Professor WILLIAM THOMSON, (Glasgow,) through the SECRETARY, directed attention to the researches of Mr. J. P. Joule, on the subject of the economical production of mechanical effect from chemical forces, which appeared not to be sufficiently known to theoretical, or practical men generally, or even to those who had investigated that most interesting branch of electrical science.

In a series of papers in the "Philosophical Magazine,"[1] Mr. Joule had shown, by an able combination of theory with experiment, what the total mechanical effect, derivable from the consumption of a stated quantity of zinc, in any of the ordinary galvanic batteries, amounted to: and, in conjunction with the late Dr. Scoresby, he constructed an electro-magnetic engine, driven by a Daniell's battery, which actually performed more than 50 per cent. of the whole theoretical duty. The theoretical duty of a grain of zinc, used in a Daniell's battery, was 145 foot lbs., according to the dynamical deduction from Mr. Joule's most recent experiments on the thermal effects of electrolysis; a conclusion which was confirmed by direct experiments made by Professor Thomson, on the absolute electro-motive force of a single cell of that form of battery. Hence the engine referred to, (constructed by Mr. Joule and Dr. Scoresby,) which actually performed 80 foot lbs. of work per grain of zinc consumed, did 54 per cent. of the full duty. These facts were of the highest importance, in estimating the applicability of electro-magnetism, as a motive power, in practice; and indeed the researches alluded to, rendered the theory of the duty of electro-magnetic engines as complete as that of the duty of waterwheels was generally admitted to be. Among other conclusions that might be drawn from these experiments was this: that until some mode was invented, of producing electricity, as many times cheaper than that of an ordinary galvanic battery, as coal was cheaper than zinc, electro-magnetic engines could not supersede the steam engine. For, supposing an electro-magnetic engine to perform 75 per cent. of the theoretical duty, instead of the 54 per cent. obtained by Joule, then, such an engine, as near perfection as could be reasonably expected, would use 5 grains of zinc per horse-power per second, or 2·6 lbs. of zinc per horse-power per hour. A perfect electro-magnetic engine, driven by a Daniell's battery, would use 2 lbs. of zinc per horse-power per hour. Some of the best steam engines would perform 143 foot lbs. of work per grain of coal, or would use 2 lbs. of coal per horse-power per hour. In a scientific point of view, the electro-magnetic engine was most interesting,

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[1] *Vide* "Philosophical Magazine," Dec. 1843, June 1846, and January 1853.

as having been the means of solving the problem of converting a large per centage of the whole energy of chemical forces (those of combination of zinc with oxygen and acid) into mechanical effect, without letting it into the form of heat at all; making, in fact, the combustion of zinc not generate more than 46 per cent. of its equivalent of heat, and directing it to raise weights, with the remaining 54 per cent. of its energy. But this very circumstance took away from its practical importance, since it showed how little could be expected from electro-magnetism, more than had been done by Joule and Scoresby. On the other hand, Joule's theory showed, that the full theoretical duty of the combustion of the coal was about eight times as much as had been obtained in the best steam-engines, and left a very wide margin for improvement in engines, deriving mechanical effect from coal fires. It ought, however, to be added, that although steam-engines fell so far short in the duty they rendered, for the consumption of the coal, the best steam-engines did, in reality, perform 50 or 60 per cent. of the duty of a perfect engine, taking in heat at the actual temperature of their boilers; and that to attain more than double, or even to attain as much as double, the present economy of a good steam-engine, it would be requisite to employ engines, taking in heat at a much higher temperature than the highest of the actual high-pressure boilers.

Mr. Robert Hunt desired to make a few remarks, in explanation of the circumstances, by which he was enabled to offer an opinion on this important problem. Some years ago, whilst he was engaged in the investigation of the subject of electro-magnetism as a motive power, accident brought him into contact with the late Mr. Benkhausen, then Russian Consul-General in this country. Having seen the apparatus which Mr. Hunt had prepared, in Cornwall, and having witnessed some of the experiments, Mr. Benkhausen expressed a wish that Mr. Hunt should communicate the results to Professor Jacobi, with whom, he eventually entered into a correspondence, through the Consul-General, and this induced an extended series of experiments, which were carried on at Falmouth. The results obtained, led him to the conclusions, stated in the Paper,—that electro-magnetism, as a motive power, could only be applied at a very disproportionate cost. At the meeting of the British Association, at Swansea, in 1848, he was applied to by some gentlemen, connected with the copper trade of that port, to make some further experiments on this subject. These gentlemen examined, with him, a boat propelled by electro-magnetism on the lake at Penllegaer, near Swansea, and were fully acquainted with the cost at which the power was obtained. They stated, that although electricity might cost thirty times as much as the power obtained from coal, it would nevertheless be sufficiently economical, to induce its employment for the auxiliary screw ships, employed in the copper trade with South America. This led him to enter upon a fresh series of experiments, which confirmed the results previously obtained.

Another point which, perhaps, required further explanation than was given in the Paper, was the force of the current, with the magnet at rest and in motion. The mode in which these experiments were tried was this — An electro-magnet being fixed, its wires were so arranged, that they were carried on from the electro-magnet to a galvanometer: the permanent deflection of the galvanometer was first noted; then an armature, in the front of the magnet, was set in motion, to produce the disturbance he had mentioned, and the result was, that the force of the current was reduced, in the ratio represented in the Table (page 395). Thus in the first place, there was the loss of power which took place in space—for, although, when in contact, an enormous weight could be raised by the magnets, yet at an almost inappreciably short distance, the power was very considerably diminished: and to apply that, practically, when the magnet was in motion, led again to the loss of a considerable amount of the mechanical power.

Mr. W. R. Grove remarked, that it was a long time since he had devoted close attention to the subject, and he had hoped, that in the thirteen years which had elapsed, since he lectured upon it at the Royal Institution, some more decided progress would have been made; but a practical application of the science appeared to be still distant. He believed, at the present time, the data which were regarded as the best on this subject were those of Professor Botto, of Turin, who estimated that, with a Grove's battery, there would be a consumption of 45 lbs. of zinc, per horse-power, exerted, per day. Page had stated the consumption to be only 3 lbs. per day, which was a matter (as was well remarked by the Author) requiring further investigation. He thought the quantity stated by Botto might be taken as the best approximation. Starting with this, and assuming a battery of one cell, the equivalent of zinc being 32, and $\frac{1}{3}$ of an equivalent of nitric acid being 18 ($\frac{1}{3}$rd of an equivalent of nitric acid being consumed in the battery for each equivalent of zinc), there would be consumed for 45 lbs. of zinc, 25·3 lbs. of nitric acid, which was equal to about 50·6 lbs. of commercial acid. Then, taking the zinc at threepence per lb. and nitric acid at sixpence per lb., and setting off the small quantity of mercury used for amalgamation, and the sulphuric acid, against the salts formed, the estimated cost would be £1. 16*s.* 7*d.* per horse-power for twenty-four hours. That was some approximation to the practical proposition to be come to, and it could not bear any comparison, as to economy, with the cost of steam power. Large allowances should, however, be made for the approximative character of these results. Then came the theoretical difficulty of the equivalents of power. The theoretical belief was, that the same quantity of matter, being changed, would produce (if all the force could be utilised) the same amount of power; so that, theoretically, whether a pound of zinc was consumed, by burning it under a steam-engine, or the same quantity was employed to decompose water and then the gases were used, or in turning an electro-magnetic machine, provided nothing was lost, but the whole of the force was utilised, the results would, in every case, be identical as to the motive power obtained. Then there was the difficulty, not only of the cost of zinc, but also of other materials, sulphuric acid, for instance, which was the cheapest; all these went through a costly process before they were employed for these purposes. Thus a manufactured and consequently expensive matter was used instead of a crude material: unless therefore the power could be utilised to a far greater degree than was the case with the steam-engine, the difficulty was apparently insuperable. He did not think, that in the present forms of magnets, those powers could be utilised to anything like the required extent. The main advantage obtained in the electro-magnetic machine was, that when the machine ceased working, the expenditure of power ceased also, which was not the case with the steam-engine, and it was not until the power was put on again, that the consumption of material re-commenced, so that it marched *pro rata* with the work; this, however, was not sufficient to compensate for the disadvantage of having to use manufactured materials for the production of the force. Another point in favour of steam was, the smaller equivalent weight of the fuel: thus taking the equivalent of zinc as 32 and of nitric acid as 18, or indeed in practice more, say, 32 parts of zinc plus 26, or 27 parts of nitric acid, instead of 6 parts of carbon, this would give a consumption of from 50 to 60 parts of manufactured products, instead of 6 parts of crude product. If electricity could be practically obtained from coal and water, or from coal and air, the problem would be solved. It was known, that an electric current could be produced by the combustion of charcoal, or as Mr. Grove had shown, from flame: they were, however, far from the utilisation of such combustion, so as to convert its force entirely, or substantially, into an electric current, although an infinitesimal portion of that form of force could be obtained from the burning fuel; but although, at present, carbon could not be used, as the positive element of a battery, he saw no reason why it might not, at some future period, be so employed. Practically speaking, coal, in no form, had hitherto been made to serve, as the positive element of a battery. It had, indeed, at one time, occurred to him, that the difficulty might arise from carbon forming, with two equivalents of oxygen, a compound which was not electrolytic, or practically soluble, and this notion was partly corroborated by the fact, that carbon acted better as the positive element, in an alkali, as potash, or soda, where the carbonic acid would be immediately absorbed, than in an acid solution; but the current even with an alkali was very feeble.

The great desideratum was, in his opinion, not so much the forms of the machine, as the improvement of the prime mover,—the battery,—or the economical mode of charging it. The forms of machine might be divided into three classes. First, there was the principle, which might be called the principle of suspension, or making and stopping the magnetism. Secondly, the principle of Ritchie, of inversion of polarity, and,—Thirdly, the deflecting principle,—*i. e.* the galvanometric principle—where the needle was deflected by a coil around it. This began with the maximum power, and by a succession of radial magnets would seem to keep it always afloat: but the power could not be concentrated in this case, as was done by means of a soft iron core in the other two forms. All the larger machines, he had seen, had been constructed upon the suspension, or inversion principle, the last being probably the best. The boat to which the Author of the Paper alluded was partly made under Mr. Grove's directions. The engine was worked upon the inversion principle—like the old toys of Ritchie, the poles being in succession inverted—of six radii acting between a large electro-magnet. In that boat he had travelled with two other persons, at a rate of three miles an hour, eight cells of a Grove's battery of 6 inches square being employed; but the expense put it out of the question, as a practical application. Thus, the important point, in relation to this subject, was to direct attention, rather to the source of power, than to the machine itself. At present, the only available use of this power must be confined to special purposes, where the danger of steam and the creation of vapour were sought to be avoided, for instance in small machines for cutlery-works, or where economy of space such as that required for chimneys, &c. was a great consideration. In special cases it might be useful, but the general application of electro-magnetism as a motive power was still, apparently, far distant.

Professor TYNDALL agreed with the conclusions of the last speaker, which were corroborated by the experience of the Author of the Paper, as to the disadvantage of employing zinc, in the production of mechanical force, in comparison with ordinary coal. With regard, however, to one of the experiments, on which Mr. Hunt's opinions were based, he would suggest, that the magnet employed was of a particular shape; and that by altering that shape, it would be possible to obtain either a speedier, or a slower diminution of the force with the distance than was shown in

Fig. 2; he felt sure that Mr. Hunt would not found a general conclusion on so special an experiment.

Another point referred to, was the alteration of the force of the current by the motion of the apparatus. That was no doubt due to the generation of induced currents, opposed in direction to the primary current, and therefore lessening its power. He would ask, whether it would not be possible to improve upon this, by some such arrangement as the following: supposing a primary current to be sent through a coil, with a bar of soft iron within it, and having its primary current weakened by an induced current; had it ever been proposed to wind round the electro-magnet a second coil of wire, not in contact with the battery, and to conduct the induced current formed in this wire, through a still longer wire, coiled round a second electro-magnet, in such a manner that the current should assist the primary-magnet? The equivalence between heat and mechanical force was of the greatest importance, both to the man of pure science and to the practical engineer, and he would suggest, that an experiment on a subject of such momentous practical bearing as this, ought to be well corroborated. It was a subject worthy the attention of engineers, and would confer a benefit, not only upon science in general, but upon their particular art, if the results already obtained, were confirmed by experiments of a delicacy commensurate with the importance and difficulty of the question.

Mr. C. Cowper said, although no practically useful result had hitherto been obtained, in the application of electricity to the production of motive power, it was advantageous to bring the subject before the Institution, even if only to obtain a record and summary of what had been accomplished, and thus to serve as a starting-point for future experimenters.

Having made several experiments on this subject, he desired to contribute his share to the general stock of information, and had therefore brought for the inspection of the members three different machines. The first was made by himself and his brother, Mr. E. A. Cowper, about the year 1838,—nearly twenty years ago. It consisted of a horse-shoe, or staple-formed, bar, $\frac{1}{2}$ inch square and 12 inches long, covered with 40 feet of copper wire about $\frac{1}{24}$ inch diameter. Over this there revolved a bar $\frac{1}{2}$ inch square and 4 inches long, covered with 20 feet of the same copper wire. At first this revolving bar was made of one piece of iron $\frac{1}{2}$ inch square; but, subsequently, he used a compound bar, made of six, or seven pieces of hoop iron riveted together, and which was found to be much superior to the solid bar. A bar was eventually built up of about fifty pieces of the thin sheet iron called "taggers," with still further advantage, as the compound bars retained much less magnetism, than the solid ones, and thus admitted of more rapid reversal of the polarity, and greater speed of rotation.

The construction of the commutator was found to be a matter of great importance: brass segments, with ivory between them, were tried, but the brass was oxidized by the sparks which were produced, and was very inefficient; it was therefore determined to avoid, as much as possible, the production of sparks, by causing the contact to be made with one segment before it was broken with the other; a commutator was therefore constructed, composed of two semicircles of silver, separated by a very small space, which was not filled with ivory, so that the rubbing wires came in contact with one segment, before leaving the other. The segments were also oiled, and by these means all the large sparks were avoided, although small ones were frequently produced, by the vibration of the wires, at high velocities.

With these improvements the machine was found to raise 3 lbs. one foot high, in a minute, being about $\frac{1}{10000}$ of a horse-power. The battery was one cell of Daniell's construction, 3 inches diameter and 6 inches high; the consumption of zinc was one ounce in eight hours. Allowing one shilling per pound as the cost of the zinc, including the acid and the sulphate of copper, less the value of the reduced copper, the cost of the power produced was about £4 per horse-power per hour. This machine was afterwards driven by a Grove's battery, and it then raised rather more than 5 lbs. one foot high, in a minute. With this arrangement, it was used to drive a bobbin and fly, at a lecture on cotton-spinning, given by his late father at the Royal Institution, in April, 1840.

A larger machine, constructed with several magnets, produced less power than this small machine. The commercial result of these experiments being so unsatisfactory, they were discontinued. The first machine frequently revolved at more than one thousand revolutions per minute, and the centre of action, of each pole of the revolving bar, then travelled about 900 feet per minute, or 15 feet per second, or $\frac{3}{16}$ inch in one-thousandth part of a second. As the chief part of the power was developed in a space of $\frac{3}{16}$ inch, over the poles of the fixed magnet, it followed, that the magnetism of the revolving bar must be reversed, or destroyed, in less than one-thousandth part of a second, to enable the machine to act effectively, at a speed of one thousand revolutions per minute. It appeared, therefore, that a greater velocity and useful effect might be obtained, if the moving magnet was made to pause, or to move very slowly, whilst the polarity was being reversed, or destroyed. A reciprocating motion, with a connecting rod and crank, was used by Mr. Davidson in 1842, and by many others subsequently, but the reciprocating motion was not adapted for high velocities, and the friction of the crank was excessive, as almost all the power was produced and applied to the crank, as it passed the centre.

Mr. Cowper succeeded, however, in combining the advantages of the crank motion with those of a rotary motion, by means of an eccentric-shaft machine, which he exhibited, constructed and tried in March and April, 1848. In this machine an iron shaft was employed having three eccentric portions, the central one being equal to the sum of the other two, and on the opposite side of the axis of the shaft. The shaft was, therefore, perfectly balanced, and was capable of revolving steadily, at high velocities. Two horse-shoe, or staple-formed electro-magnets, of the same dimensions as that employed in the first machine, were placed on opposite sides of the shaft. The poles of these magnets being flat, it would be obvious, that the eccentric portions of the shaft approached and receded from them, at the same velocities as if they were governed by a crank. The current of electricity was caused to traverse the wires of the two electro-magnets alternately, and the shaft was thus alternately attracted by them, and was caused to revolve with great rapidity. It was originally intended to add two other magnets, to act upon the central eccentric part of the shaft, but the results of the experiments were not sufficiently favourable to induce the completion of the machine in that manner. Various shafts were tried, from $\frac{1}{4}$ inch diameter to $1\frac{1}{8}$ inch diameter, and also a hollow shaft made of a piece of gas-pipe. The best result was obtained with a shaft of $\frac{9}{16}$ inch diameter, which was now used. The batteries employed were six Smee's batteries, charged with one volume of strong sulphuric acid, diluted with sixteen volumes of water. The active surface of the platinized silver of each battery was 25 square inches. The batteries were connected as a series, or the zinc of one battery to the silver of the next. The machine ran about 4,000 revolutions per minute, unloaded. With a load, the most effective velocity was from 1,800 to 2,600 revolutions per minute, and it then raised 21 lbs. one foot high in a minute, being $\frac{1}{1500}$ of a horse-power.

With a single Daniell's battery, $3\frac{3}{4}$ inches diameter and 20 inches high, the machine made one thousand and forty revolutions per minute, when raising 1 lb. one foot high per minute. It was allowed to work for one hour and a quarter, and at the end of that time it raised 1 lb. 6 oz. one foot per minute. The average was 1 lb. 3 oz., or during one hour and a quarter 89 lbs. raised one foot. The zinc consumed was barely one-sixteenth of an ounce. Thus to obtain one horse-power there would have been $1\frac{1}{4}$ lb. of zinc consumed per minute, at a cost of about fifteen-pence, or £3. 15*s*. per horse-power per hour.

The first magnets employed in this machine were made of solid iron, $\frac{1}{2}$ inch square, but the above results were obtained from compound magnets, made of ten thicknesses of No. 18 charcoal plate iron, riveted together. The commutator employed in this machine was the same that had been used in the first machine. One pole, or electrode, of the battery, was connected to one end of the coil on each magnet; the other ends being connected respectively to the two segments of the commutator. The other pole, or electrode, of the battery, was connected to one of the bearings of the shaft. A brass spring, tipped with silver, was attached to the shaft, and the silver tip rubbed on the inside of the segments. It was at first made to rub on the outside of the segments, but it was thrown off by centrifugal force at high velocities, and when the spring was made strong enough to resist the centrifugal force, the machine would not run at low velocities.

In July 1848, Mr. Richard Roberts, of Manchester, showed him some very powerful electro-magnets, made by cutting parallel grooves in a square slab of iron, and winding a bundle of wires backwards and forwards in the grooves. Each rib thus acquired the opposite polarity to the adjoining ribs. It appeared, that circular magnets, constructed in a somewhat similar manner, would be well adapted for electro-magnetic engines. Accordingly, in November 1848, Mr. Cowper constructed the third engine exhibited, which might be called a " clutch engine." It consisted of two similar electro-magnets, the lower one being fixed, and the upper one revolving over it. Each magnet was in the form of a clutch, consisting of an iron disc 4 inches diameter and $\frac{1}{4}$ inch thick, from which twelve teeth projected $\frac{5}{8}$ inch, and had twelve equal spaces between them. The teeth extended from the circumference to within $\frac{7}{8}$ inch of the centre. Three bundles of copper ribbon were wound, alternately, in and out, round these teeth. In each bundle there were eight ribbons, $\frac{1}{8}$ inch wide and about $\frac{1}{45}$ inch thick. The ribbons were all connected, so as to form one continuous ribbon of 49 feet in length, and weighing 8 ounces. The iron of the lower magnet weighed 2 lbs. 2 oz. The upper one, with the iron shaft on which it was mounted and the silver commutator, weighed 2 lbs. $5\frac{3}{4}$ oz.

The commutator consisted of two clutch-formed silver rings, each of which had six teeth, which entered the spaces in the other ring, leaving a slight interval between them for insulation. The interior of the rings was filled with a resinous cement, to prevent the entrance of abraded particles of metal, which might form a connection, and destroy the insulation. The surface of the cement had, however, been carefully lowered, so that it might not come into contact with the silver tips of the wires which rubbed upon the commutator. The upper ring of the commutator was in contact with the iron shaft, to which was also attached one end of the ribbon, on the revolving magnet. The other end of the ribbon was connected, by an insulated wire, to the lower ring of the commutator. One of the rubbing wires was connected to one pole, or electrode, of the battery, while the other rubbing wire was connected to one end of the ribbon, on the fixed magnet, the other end of which ribbon was connected to the other pole, or electrode, of the battery. The poles of the upper magnet were thus reversed twelve times, in each revolution, at the moment of their passing the poles of the lower magnet. In all the machines "lead" was given, and that "lead" was adjusted, until it was considered to produce the maximum effect, which diminished rapidly if too much "lead" was given.

This machine, with five Smee's batteries and one small Grove's battery, in a series, raised 8 lbs. 3 oz. one foot, per minute, making one hundred and five revolutions per minute; unloaded, it ran eight hundred and fifty revolutions per minute. The load was raised by a thread, winding on a boss on the shaft, and the machine had not sufficient time to get up to its full speed. It was, therefore, now fitted with Prony's brake, the lever, or arm, of which was $3\frac{13}{16}$ inches long, and described a circle of 2 feet in circumference. This lever was connected to the vertical arm of a bent lever, whose horizontal arm was of equal length, and carried a scale-pan. The power was thus equivalent to the weight in the scale-pan, raised 2 feet, by each revolution of the machine. The machine was tried in this manner very recently, and was found to run from two hundred and sixty to three hundred revolutions per minute, with a load of about 260 grains in the scale-pan, various loads being tried, with the brake adjusted to them. The maximum effect obtained was 21 lbs. one foot high in a minute. The battery consisted of two of Lemolt's batteries, connected as a series. The carbon element of each battery was $1\frac{3}{8}$ inch wide by $\frac{5}{8}$ inch thick, and immersed $4\frac{1}{4}$ inches in nitric acid, of a specific gravity of about $1 \cdot 38$, to which a little concentrated sulphuric acid had been added. The zinc cylinder was $2\frac{1}{2}$ inches diameter, and was immersed in very dilute sulphuric acid, containing sulphate of zinc, from previous experiments. The nitric acid had also been used in previous experiments.

This machine might probably be rendered more powerful, by making the iron teeth, or poles, of greater length, and winding round them a greater quantity of conducting wire, or ribbon. It would also be advantageous to make the teeth, or poles, of the revolving magnet of an assemblage of thin plates of iron, instead of making them solid.

Although there was not any proof of the fact, it did not appear improbable, that a chemical equivalent of zinc, consumed and oxidized, in driving a perfect electro-magnetic engine, would produce the same amount of power as an equivalent of coal, consumed and oxidized, in driving a perfect steam-engine. Zinc costs about sixty times as much per ton, and about three hundred times as much, per equivalent, as coal. If, therefore, there was only realized one-tenth of the total effect from coal, and if the whole of the effect was realized from zinc, the cost of the power would still be thirty times that of steam power. This estimate was merely given as a suggestion, as there was not any proof of its correctness. In order to reduce the excessive cost of the power, it had repeatedly been proposed to sell the sulphate of zinc, or other products of the battery, for as much as the cost of the zinc and the other materials employed. The chief obstacle to this was, that purchasers on such terms were not to be found.

On the other hand, it had sometimes been admitted, that the cost of working these engines was much greater than the cost of obtaining the same power from steam, but that, owing to the lightness and compactness of electro-magnetic engines, they would be preferable, where lightness was of great importance, as in locomotive and marine engines. This proposition depended on the assumption, that they were lighter, for equal power, than steam-engines. This might be ascertained by calculating the velocity at which any of the engines could raise their own weight. Thus the clutch-engine, exhibited, might weigh, with the necessary batteries, about 15 lbs. This machine would, therefore, raise itself about 1 foot 5 inches per minute. The small locomotive exhibited by Mr. Davidson in the Egyptian Hall, in 1842, which he considered his best machine, would not have raised itself more than 8 inches per minute. A locomotive steam-engine of 30 tons weight and 100 H. P. would raise itself 50 feet per minute. In fact, the clutch engine, exhibited, weighed, with the batteries, about 10 tons per H. P. There was no doubt, that electro-magnetic engines of less weight, in proportion to power, might be made; but, as far as present experience went, there appeared to be no reason for supposing, that they could be made as light as steam-engines.

It had also been proposed to employ electro-magnetic engines, where only a small amount of power was required, as the tenth, or hundredth of a horse-power, and where the cost of the power was of less consequence. But even in such cases, a boy, or a man, turning a winch, would probably furnish the power at a cheaper rate.

Mr. Joule's experiments, as recorded in the "Philosophical Magazine,"[1] were valuable and interesting, but Mr. Cowper doubted whether any engine had ever been made to give a useful effect of 54 per cent. of the theoretical power developed, or been worked with so little as 4 lbs. of zinc per horse-power per hour. His own small engines consumed 70 lbs. or 80 lbs. per horse-power per hour by friction break, or weight lifted, and he thought Mr. Joule's would have consumed half that quantity, if tried in

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[1] "Phil. Mag." (3rd series) vol. xxviii.

the same way. In Mr. Joule's experiments three batteries in a series were used, and each was allowed to consume the theoretical equivalent of zinc. This at once reduced the useful effect from 54 per cent. to 18 per cent. The power was estimated by allowing the engine to run without any load, the speed and the consumption of zinc being noted. The batteries were then disconnected, and the engine driven by a weight on a cord going round the shaft, and this weight was increased, until the engine ran at the same speed as before. The rate of descent of the weight having been found, and that multiplied by the weight, the result was called the power developed. But this was not useful effect, as the whole of it was consumed in friction and resistance of the air, &c., so that the useful effect at that speed was nil. If a load had been put upon the engine, its speed would have been reduced, and the consumption of zinc increased, so that the useful effect was probably not more than 6 per cent. of the theoretical maximum.

Mr. Smee agreed with, and had constantly and earnestly, in his various works, during many years, enforced, the doctrine advanced by the Author of the Paper, with regard to the cause of failure of electro-magnetic machines, in an economic point of view. In all forces it was essential to regard the primary change of matter, or the new attraction set up, to produce the phenomena which were manifested. In the steam-engine, the power was derived from the attraction which was exerted between the coals and the oxygen of the atmosphere. In that case, the oxygen cost nothing, and coals were obtained at a cheap rate. In a battery, the attraction between the zinc and the oxygen of the water was the source of the power. Although zinc was dear, and the water required the addition of sulphuric acid, the battery had one great advantage, because, in a well-constructed instrument, the initial change which occurred to produce the power could all be used, within a very small per centage of waste, for numerous purposes. He had ascertained this fact in his own battery, whilst making the types by which the Bank of England notes were printed. Although it had been in use for three weeks, without re-amalgamation, or changing, it did its work, within a small fraction, equivalent to the change which took place in the battery; and he found that a well-arranged instrument would act for many months without alteration. He considered that the most perfect results, with regard to the primary changes, were obtained with the voltaic battery; but when, in comparing the equivalents of zinc with the equivalents of coal—the former being 32, and the latter only, as hydrogen and carbon, 1 and 6—there was a difference greatly in favour of coal, as a source of power, and, moreover, carbon entered into two attractions with oxygen to form carbonic acid. Then there was the great difference of cost with regard to zinc; and if other metals were employed, to generate power in the battery, in the majority of instances the expense would be greater. He had tried tin, but it was more expensive; iron, although cheaper, had also been employed, but not advantageously; and it would be found that, unless the products of the new attraction were commercially utilized metals, all metals having in the first instance to be manufactured with hydrocarbon, or coal, were much dearer than when the coals were used direct. He had tried extensively the use of hydrocarbons for a positive pole, but they were not practically efficient. He thought, with regard to the voltaic combinations, that the hydrogen which was allowed to escape might be utilised advantageously for some purposes. With reference to the sulphate of zinc, which was the compound formed by the new attraction in his battery, although it was extensively used in surgery, and theoretically should be sold at a profit, as a manufactured article, yet he had found it cheaper to throw away that produce of the batteries, than to evaporate the solution into a marketable material. He had taken great pains to find a market for the sulphate of zinc formed in his batteries, but hitherto without success. The sulphate of zinc required a certain quantity of water to dissolve it, whilst the new matters formed in the burning of a furnace were sent out into the atmosphere. Hence there was no such thing as a small productive battery. The trough of the battery must be of sufficient size to dissolve a certain amount of zinc, which was a great disadvantage as against the battery, in large operations. With regard to the operation of magnetic machines, he had found, in common with all who had experimented upon the subject, that the cost, from the above causes, would be enormous for heavy work; and he thought the true theory of the cost was to be sought from the equivalent number of the matter changed, and the expense of the materials which entered into the new attraction. Although motive power could not at present be produced at the same expense, on a large scale, by the agency of the battery, as it could be by coal, still they were enabled readily to apply the power at any distance from its source, and the achievements of the electric telegraph might be regarded as an application of motive power by electricity, which was by no means to be despised. From his experiments, he believed that in animals force was applied, at a distance from the brain, by electrical agency; and whenever it was desirable to regulate, or to apply force at a distance, electro-motive power might now be very advantageously employed.

Mr. Petrie said, he had devoted much time and thought to the action of the permanent magnet, and had arrived at identical results with those described by the Author and by the previous speakers. The system could only be practically applied at enormous cost. The results of the relative value of the power produced from zinc in a battery and the amount of zinc consumed per horse-power produced, agreed with his own observations. His particular object, in experimenting, was to obviate the difficulty of the short distances over which the power acted, in the case of ordinary electro-magnets. The advantage of the deflective power, giving action over a distance of 12 inches, in the place of only a fraction of an inch, was of great benefit. He obtained a permanent action equal to raising about 18 lbs., but that was reduced, directly it was attempted to attain any velocity. All the difficulties described with regard to the form of the magnet, &c., were minor considerations. The grand point appeared to be, the mode of dealing with the induced current, which was the secret of the great reduction of force, whenever motion commenced; and the induced current increased in proportion to the rate of motion, and up to the present time that difficulty appeared to be insurmountable. Many remedies had been suggested, but most of them appeared to be of the same nature as the attempts to produce perpetual motion, by mechanical means. Induced currents were the necessary effects of the generation of the power, and it was by virtue of those induced currents, that they were prevented from obtaining infinite power from batteries of finite dimensions. If it was not for these currents, it would be possible to work at any velocity. Not being aware of the real effect of the induced currents, when he commenced his experiments, he fancied that he was on the eve of obtaining infinite power by finite means; but he soon discovered the mistake, and became aware that he was attempting to obtain little short of perpetual motion. It seemed to be a loss of time to attempt to deal with this induced current; therefore it was necessary to search in some other direction, to improve the power, in order to bring it into practical working condition.

The main idea, which had been so well noticed, was the comparative value of the forces produced from zinc and from carbon, the results being decidedly against the former. The relative affinities of atoms of carbon and atoms of zinc, for oxygen, must be borne in mind, as they were so different as to preclude the economical use of zinc, for the production of power; hence arose the idea of obtaining power from carbon, by first producing electricity, instead of heat from oxidation. As to the nitric acid used in the batteries, it was only necessary to expose the residuum to the action of air and moisture, and it would be reconverted into nitric acid; or the same result might be effected by filtration through finely-divided matter, such as pounded coke, while exposing it to the action of the atmospheric air. Thus an important item of expense in a battery might be reduced.

Mr. G. P. Bidder, V. P., said, the Paper was one of great interest; the Author had treated the question very ably, and had brought it to a point which admitted of its being examined, as to the commercial results; but, at the same time, he had shown, that there had, hitherto, been a lamentable waste of mechanical ingenuity, in attempting to bring electro-magnetism into use on a large scale. The several created forces now used were—manual power, produced by animal and vegetable food; horse power, produced by oats, grass, and hay; electro-magnetism, resulting from zinc and acids, and steam-power, produced by the action of coal. Assuming, that a man could not be kept in good working condition for less than two shillings per day, nor a horse for less than two shillings per day, on comparing the cost of different means of producing power, it would be seen that, for every shilling expended, there might be raised by

Manual power .	600,000 lbs.	one foot high per day.
Horse " .	3,600,000 lbs.	ditto.
Steam " .	56,000,000 lbs.	ditto.
Electro-magnetism .	900,000 lbs.	ditto.

Mr. R. HUNT, adverting to the remarks of the previous speakers, as to the action of magnetic forces through space, said it had been asked if the electro-magnets of the horse-shoe form had shorter arms than those represented in Fig. 2, and whether the diminution of force, through space, would not be different from the rate of diminution observed with such a magnet as that represented. Now, the numerical results given in Fig. 2 were the mean average results actually obtained by experiments with magnets of various forms—some having long and others short arms, and especially from one, as contrived by Mr. Joule, which had exceedingly short arms, and was made of a series of plates of iron, each plate covered with clothed wire, and then bound together. The results there represented, and those (on Fig. 7) of Hjörth's engine, were obtained under the best possible conditions, giving the mean average of a great number of experiments. With regard to the force of the currents, with the magnet at rest and in motion, it had been suggested, that the induced current was the cause of the falling off of the force, when the magnet was in motion. As had been remarked, this might, in some degree, be remedied by winding round the magnet a closed coil of wire, not connected with the battery, the induced electricity in which might be employed to produce magnetism in another bar of iron, which magnetism it was argued could be employed. This plan was tried by Hjörth; but, from the difficulty he experienced, in dealing with this current, when the magnet was in motion, he was induced to abandon it. Mr. Hunt had also tried it, and had found that the power from the second magnet, thus created, was of very inferior moment, in any form of machine which he could devise, and was not available for any practical use. He had recently received a communication from Mr. Joule, and as the opinions of so eminent an authority might be interesting, he would briefly quote them :—

Mr. Joule said, " It was to be regretted that, in France, the delusion, as to the possibility of electro-magnetic engines superseding steam, still prevailed. Fifteen years ago, it had been proved, experimentally, that the heat evolved by any voltaic circuit, in which an engine was not included, was exactly that due to the chemical actions taking place, the conducting wire merely presenting the means of evolving the heat in any given locality, instead of its being all evolved where the chemical action took place. This discovery, which had been erroneously attributed to M. Favre, whose experiments were only three years' old, was followed up by the discovery, that if an electro-magnetic engine was placed in the voltaic circuit, the heat evolved, corresponding to a certain chemical action, was diminished, the heat which disappeared, being converted into the mechanical force given out by the engine. The greater the quantity of heat which disappeared from the voltaic circuit, relatively to the heat due to the chemical actions, the more perfect would be the economy of the electro-magnetic engine; and as it was possible to make the engine work, so as to reduce the intensity of the current to a very small fraction of its strength, when the engine was not working, nearly the whole of the heat due to the chemical actions of the battery might be evolved as work. Supposing all of it were converted into work, there would result 145 foot lbs. for each grain of zinc consumed in a Daniell's battery. It was the weakness of the chemical actions of a voltaic pile, as compared with that of the combustion of coal, and the relative cost of zinc and coal, which decided so completely in favour of the steam-engine. As regarded the strength of the chemical actions, one grain of zinc, consumed in a Daniell's battery, gave out heat equivalent to 145 foot lbs.; but one grain of coal, burnt in air, produced heat equivalent to 1,261 foot lbs., or nine times as much; so that if a steam-engine was so bad as to convert only one-ninth part as much heat as the electro-magnetic engine, the two would still be on a par. As to expense, it was obviously impossible that the cost of coal could ever become more than a minute fraction of that of zinc, to say nothing of that of other necessary materials."

It has been asserted, that the results arrived at by Joule, had not been confirmed by other experimentalists. This was not the case, as similar researches had been undertaken by Professor W. Thomson, and Dr. Scoresby had worked with Joule on this problem; it had also engaged the attention of Professor Bunsen, of Marburg, and, more recently, of M. Favre, who had arrived at the same conclusions, as those recorded by Joule, and the general testimony was entirely in favour of the views which Joule entertained.

Mr. T. ALLAN said, it would appear that those who had hitherto directed their attention to the subject of electro-motive power, had commenced at the wrong end. They seemed to consider, that the whole question resolved itself into producing a certain amount of electricity at a given cost. The chemical question, in fact, was considered, instead of the mechanical application of a given force. Magnetic force died rapidly away through but a short space. If the geometrical curve of the dynamic force of magnetic attraction was drawn, and was divided into ten parts, it would be found, that if the tenth nearest the magnet gave a mean power equal to 1,000 lbs., the mean force of the tenth part furthest from the magnet would only be 3 lbs., though the same amount of electricity would be used in the one case as in the other. Taking the mean of the whole attraction of a magnet, only a small power was obtained, but through so short a distance as to be mechanically unavailable. In Jacobi's engine, in which the rotary principle was adopted, the minimum portion of the magnetic attraction only was applied, giving but a small power, with a large consumption of electricity. In Mr. Allan's electro-magnetic engine, in which a different form of magnet, with four, six, or eight poles placed upon a plate, had been adopted, it had been endeavoured, by a direct action, to apply the maximum portion, only, of the dynamic force, and this, by a succession of magnets, was successively and continuously brought into action, giving a comparatively large power, with a small consumption of electricity, and producing, in a machine, a continuous motion analogous to the overshot water-wheel.

It was to be hoped that, though apparently impracticable now, in process of time electricity might be applied as a motive power; for when it was considered, what had taken place with regard to electricity,—how, in the first instance, it had been obtained from friction upon amber, or glass—was then developed by chemical action from metals—and was subsequently manifested by the influence of heat on solid bodies, as shown in the form to which the name of thermo-electricity had been given,—it was felt, that a series of careful researches into the undeveloped secrets of this marvellous element, might result in a means of producing the power, which would render it as economical and advantageous as the heat which was now obtained so easily. It was only a few years since Sir Humphry Davy was compelled to employ a thousand pairs of zinc and copper-plates to do the work which twelve of the same agents would perform, in a modern battery.

Mr. SMEE said, with respect to the question of how near a battery, acting over a considerable time, would do the work, that was due to the attraction going on in that battery, he found, from his experiments upon the plates for the production of the Bank of England notes, that the waste of zinc in a single cell of the battery during eighteen days was 19,414 grains, and that in the decomposition cell the positive poles lost 19,139 grains. The difference between these two would be the real difference, or loss of power, between the work performed and the new attraction set up in the battery, which he apprehended was for the work done in relation to the matter changed or burnt, nearer than could be obtained by any other means. This was accomplished in one of the batteries devised by him and ordinarily called "Smee's Battery." But with a "Daniell" battery another change was going on; the hydrogen was decomposing the sulphate of copper, and the equivalent of power could not be obtained at less than double the expenditure of simply employing zinc. Then again with a "Grove" battery, the nitric acid was decomposed by the hydrogen, and was even more costly than the "Daniell" battery. The nitric acid was destroyed, and the change that occurred was three, or four times as much as when zinc alone was dissolved. He was not aware, that either Daniell's, or Grove's batteries had ever been employed for any lengthened period. It appeared to him, that batteries would effect that, which he believed, no mechanical force would alone effect. First, the power could be used at any distance; and secondly, the battery, when once charged, would continue to work, over a long period of time, without further attention. The fall of the time-ball at Deal, by which the chronometers of the mercantile navy were regulated, was *de facto* an application of motive power, produced by one of his batteries at the Greenwich Observatory. The same motive power was employed for regulating the time at the Post-Office, the Great Western Railway Station, and other places, and the point in which this power exceeded all others was the extreme distance at which it could be applied. Theoretically, battery power ought to be generated at a profit. The sulphate of zinc produced in these batteries was a product of value in the arts, and should find a ready market; it ought to be sold at a profit to the manufacturer, and by that means electricians should obtain their power almost without cost. At present, no profit had been derived from the sale of the sulphate of zinc, as the manufacturers preferred preparing it themselves, rather than incur the expense of sending carts for the solution made by the battery. The residuum was produced in large quantities in the preparation of the plates for the Ordnance Survey, where his batteries were employed on a large scale; the sulphate of zinc so obtained had been sold, and had become a matter of consideration in a commercial point of view. The great desideratum was to obtain electro-motive power, not only without cost, but at an actual profit. It had been attempted, as a commercial speculation, but hitherto, he believed, without success. He could not agree that the theory of the battery was not a fundamental question, in considering the question of electro-magnetic power. In the production of all forces there must be an atomic change. The cost of that change alone precluded the use of zinc instead of coal, in producing gas. Nearly twenty years ago he attempted to use the gas from one of his large batteries, for the purpose of lighting his own house; there was not any difficulty in arranging a small apparatus for the purpose, but he estimated that the gas so obtained, instead of costing six, or seven shillings, per thousand feet, which was the price of coal gas at that time, would cost £7 per thousand feet. He believed zinc at the present time was the best and most economical material for obtaining battery power, even when all the products were thrown away; but, at the same time, the power thus obtained was nearly a thousand times dearer than if coal was employed. In using the term coal, he meant it in the more extended term of hydro-carbons generally, as he had attempted to employ them. He had obtained a certain amount of voltaic power when sugar, oxalic acid, and various other materials, were used as positive poles, but it was very insignificant, as compared with the power obtained from zinc; and if a substantial amount of power was required, enduring week after week and month after month, and even for a whole year, without deviation—as, for instance, for an electric clock—no other substance was at present known, which would produce effective power so well as zinc. He was, therefore, sorry to hear it asserted, that the battery power might be neglected, in the consideration of electro-motive power, as he was satisfied, on the contrary, that it was the primary object to which attention should be devoted. With regard to the mode of employing the magnet, he believed that human ingenuity was by no means exhausted, as to the best form of applying this power. At present it was used for long periods of time and at considerable distances, and in that respect was, perhaps, superior to any other mechanical power for small effects; it was similar to the operation upon the nervous system on animal nature, where the power was transmitted from the brain to the extremities, to impart motion. Electrical power could be used at immense distances from where it was produced, as, for instance, in working electrical clocks, detaching the time-ball, &c., to which he had previously alluded. These were the legitimate uses of electric power, and in this direction science would yet produce more marked results, and there was reason to hope that electrical power might still be obtained more economically, and be used more extensively.

Mr. R. Hunt still hoped, that in process of time electricity might be applied as a motive power. The object he had in view in bringing forward the Paper, was to endeavour to show that, with the present voltaic battery and appliances, it was absolutely impossible to employ electro-magnetism as a motive agent with any practical advantage. He could not agree with the remark, that they had began at the wrong end. Before a steam-engine could be driven, the construction of the boiler and of the furnace must be considered; so likewise, as the battery was the primary source of power, it was essential to establish that form and combination which produced the power most effectively and economically.

It should be observed, with reference to the convertibility of chemical into mechanical forces, that in the oxidation of the zinc in a voltaic battery a certain amount of power was developed, in the shape of electricity; so, in like manner, a certain amount of power was obtained in the shape of heat from the oxidation of carbon in the furnace, to be employed in vapourizing water, and the expansive powers of that vapour were used in driving machinery. Now, although in the battery another form of force was developed as electricity, it appeared to him that electricity might be employed in some way analogous to the method in which heat was now employed. Electricity was now operated with, having particular reference only to its attracting and repelling powers, and there appeared to be considerable difficulties in its application, especially the small distance through which the force acted, and the rapid ratio of its decline in power. The nearest mechanical arrangement which might be considered, in relation to the steam-engine, was in Hjörth's machine, which consisted of an electro-magnetic cylinder, into which, and from which, there moved an electro-magnetic piston. When first the action commenced, drawing the piston into the cylinder, the mechanical force continually increased, as the piston passed towards and partially into that cylinder; but when it came to the repelling force, to drive the piston back again, there was a continual diminution of mechanical force from the first commencement of motion, and in that respect the difference, as compared to the steam-engine, was manifested.

Mr. Gravatt remarked, that in decomposing water hydrogen and oxygen were produced, and being both elastic gases, the process might, when these gases were generated under pressure and made to raise a piston, to some extent, be compared to the production of steam, and this was the nearest approach to the condition of the steam in a boiler. Of course the gases might be afterwards burnt together, and in this manner he had worked a miniature experimental engine: the only question was the expense; in fact, in the one case zinc, and in the other case coal, were respectively the fuels used to obtain power.

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Mr. E. HIGHTON thought, that the subject under discussion ought to be divided into two distinct parts—first, the mode of producing electricity, and second, the apparatus to which such electricity was to be applied. If possible, the natural products to be found in the earth ought, for the sake of economy, to be employed in both cases, instead of products manufactured at considerable cost. Hitherto, electro-magnetic engines had not been constructed in accordance with a power varying inversely as the square of the distance, for which he suggested certain remedies. He also recommended, that a modification of the waves of contraction in muscular fibre should be adopted in electro-magnetic engines, and stated that there were certain peculiarities common both to muscular fibre and to the electro-magnet, particularly as regarded sound, which was developed in both, on the production of a pulling power; and each was a substitute for nervous energy. Electricity could be used either directly, by means of the electro-magnet, or indirectly, by the explosion of gases. Heat, electricity, electro-magnetism, magnetism, and pulling power were all only different manifestations of one and the same force, and each was convertible into any other. He then analysed the mechanical effect of a flash of lightning, and showed that, in a certain instance, the power developed through 50 feet was equal to a 12,220 H.P. engine, and that the initial explosive power was equal to a pressure of three hundred millions of tons. The desirability of obtaining a motive power requiring less weight per H.P. than the steam-engine was unquestioned, and he referred, incidentally, to some experiments which had been tried, at different times, with this object in view. In this way it had been ascertained, that the motive power derivable from the chalk formation near London, would cost four times more than that obtained from coal. The power to be derived by the production of the vapour of a volatile spirit by the condensation of steam—from the explosion of a mixture of hydrogen and oxygen by electricity—from the condensation of the vapour of a highly-volatile spirit by ice—and by a certain quantity of solid hydrogen and oxygen, by means of the steam-engine and by means of the muscle of the horse, were successively described; and it was stated, that the latter gave out nearly ten times as much power as the most perfect present arrangement of the steam-engine in Cornwall.

Mr. R. STEPHENSON, M.P.,—President,—in closing the discussion, remarked, that there could be no doubt, from what had been said, that the application of voltaic electricity, in whatever shape it might be developed, was entirely out of the question, commercially speaking. Without, however, considering the subject in that point of view, the mechanical application seemed to involve almost insuperable difficulties. The power exhibited by electro-magnetism, though very great, extended through so small a space as to be practically useless. A powerful magnet might be compared, for the sake of illustration, to a steam-engine with an enormous piston, but with an exceedingly short stroke. Such an arrangement was well known to be very undesirable.

In the mechanical application of power, velocity, or in other words, the space passed over, was made as large as possible, and in proportion as this was accomplished had the efficiency of the machine been extended. Now this was precisely the difficulty under which the application of magnetism laboured, the space through which it could be made to extend being so exceedingly small. The example of letting fall the time-ball at Deal, and in other places, could not be quoted as an exertion of power; the abstract fact of the falling of the ball was evident, but the apparatus by which the ball was set free was of a very delicate nature, so that a very slight impulse sufficed. If the ball was raised by electric action it might be adduced as an exertion of power.

With respect to the very imperfect use of heat in the ordinary steam-engine, some reasonable doubt might be entertained as to the correctness of the methods employed, to arrive at the unit of heat now employed by scientific men; for when it was stated, that the ordinary duty obtained by a good steam-engine was about $\frac{1}{10}$th of what the quantity of heat, actually generated by the consumption of a given weight of carbon, was really capable of performing, some doubts naturally suggested themselves, as to the correctness of the mode by which such a result was arrived at; for it appeared impossible to conceive where such an enormous loss could take place.

This part of the subject would seem to require further investigation, and it might be suggested, that the power necessary to destroy molecular attraction might not be comparable with the ordinary mode of developing power, by imparting heat to elastic vapours. The one was an enormous force exerted over an infinitely small space, and the other, on the contrary, was a limited power exerted over a very large space. This view would seem to be corroborated, or might derive illustration, from considering the well-known mechanical difficulty of comparing a given pressure at rest, and another pressure with a given velocity. It was well known, in fact, that they were not comparable.