen valve at *V*, is elevated by the rod *wx* coming in contact with an obstacle on a fixed axle ***RZ***, with which the lever ***XY*** is connected. This small apparatus, is represented on twice as large a scale as the rest of the engine.

At the end of each of the narrow cylinders ***FG, F′G′***, is a valve opening outwards, which, for the sake of lightness, is a thin circular plate of brass or sheet copper, upon which is cemented a covering of soft leather, so as to be moderately air-tight when pressed against the end of the cylinder by a spiral spring at the back of the valve: The parts of this valve are seen detached in Fig. 5.

sv (Fig. 5.) is an immoveable brass cylinder, having upon it a spiral spring; *rst* is the valve, having a hollow cylinder *s′v′* attached to it, whose axis is at right angles to the plane of the circle, and passes through its centre.—This pipe *s′v′* is closed at the end *s′* and open at *v′*, so as to slide upon the fixed solid cylinder *sv*. Thus the centre of the valve is confined to move through a small space, ($\frac{1}{2}$ inch,) in a horizontal line, coinciding with the axis of the cylinder ***FG***: and the valve may upon this construction be made extremely light, which is a matter of prime importance. The valve may be made still lighter by attaching the leather packing to the end of the cylinder instead of cementing it upon the valve. There is also at the back of the valve an annular cushion of Indian rubber, or some other soft and elastic material, to break the impetus, which otherwise would injure its form, which is a segment of a sphere, a little flattened at the edge.

At *G′* is represented a flap valve, such as is used in a common pair of bellows. This kind of valve is more simple; and may be as effective, if made light, and pressed close by an elastic cushion.

The engine is represented with the piston descending, and about the middle of its stroke. Let the fly wheel be turned round $\frac{3}{4}$ of a revolution, so as to bring the piston to the top of the cylinder. At this instant, the rod *wx* will sweep across with a rapid angular motion carrying the lever *rqs*, and the plug *abcd* to the *right*, as in the picture. By this motion of the plug, the vertical cylinder *ABCD* will be separated from the horizontal cylinders *FG*, *F′G′*;—the small apertures *F*, *F′*, will be opened, admitting the atmospheric air freely into the horizontal cylinders; and the mouth of the pipe *no* will be opened to the inside of the cube, i. e. to the cylinder *ABCD*. The piston beginning to descend, by the continued motion of the fly wheel, the atmospheric air will rush in at the lower valve *W*, which opens spontaneously, and will occupy whatever portion of the cylinder *ABCD* is relinquished by the descent of the piston. When the piston has descended about $\frac{2}{7}$ths of its stroke, the hydrogen valve at *V* is opened, by the rod *wx* touching an obstacle *Z* on the fixed axis *RZ*. The lower valve *W* is closed by its own weight, and also by the superincumbent pressure of the hydrogen, which now flows freely into the cylinder *ABCD*; and the quantity admitted is determined by *the space through which the piston descends*, while the hydrogen valve continues open. The hydrogen valve will be closed by its own weight when it ceases to be supported by the rod *wx*; i. e. when the piston has descended $\frac{3}{7}$ths more of its stroke; the obstacle on the fixed axle *RZ* being properly adjusted. The atmospheric air will now again rush in at the lower valve *W*, till the piston comes within a quarter of an inch of its lowest point, at which time the rod *wx* strikes against the shoulder *y* of the lever *qrs*, causing a rapid motion of the plug *abcd* to the left: by which, first, the pipe *no*, and the two apertures *F*, *F′*, all being small, are closed at the *beginning* of the motion; then the piston finishes its stroke by descending a quarter of an inch *during* the motion of the lever *ef*; and lastly, the touch-hole *c′* is opened and shut again at the *end* of the motion; and there will be a gentle absorption at this touch-hole, *the valves* **G**, **G′**, *being closed,* and the piston having descended a quarter of an inch, between the closing of the pipe *n o* and the opening of the touch-hole *c′*. By this absorption the flame of a lamp or gas light constantly burning before the touch-hole *c′*, and supplied with pure hydrogen by a separate pipe from the gazometer, is drawn into the cylinder, and the mixed gas is ignited, and expands so as to occupy the whole content of the three cylinders, as far as *G* and *G′*, the common air in the cylinders *FG*, *F′G′*, being expelled at the valves.

Hence an imperfect vacuum, (density of the air $\frac{1}{6}$,) will be formed in all the three cylinders, and the piston will ascend from *C* to *A* by the pressure of the atmosphere. The plug is now moved to the right by the transition of the rod *w x*, and the piston descends by the momentum of the fly wheel acquired during the ascent, and is followed by a fresh portion of mixed gas drawn in from the pipe *n o* as before.*

The principal supports of this engine are two horizontal boards, 8 inches wide, 2 inches thick, 30 inches long, and 15 inches asunder: The plane of the upper board coincides with the base of the cube *ABF′*, which rests upon its upper surface. The same plane supports the uprights belonging to the lever *q r s*; on the under side of the same board, are two cast-iron bearings for the

* The pressure upon the piston, at the beginning of its ascent, is $\frac{5}{6}$ths of an atmosphere; or 12,5 pounds on the square inch: when the piston reaches the top of the cylinder, the pressure upon it is $\frac{3}{4}$ of an atmosphere; or 11,25 pounds on the square inch: supposing the common air to be completely expelled from the cylinders *FG*, *F′G′*, and that the machine is perfectly air-tight. It is evident that a large portion of the vacuum produced by the explosion is turned to no account in working the engine; the residual vacuum, density of the air $\frac{1}{4}$, being destroyed by the admission of atmospheric air at the apertures *F*, *F′*. It is probable, however, that no advantage would arise from employing the residual vacuum, which in practice is very imperfect, unless it could be accomplished without increasing the range and friction of the piston; especially in an engine which works only by a single stroke.

axle ***PQ***. The lower board supports the bearings of the fixed axles ***LM*** and ***L'***: also the ring at the fixed point x: the two parallel boards are connected at the ends by two uprights of the same width and thickness.

An engine upon this principle is found in practice to work with considerable power, and with perfect regularity. The advantages of it are; that it may be kept, without expense, for any length of time in readiness for immediate action: that the engine, together with the means of working it, may easily be transferred from one place to another: that it may be worked in many places where a steam engine is inadmissible, from the smoke and other nuisances connected with it: a gas engine may be used in any place where a gas light may be burnt: in places which are already supplied with hydrogen for the purpose of illumination, the convenience of such an engine is sufficiently obvious: it may be added, that it requires no attention so long as it is freely supplied with hydrogen.

The supply of hydrogen is obtained, either from a large gazometer, which may be at any distance from the engine, or from a number of long copper cylinders filled with condensed hydrogen. In the latter case, the engine, with the apparatus for working it, will be transferable from one place to another. For pure hydrogen may perhaps be substituted carburetted hydrogen, coal gas, vapour of oil, turpentine, or any ardent spirit: but none of these have been tried; nor is it expected that any of them will be found so effective as pure hydrogen.

Before the hydrogen enters the engine it is received into a small gazometer, containing about two gallons, and placed at a distance of about twenty inches from the engine. The gazometer has three pipes, each furnished with a stop-cock. Through one of them, the hydrogen passes from the reservoir into the small gazometer, and is regulated by the stop-cock, which is connected with the moveable part of the gazometer, after the manner of a ball and stop-cock. The other two pipes are placed on the opposite side of the gazometer, parallel to each other, and about three inches asunder. One of them supplies the gas light, which burns before the touch-hole *c*; the other is a continuation of the hydrogen pipe *lm*, which enters the small cylinder *UV*. The two pipes must not communicate with each other, but each must enter the small gazometer by a separate aperture; otherwise the gas light will be extinguished by the absorption from the other pipe when open to the engine. The use of the small gazometer, is to supply these two pipes separately with pure hydrogen, under a moderate but uniform pressure.—A column of water three inches in altitude will occasion sufficient pressure for the supply of the gas light.*

The consumption of hydrogen gas may be thus estimated. In the model exhibited to the Society, the capacity of the working cylinder is about thirty cubic inches; which, at the rate of sixty revolutions in a minute, requires 1800 cubic inches of mixed gas, or 450 cubic inches of pure hydrogen; the hydrogen being taken at one fourth part of the mixed gas. This multiplied by 60, gives 15,6 cubic feet of hydrogen for the consumption in one hour: and to this must be added two more cubic feet, of pure or carburetted hydrogen, for the supply of the gas light during the same time, making altogether about 17,6 cubic feet in an hour.

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* In order to ascertain with accuracy the proportion of hydrogen and common air in the mixed gas, for a given arrangement of the valves *V* and *W*, this small gazometer was filled with air: then, the valve *W* being kept closed, and the hydrogen valve *V* being continually open, it was found that twelve revolutions of the fly wheel were sufficient to empty the gazometer. Next, the valves being restored to their natural order, the gazometer was emptied by forty-eight revolutions of the fly wheel. From this it appeared that the quantity of air drawn in from the atmosphere was three-fourths of the mixture, which therefore consisted of three parts of common air, and one of hydrogen. By repeating the experiment with a new arrangement of the valves, i. e. by a fresh adjustment of the obstacle on the axle *RZ*, the gases may be mixed in any required proportion; depending however in some measure upon the velocity of the engine.

at pleasure by a stop-cock, the hydrogen is retarded in it's progress from the gazometer; which will occasion a larger admission of common air at the lower valve *W*, which opens spontaneously. If the velocity be increased, the proportion of common air in the mixed gas will also be increased; and a less perfect vacuum will be formed, attended with a decrease of power. The *momentary* regulation of the engine is not produced by an alteration in the stop-cock, but by an increased absorption of common air at the valve *W*, which increases with the velocity of the engine, the stop-cock being unaltered.

If the scale of the engine be considerably enlarged, the admixture of the hydrogen and common air may be less perfect, though the proportion of them may be determined with even greater accuracy than before. Let then the hydrogen valve be elevated twice, instead of once, during the descent of the piston: the gases will be admitted in the following order; common air, hydrogen, common air, hydrogen, common air: this will secure a perfect mixture; but in all cases the common air should be let in *first;* so that the equilibrium may be restored in the horizontal cylinders *FG*, *F′G′*, before any hydrogen is admitted.

That the upright axle, by which the plug *abcd* is moved, may be able to adapt itself to the collar through which it passes at *e*, it must be connected with the plug loosely; yet so as not to admit of any relative angular motion in an horizontal plane. To this end the upright axle terminates in a solid cube at its lower extremity, which is imbedded in the *under* side of the solid metal, (three quarters of an inch thick,) which forms the top of the plug; and the whole is covered and made air-tight by a brass plate screwed, with two small screws, pointing upwards, against the under side of the same solid. See Fig. 3.

The wear and friction of the plug *abcd*, which is nearly cylindrical, are entirely removed, by elevating it about one-fortieth of an inch above its natural position; its whole weight being supported upon the small cube at *e*. It is nevertheless sufficiently air-tight, having its upper surface covered with water, which is supplied through an aperture in the top of the cube *ABF'*. As far as respects the communication of the three large cylinders, it is not at all necessary that the plug *abcd* should be air-tight: it serves only as a *momentary* partition between two portions of air, each of which is in equilibrio with the atmosphere: but to prevent the influx of common air into the vacuum through the *smaller* apertures, the plug should be moderately air-tight.

A part of the water which covers the plug, thus elevated, is pressed through it by the weight of the atmosphere, and falls upon the piston, which carries it up again, and leaves it in the horizontal cylinders *FG*, *F'G'*, from whence it is expelled at the valves *G*, *G'*, with great velocity by the next explosion, and is received into a cistern placed below. Thus the packing of the piston and of the valves is secured from injury, and the engine is kept cool and clean in the inside. The piston may be packed with soft leather; nor will the packing be affected in the smallest degree by the explosion; for it is completely protected by a lamina of cold water, a quarter of an inch deep, which constantly covers the upper surface of the piston.

In every engine where there are packed pistons required to be air-tight, the friction arising from the motion of these pistons will cause a considerable diminution of the power: and where the pressure on the piston takes place only in one direction, as in the gas engine, the loss of power by friction is twice as great as where the engine works with a double stroke. In every such engine it becomes an object of importance to reduce the friction of the piston as much as possible: and this may be done very effectually by immersing the cylinder *ABCD*, which is partly open at bottom, in a cistern of water. In this case the piston will need scarcely any packing, and the friction will be inconsiderable. A small quantity of water will be forced through the piston by the pressure of the atmosphere upon the vacuum, and will be afterwards expelled at the valves *G*, *G′*, by the explosion. Where this improvement is adopted, it will be found convenient to invert the whole machine; making it to rest upon the four upper corners of the cube *ABF′*. A small cistern is also to be attached to the cap *CD*, and to be kept continually full of cold water.—The water is gradually forced into the engine by the pressure of the atmosphere, and is afterwards expelled at the valves *G*, *G′*. By this arrangement the friction is so much diminished, that the engine will continue in motion, though the hydrogen be so far diluted with common air as to be scarcely explosive.

Among the different constructions which may be adopted for a gas engine, there is one which, on account of its simplicity, should not be altogether omitted. It is represented in Fig. 6. *ABCD* is a long narrow vertical cylinder, divided into two parts at *a b d*, so that the upper part *ABa b* may be one third part of the whole cylinder. In the partition *a b d* is a large circular hole, covered by a choke valve turning upon an axis *a b* which passes through a small stuffing-box at *a* on the side of the cylinder. At the point *e* in the axle *b a* produced, is an upright handle *ef* connected by a cross bar *fr* with the lever *q r s*, moveable about *q*.* In the upper division *ABab* of the cylinder is a piston *ghk*, connected by two upright rods *FH*, *GK*, jointed at their extremities, with the horizontal frame *NLH*, moveable about the fixed axle *LM*. The frame is connected, at the point *N*, with a crank on the axle *PQ*, which carries a fly wheel at *P*. Immediately above the partition *a b d*, a pipe *no* enters the cylinder,

* This choke valve performs nearly the same office as the plug *a b c d*, Fig. 2; and does not require to be *air-tight*, for the reason already stated.

from a vessel containing hydrogen gas, which is mixed with common air by an apparatus already described. Upon the pipe *no* is a stop-cock, which is opened upon the appulse of the piston to the partition *abd*, and shut again upon its appulse to the top of the cylinder. At *CD* is a light valve *RST* described above, moderately air-tight, and opening downwards.

The piston, during its ascent, draws in from the pipe *no* a charge of mixed gas, which is exploded, on the appulse of the piston to the top of the cylinder, by the flame of a gas light, absorbed at the touch-hole *c*, which is opened for a single instant by the motion of a small sliding plate. The common air is expelled from the lower division *abCD* of the cylinder at the valve *RST*; leaving an imperfect vacuum, density $\frac{1}{6}$, in the whole cylinder *ABCD*. The piston descends from *A* to *a* by the pressure of the atmosphere, and is raised again by the momentum of the fly wheel, being followed in its ascent by a fresh portion of mixed gas, drawn in from the pipe *no*. The upper division *ABab*, is a cylinder of brass, accurately bored: the lower division *abCD*, requires no accuracy of bore, and very little strength: it may therefore be made of sheet copper with a strong flange at the bottom, presenting a flat face to the valve *RST*. The smaller contrivances necessary for perfecting this construction, may be learnt by comparing it with the former, which has been described at large: the principle is the same in both.

To remedy the noise which is occasioned by the explosion, the lower end of the cylinder *ABCD* may be buried in a well: or it may be inclosed in a large air-tight vessel. This vessel will be filled with condensed air, expelled together with a quantity of water from the cylinder *abCD*. This condensed air may be made to co-operate with the vacuum in working the engine; and will occasion a considerable increase of power, without adding to the friction.

In the description of a gas engine, the power is shewn to arise from the pressure of the atmosphere upon an imperfect vacuum; and is therefore quite independent of the exploding force of the mixed gas. But an engine might be constructed to work by the exploding force only; or by the exploding force and the pressure of the atmosphere jointly. A small model of this kind was exhibited, about three years ago, at the Philosophical Lectures of Professor Farish. Not to enter into the construction of such engines, which would exceed these limits, it will be sufficient to add, in conclusion, a few remarks upon exploding forces in general, and the manner of applying them, with the least danger, to produce moving force.

It may be laid down as a principle, that any explosion may be safely opposed by an elastic force, (the force of condensed air for example,) if the elastic force opposed has little or no *inertia* connected with it. On the contrary, the smallest quantity of inertia, opposed to an exploding mixture *fully ignited*, is nearly equivalent to an immoveable obstacle. Thus a small quantity of gunpowder, or a mixture of oxygen and hydrogen may be safely ignited in a *large* close vessel filled with air; for the pressure of the exploding substance, against the sides of the vessel, can never be much greater than the elasticity of the air which it condenses.* Again, if a small quantity of earth, or a piece of paper, be inserted in the muzzle of a gun, charged with powder only, the gun will commonly burst upon being fired; for in this case the powder, after being fully ignited, comes to act upon a body at *rest*, having *inertia;* and such a body cannot be moved

* By a large vessel, is meant one whose capacity is not less than the greatest expansion of the exploding mixture. The case here supposed is exactly what would take place in a gas engine, if the mixed gas were exploded, the apertures at *G* and *G′* being permanently closed.

out of the way, in an indefinitely small time, without a force indefinitely great; or it is equivalent to an immoveable obstacle.

Of all exploding mixtures, therefore, having the same field of expansion, those are the most dangerous, and the least adapted to produce moving force, which are ignited with the greatest rapidity. Thus a mixture of oxygen and hydrogen, of which the ignition is extremely rapid, is far less adapted for such purposes than a mixture of common air and hydrogen, which is ignited more slowly.

There is scarcely any exploding mixture which is ignited so slowly as gunpowder. This therefore, notwithstanding its great force and large field of expansion, is peculiarly adapted to produce either momentum or moving force; and, when opposed by a moderate quantity of inertia, is attended with less danger than some other mixtures, which explode with less force, but which are ignited with greater rapidity. But great care must be taken that the mass opposed be placed in close contact with the powder; so that the exploding force may begin to act upon it the instant the ignition commences, and that the action may cease before the ignition is completed. Thus in a common musket, if the ball be placed at a small interval, so that the powder may be fully ignited before it begins to move it, the ball in this case becomes an immoveable obstacle, and the gun will burst. It is here supposed, that the exploding mixture has itself no inertia; or that it is capable of following up the body upon which it acts, with a velocity incomparably greater than that body can acquire.

Upon these principles an engine was constructed which was moved by the exploding force of gunpowder. The gunpowder was employed to contract a very strong but light spring, by a regular series of explosions: and the elastic force of the spring in recovering its former position, formed the moving power of the engine. The danger to be apprehended from an explosion, thus resisted, depends not upon the strength of the spring so much as upon the weight of it. An engine of this kind may be made to work with regularity for a short time; and the power of it, compared with its whole weight, is extremely great. It is not however proposed with any view to practical utility, being liable to great and obvious objections: particularly from the corrosion of the metals by the sulphur contained in the gunpowder, and by the sulphuric acid which is produced during combustion. It is here noticed merely to illustrate the foregoing principle.

W. CECIL.

Papworth Everard,
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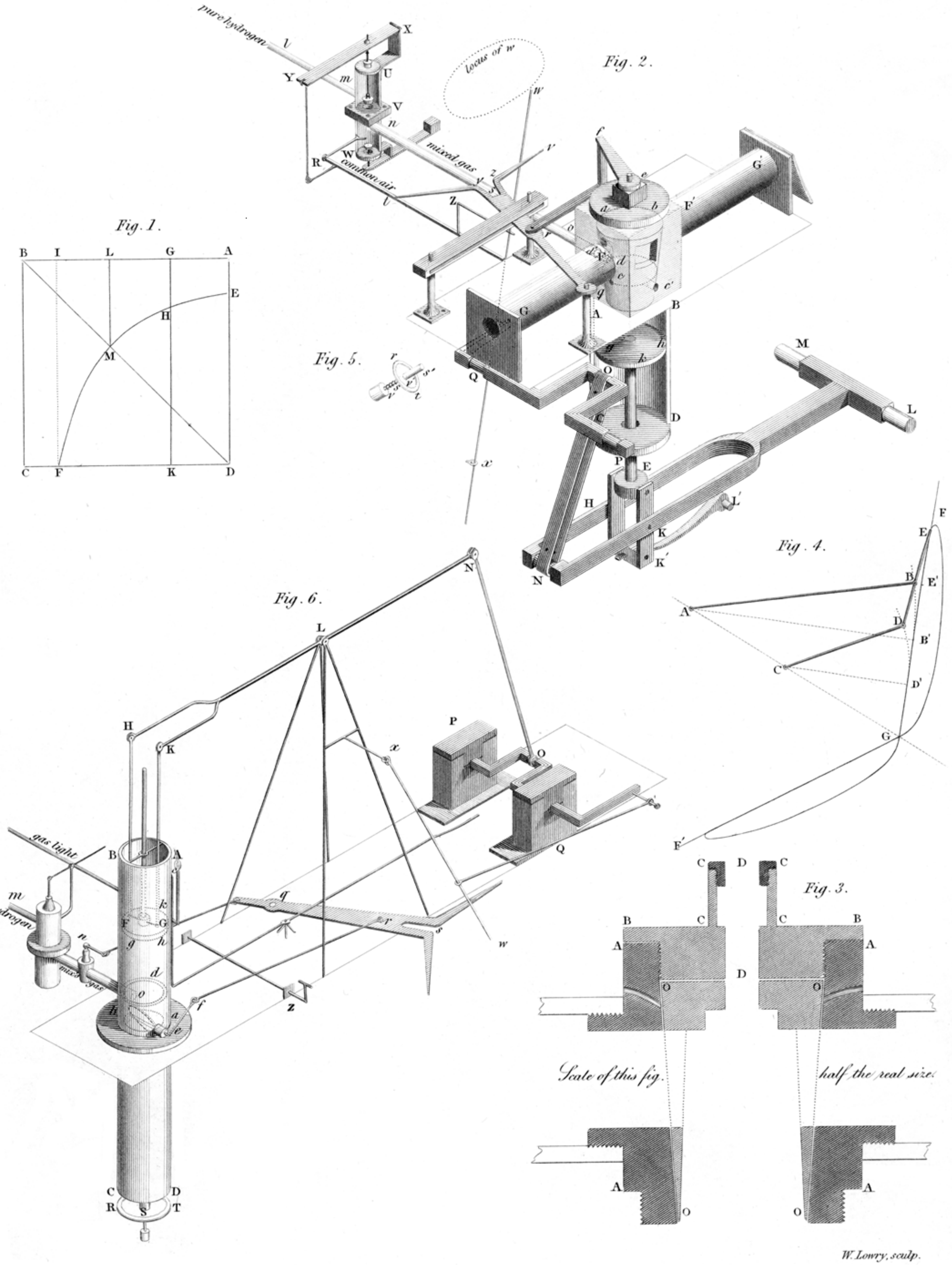

W. Lowry, sculp.