forces, these again depending on the quantities of electricity and matter in the atoms. This has been merely hinted at, not for explanation, but to show that the theory gives the property referred to, to inherent powers in bodies themselves, and not to the space in which they are situated, and by which they are surrounded. My reasons for considering the atoms of bodies as mere centres of force, have not been given, as they are connected with other subjects on which you may not be able to afford space for entering.

I am, Sir,
Yours, &c.,
HENRY SLOGGETT.

Killigrew St., Falmouth,
Jan. 19, 1846.

LXXV. *Experiments and Observations on the Mechanical Powers of Electro-Magnetism, Steam, and Horses. By the* Rev. WILLIAM SCORESBY, *D.D., F.R.SS. L. and E., Corr. Memb. Inst. Fr., &c., and* JAMES P. JOULE, *Secretary of the Literary and Philosophical Society of Manchester, Mem. Chem. Soc., &c.**

AT the last Meeting of the British Association, Dr. Scoresby described a magnetic apparatus of very great power, and gave an account of some experiments he had made with a view to test its capabilities for exciting electrical currents. The coils employed in those experiments were hastily constructed, and by no means calculated to produce a maximum effect. We agreed, therefore, to construct and try more efficient ones on the first opportunity.

Two kinds of revolving armature occurred to us as worthy of trial. One of them consisted of a hollow tube of drawn iron, 24 inches long, $1\frac{5}{8}$th inch in diameter, and $\frac{3}{16}$ths of an inch thick in the metal, bent into the shape of the letter U. It had a saw-cut along its entire length, in order to prevent the circulation of electrical currents in the substance of the iron. Each of the legs of this armature was wound with 274 feet of covered copper wire, $\frac{1}{10}$th of an inch in diameter. The other armature consisted of two bars of iron, each 20 inches long, 4 inches broad, and $\frac{3}{8}$ths of an inch thick. These bars were bent edgeways into the form of a semicircle, and then fastened together with the interposition of a piece of calico in order to prevent currents in the iron as much as possible. Each leg of this armature was furnished with two coils of covered copper wire $\frac{1}{10}$th of an inch thick. The two coils that were nearest the iron were each 276 feet long; and each of the other two coils was 296 feet long.

* Communicated by the Authors.

Having placed the two straight steel magnets (each of which was 4 feet 4 inches long, 4 to 5 inches square, and had poles of $7\frac{1}{2}$ square inches surface) side by side, in a horizontal position, and with two of their poles connected by a suitable armature, we placed the *hollow electro-magnetic armature* on the axis of a revolving apparatus, in such a position that the poles of the armature could revolve at the distance of about $\frac{1}{4}$th of an inch from the poles of the steel magnets. The coils were arranged for quantity, and connected by means of a proper "commutator" with platinum plates (each exposing an active surface of 5 or 6 square inches) immersed in a dilute solution of sulphuric acid. The maximum amount of decomposition was effected when the armature revolved 500 times per minute. At this velocity $\frac{3}{4}$ths of a cubic inch of the mixed gases were collected per minute.

Having removed the hollow armature, we now fastened the *flat semicircular armature* upon the axis. When this armature, with its four coils arranged for quantity, was rotated at the rate of 500 revolutions per minute, we collected as much as 1·4 cubic inch of the mixed gases per minute. With the same velocity of rotation, two inches of steel wire, $\frac{1}{90}$th of an inch thick, were raised to a bright red heat; and one inch of the same kind of wire was fused.

Great as the above effects undoubtedly are, in comparison with previously recorded results, we expect to be able to augment them very much by causing the armatures to revolve opposite the *true poles* of the magnets, and not, as heretofore, opposite their ends. It is proper also to observe, that on account of the imperfect hardness of many of the steel bars*, the magnets did not possess one quarter of the power due to Dr. Scoresby's principle of construction. We have not, however, hitherto cared to reconstruct the apparatus, because our principal object in the present research was to make experiments with the machine working as an engine, for which purpose the magnets were quite powerful enough.

The battery employed for working the machine as an engine, consisted of three cells of Daniell's constant arrangement. In each cell the copper element exposed an active surface of two

* The bars of which the magnetic apparatus was constructed were of various lengths, but of otherwise uniform dimensions, viz. $1\frac{1}{2}$ inch broad and $\frac{1}{4}$th of an inch thick. The thickness and mass were found too great for effective hardening, at least for obtaining a degree of hardness capable of sustaining the severity of the magnetic test. Œconomy and facility of arrangement were the reasons for adopting this construction, rather than the more certain and effective one of *hard thin plates*, described by Dr. Scoresby in his "Magnetical Investigations."

square feet, and the amalgamated zinc plate a surface of ⅔rds of a square foot. A pretty correct galvanometer, consisting of a circle of thick copper wire and a magnetic needle 3 inches long, was employed for measuring the currents of electricity which were transmitted by the battery through the revolving armatures. The tangents of the deflections of the magnetic needle, corrected by a small equation, indicated the absolute quantities of transmitted electricity. The quantity of zinc consumed in the battery was deduced from the deflections of the needle; the data of the calculation being derived from previous experiments on the quantity of mixed gases evolved from acidulated water by a current capable of producing a given deflection of the needle.

Our first experiments were made with the flat semicircular revolving armature, its four coils being arranged for quantity. The deflection of the needle before the engine was allowed to start amounted to 64°, which indicated a current of 2232, calling the current corresponding to 45°, 1000. The engine, being then allowed to start, presently attained a velocity of 140 revolutions per minute. The needle was then observed to stand steadily at 43°, indicating a current of 920. The consumption of zinc in the battery was estimated to be at the rate of 205 grs. per hour.

Although we were not able to apply as exact a dynamometer as we could have wished, we were nevertheless enabled to arrive at a pretty correct estimation of the power developed, by ascertaining the weight which, when thrown over a wheel connected with the engine, was sufficient to keep it in uniform motion. In this way we found that the force developed in the above experiment was equal to raise 21,100 lbs. to the height of a foot per hour.

On making a second experiment with the same revolving armature and battery, we obtained the following results:— Current before the engine was allowed to start, 2232; current when the armature was rotating at the rate of 180 revolutions per minute, 850; consumption of zinc per hour, 190 grains; force given out per hour, 17,820 lbs. raised a foot.

Mr. J. P. Joule has already proved that the heat evolved by voltaic and magneto-electrical currents is, *cæteris paribus*, proportional to the square of their intensity*; and that the power of the electro-magnetic engine is obtained at the expense of the heat due to the chemical reactions of the voltaic battery by which it is worked. He has also shown, that if the whole of the heat developed by the consumption of a grain of zinc in a Daniell's battery could be converted into useful

* Phil. Mag., vol. xviii. p. 308, and vol. xix. p. 260.

mechanical power, it would be equal to raise a weight of 158 lbs. to the height of a foot*. Hence, if we designate the current when the engine is *at rest* by a, and the current when the engine is *in motion* by b, the heat evolved by the circuit in a given time, will, in the two instances, be as a^2 to b^2. But the quantities of zinc consumed being as a to b, the heat, per a given consumption of zinc, will be as a to b, or directly as the currents; $a-b$ will therefore represent the quantity of heat converted by the engine into useful mechanical effect. Therefore, putting x for the mechanical effect in lbs. raised a foot high per the consumption of a grain of zinc, we have

$$x = \frac{158\,(a-b)}{a}.$$

From the above equation it is evident that the œconomical duty will be a maximum when b vanishes or becomes infinitely small in comparison with a. In this case $x = 158$, while the power of the engine will become infinitely small with regard to work performed in a given time. We must, however, observe that the equation can only be strictly correct when the current b is uniform, which it never can be exactly, in consequence of the resistance of the magnetic induction against the voltaic current varying in the different positions of the revolving electro-magnetic armature. Hence the current b is always, to a certain extent, of a *pulsatory* character, which has the effect of causing it to develope more heat than an *uniform* current of the same quantity. From this circumstance, as well as from the unavoidable existence of some slight currents in the substance of the iron of the revolving armature, the actual œconomical effect will always be somewhat below the duty indicated by our formula.

Applying the formula to our first experiment, we have for the *theoretical* œconomical effect,

$$\frac{158\,(2232-920)}{2232} = 92{\cdot}9,$$

while the *actual* œconomical effect was

$$\frac{21100}{205} = 102{\cdot}9.$$

In our second experiment, the theoretical œconomical effect will be

$$\frac{158\,(2232-850)}{2232} = 97{\cdot}8,$$

* Phil. Mag., vol. xxiii. p. 441.

and the actual duty,

$$\frac{17820}{190} = 93 \cdot 8.$$

Taking the mean of the two experiments, we have for the theoretical duty 95·3, and for the actual performance 98·3. Here, therefore, in apparent contradiction to what we have just said, the actual exceeds the theoretical duty. This circumstance is however partly explained by the fact that the solution of sulphuric acid employed in charging the battery had been mixed immediately before the experiments were made, and was in consequence considerably heated; for Daniell has shown that the intensity of his battery increases with its temperature, and it is evident that an increase of the intensity or electromotive force of the cells of the battery must be productive of an increased œconomical effect.

The next two experiments were made with the hollow revolving armature, its two coils being arranged for quantity. In these and the subsequent experiments, the battery was charged with a *cold* solution.

Experiment 3.—Current when the engine was kept at rest, 1381; current when the armature was revolving 80 times per minute, 850; consumption of zinc, 190 grains per hour; power developed, 8800 lbs. raised a foot high per hour. From these data, the theoretical duty will be

$$\frac{158\,(1381 - 850)}{1381} = 60 \cdot 7,$$

and the actual duty will be

$$\frac{8800}{190} = 46 \cdot 3.$$

Experiment 4.—Current before the engine was allowed to start, 1381; current when the engine was revolving 102 times per minute, 678; consumption of zinc, 151 grains per hour; power developed, 9000 lbs. raised a foot per hour. Hence for the theoretical duty we have,

$$\frac{158\,(1381 - 678)}{1381} = 80 \cdot 4,$$

and for the actual duty,

$$\frac{9000}{151} = 59 \cdot 6.$$

Lastly, we made two experiments in which the engine was fitted up with two straight electro-magnets fastened parallel to the axis. Each of these straight electro-magnets consisted of a piece of drawn iron tube, 12 inches long, $1\frac{5}{8}$th inch in

diameter, and $\frac{3}{16}$ths of an inch thick, cut longitudinally to prevent the circulation of electrical currents in the iron, and furnished with a coil of 210 feet of covered copper wire $\frac{1}{10}$th of an inch thick. A steel magnet consisting of a considerable number of bars was fitted up in order to excite those ends of the straight electro-magnets which were distant from the large steel magnets. The coils were arranged for quantity.

Experiment 5.—Current when the engine was kept still, 2081; current when the armature was revolving 114 times per minute, 1300; consumption of zinc, 291 grains per hour; power developed, 10030 lbs. raised a foot per hour. Hence the theoretical duty will be

$$\frac{158\,(2081 - 1300)}{2081} = 59 \cdot 3,$$

and the actual duty,

$$\frac{10030}{291} = 34 \cdot 5.$$

Experiment 6.—Current before starting, 2035; current when revolving 192 times per minute, 1000; consumption of zinc, 223 grains per hour; power developed, 12,672 lbs. raised a foot per hour. In this case the theoretical duty will be

$$\frac{158\,(2035 - 1000)}{2035} = 80 \cdot 3;$$

the actual performance will be

$$\frac{12672}{223} = 56 \cdot 8.$$

The mean of the six experiments gives a theoretical duty of 78·5, and an actual duty of 65·6. But, making allowance for the hot solution employed in the first two experiments, we may state that the actual was in general about $\frac{4}{5}$ths of the theoretical duty.

Upon the whole we feel ourselves justified in fixing the maximum available duty of an electro-magnetic engine worked by a Daniell's battery at 80 lbs. raised a foot high for each grain of zinc consumed*, or, in other words, at about half the theoretical maximum of duty.

Before we leave this part of the subject, we may state that the above experiments fully bear out the idea expressed by

* Dr. Botto states that 45 lbs. of zinc consumed in a Grove's battery are sufficient to work a one-horse power electro-magnetic engine for 24 hours. The intensity of Daniell's battery being $\frac{3}{5}$ths of that of Grove, it follows that 75 lbs. of zinc would have been consumed had Dr. Botto employed a Daniell's battery,—a result not widely different from our own.

Dr. Scoresby in his "Magnetical Investigations," that steel magnets on his construction may be employed in the stationary part of the electro-magnetic engine with much greater advantage than electro-magnets. We have already adverted to the imperfect construction of the magnetic apparatus employed in the above experiments; had we employed one of equal weight, but constructed of thin plates of hardened steel, and furnished with armatures and batteries in proportion, we think it highly probable that a power equal to that of one horse might have been attained, the whole weight of the apparatus being considerably under half a ton.

Having thus determined the capabilities of electro-magnetism as a first mover of machinery, it will be interesting and instructive to compare it with two other sources of power, viz. steam and horses.

1. A grain of coal produces, by combustion, sufficient heat to raise the temperature of a lb. of water 1°·634. In other words, we may say that the *vis viva* developed by the combustion of a grain of coal is equal to raise a weight of 1335 lbs. to the height of one foot. Now the best Cornish steam-engines raise 143 lbs. per grain of coal; whence it appears that the steam-engine in its most improved state is not able to develope much more than $\frac{1}{10}$th of the *vis viva* due to the combustion of coal into useful power, the remaining $\frac{9}{10}$ths being given off in the form of heat.

2. A horse, when its power is advantageously applied, is able to raise a weight of 24,000,000 lbs. to the height of one foot per day. In the same time (24 hours) he will consume 12 lbs. of hay and 12 lbs. of corn*. He is therefore able to raise 143 lbs. by the consumption of one grain of the mixed food. From our own experiments on the combustion of a mixture of hay and corn in oxygen gas, we find that each grain of food, consisting of equal parts of undried hay and corn, is able to give 0°·682 to a lb. of water, a quantity of heat equivalent to the raising of a weight of 557 lbs. to the height of a foot. Whence it appears, that one quarter of the whole amount of *vis viva* generated by the combustion of food in the animal frame, is capable of being applied in producing a useful mechanical effect,—the remaining three-quarters being required in order to keep up the animal heat, &c.

* We have been kindly informed by Mr. J. V. Gibson of Manchester, an eminent veterinary surgeon, that 14 lbs. of hay and 10 lbs. of corn is the average provender requisite to support a horse of average size, so as to enable him to work daily without any depreciation of his physical condition. We have however equalized the quantities of hay and corn, on account of the experiments on combustion having been made with a mixture containing equal portions.

Prof. Magnus of Berlin, has endeavoured to prove that the oxygen which an animal inspires does not combine chemically with the blood, but is merely *absorbed* by it*. The blood thus charged with oxygen arrives in the capillary vessels, where the oxygen effects a chemical combination with *certain substances*, converting them into carbonic acid and water. The carbonic acid, instead of oxygen, is then absorbed by the blood, and thus reaches the lungs to be removed by contact with the atmosphere. Adopting this view, it becomes exceedingly probable that the *whole* of the *vis viva* due to the oxidation or combustion of the "certain substances" mentioned by Magnus is developed by the muscles. The muscles, by their motion, can communicate *vis viva* to external objects; and, by their friction within the body, can develope heat in various quantities according to circumstances, so as to maintain the animal at an uniform temperature. If these theoretic views be correct, they would lead to the interesting conclusion (which is the same as that announced by Matteucci from other considerations) that the animal frame, though destined to fulfill so many other ends, is, as an engine, more perfect in the œconomy of *vis viva* than the best of human contrivances.

LXXVI. *Experimental Researches in Electricity.—Twentieth Series.* By Michael Faraday, *Esq., D.C.L., F.R.S., Fullerian Prof., &c. &c.*

[Concluded from p. 406.]

¶ iv. *Action of magnets on metals generally.*

2287. THE metals, as a class, stand amongst bodies having a high and distinct interest in relation both to magnetic and electric forces, and might at first well be expected to present some peculiar phænomena, in relation to the striking property found to be possessed in common by so large a number of substances, so varied in their general characters. As yet no distinction associated with conduction or non-conduction, transparent or opake, solid or liquid, crystalline or amorphous, whole or broken, has presented itself; whether the metals, distinct as they are as a class, would fall into the great generalization, or whether at last a separation would occur, was to me a point of the highest interest.

2288. That the metals, iron, nickel and cobalt, would stand in a distinct class, appeared almost undoubted; and it will be,

* [See Phil. Mag. S. 3. vol. xxvii. p. 561.]