



# XXV. On electro-magnets

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If the plan and elevation show the dimensions of the constituent parts, and the disposition of the several courses, they will at once remove all doubts on this head.

April 5, 1823.

If the paper on the plans for erecting a new London Bridge, distinguished by the signature "Amicus," and the letter addressed to the Comptroller of the Bridge House Estates, be laid before the Committee of the House of Commons, they will of course be accompanied by the requisite plans and elevations. But besides these, I think it would be advisable to send with them a letter, addressed to the Chairman of the Committee of the House of Commons, in which he should be informed as briefly as possible, that these two papers were laid before the Bridge House Committee, and that the author of them offered to lay before that Committee a third communication, in which his ideas should be further developed; but that they refused to receive any further communication. That you now, therefore, beg to solicit the attention of the Committee of the House of Commons to the same subject, hoping that you will be able to convince them that a bridge upon the cementitious principle, while it should possess all desirable elegance, would be at least as durable as any other structure that could be proposed, and would also be cheaper by about a fourth of the whole sum, than an elegant, commodious and durable bridge, erected upon any other plan. You should also advert concisely to the advantages that would result from the adoption of a proper system of lockage, as more fully explained in the second paper. And query,—should you not add that you are ready to give the Committee personally any further explanations they may require?

Dr. Gregory also suggests, that it would be a very great advantage if the road could be carried nearly on a level to a point someway up Fish-street Hill, with an arch underneath, allowing carts, &c. to pass from Thames-street, without obstructing the passengers over the bridge.

[To be continued.]

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XXV. *On Electro-Magnets.* By W. STURGEON, *Lecturer on Experimental Philosophy at the Honourable East India Company's Military Academy, Addiscombe.\**

WHEN first I showed that the magnetic energies of a galvanic conducting wire are more conspicuously exhibited

\* Communicated by the Author.

by

by exercising them on *soft iron* than on *hard steel*, my experiments were limited to small masses, generally to a few inches of rod iron about half an inch in diameter. Some of those pieces were employed whilst straight, and others were bent into the form of a horse-shoe magnet, each piece being encompassed by a spiral conductor of copper wire\*. The magnetic energies developed by these simple arrangements are of a very distinguished and exalted character, as is conspicuously manifested by the suspension of a considerable weight at the poles during the period of excitation by the electric influence.

An unparalleled transiliency of magnetic action is also displayed in soft iron, by an instantaneous transition from a state of total inactivity to that of vigorous polarity, and also by a simultaneous reciprocity of polarity in the extremities of the bar;—versatilities in this branch of physics to which soft iron is preeminently prone, and which by the agency of electricity become demonstrable with the celerity of thought, and illustrated by experiments the most splendid in magnetics.

It is, moreover, abundantly manifested by ample experiments, that galvanic electricity exercises a superlative degree of excitation on the latent magnetism of soft iron, and calls forth its recondite powers with astonishing promptitude, to an intensity of action far surpassing anything which can be accomplished by any known application of the most vigorous permanent magnet, or by any other mode of experimenting hitherto discovered. It has been observed, however, by experimenting on different pieces selected from various sources, that notwithstanding the greatest care be observed in preparing them of an uniform figure and dimensions, there appears a considerable difference in the susceptibility which they individually possess of developing the magnetic powers; much of which depends upon the manner of treatment at the forge, as well as upon the natural character of the iron itself†.

The superlative intensity of electro-magnets, and the facility and promptitude with which their energies can be brought into play, are qualifications admirably adapted for their introduction into a variety of arrangements in which powerful magnets so essentially operate, and perform a distinguished part

\* The pieces of soft iron which were first magnetized in this way are members of an electro-magnetic apparatus, which I had the honour to present to the "Society of Arts, &c." in the spring of 1825; for which the Society presented me with their large silver medal, and a purse of thirty guineas.

† I have made a number of experiments on small pieces, from the results of which it appears that *much hammering* is highly detrimental to the

part in the production of electro-magnetic rotations; whilst the versatilities of polarity, of which they are susceptible, are eminently calculated to give a pleasing diversity in the exhibition of that highly interesting class of phenomena, and lead to the production of others, inimitable by any other means.

An experiment of this character is noticed in the *Phil. Mag.* for January 1825; but as the arrangement by which it is accomplished has not yet been published, a description of it in this place may perhaps still be interesting, especially as it affords a clue to several others which may be exhibited in this curious branch of science.

*Experiment.*—Fig. 1. is a representation of the apparatus complete. It consists of a cylindrical rod of soft iron, supported in a vertical position by a round wooden foot, into which its inferior extremity is inserted. The superior extremity of the iron rod passes through the centre of a shallow wooden dish, which is kept firmly in its place by means of cement. The inside of this dish, and also the iron rod, is covered with sealing-wax varnish. A copper wire, one end of which passes through the bottom of the dish and appears at the upper surface, is wound several times round the iron cylinder between the dish at its upper extremity, and the wooden foot in which it is supported. The other extremity of the wire terminates in a small cup, as is seen in the figure.

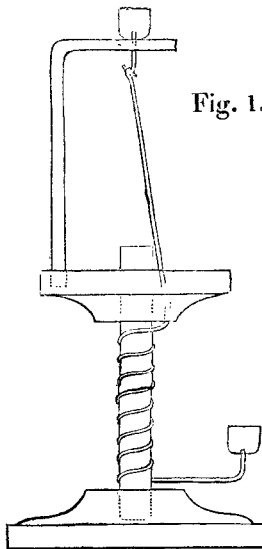


Fig. 1.

A stout brass wire, one end of which is screwed firmly into the upper edge of the wooden dish, rises vertically about five inches of its length, at which place it is bent at right angles, and continued in a horizontal direction over the axis of the iron rod. A small brass wire screw, the upper end of which is inserted in a small cup, passes through the

the development of magnetism in soft iron, whether the exciting cause be galvanic or any other. And although good annealing is always essential, and facilitates to a considerable extent the display of polarity, that process is very far from restoring to the iron that degree of *susceptibility* which it frequently loses by the operation of the hammer.

Cylindric rod iron of small dimensions may very easily be bent into the required form, without any hammering whatever; and I have found that  
small

the horizontal arm, and terminates with a hook at its lower end. A light copper wire, having a hook at one end, is by this means suspended to the hook of the screw. The inferior extremity of the pendent wire is pointed, and reaches into the wooden vessel, but not sufficiently low as to touch its inner surface.

When an experiment is to be made with this apparatus, the extremities of the helical wire which pass through the dish and the lower cup, and also the extremity of the short wire which passes through the bottom of the upper cup, are to be well amalgamated. Mercury is now to be placed in the two cups for the convenience of connection, and also in the wooden dish, until the point of the pendent wire (which must also be amalgamated) dips slightly into it. By this means there will be formed a complete metallic connection between the mercury in the upper cup, and that which is placed in the lower.

If the connecting wire from the copper plate of a single galvanic pair be now permitted to enter the upper cup, and that from the zinc to enter the lower, then the direction of the electric current through the system of conductors will be from the upper to the lower cup. The cylindrical rod of iron, inclosed in the spiral, will become highly magnetic, and the suspended moveable wire will perform its revolutions round the upper pole.

With this arrangement the *direction* in which the pendent wire performs its revolutions will entirely depend upon the character of the spiral, or upon the direction in which that part of the conductor passes round the iron rod from the upper to the lower extremity, and not upon any other circumstance whatever. For, it being an established *law* in electro-magnetics that *the direction of its revolutions is not altered* by simultaneously reversing the magnetic polarity and electric current; and as, in the present arrangement, the character of

small electro-magnets made in this way display the magnetic powers in a very exalted degree.

An electro-magnet of the above description, weighing 3 ounces, and furnished with one coil of wire, supported 14 pounds. The poles were afterwards made to expose a larger surface by welding to each end of the cylindric bar a square piece of good soft iron: with this alteration only, the lifting power was reduced to about 5 pounds, although the magnet was annealed as much as possible.

It appears to me that the superior magnetic energies displayed by these cylindric rods of iron whilst subjected to the electric influence, are owing in a great measure to the peculiar fibrous texture which the metal is made to assume by the process which brings it to their particular shape.

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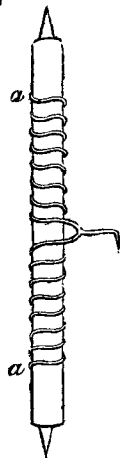
the magnetic poles in the extremities of the bar will at all times be determined by the direction of the electric stream, and that no vicissitude can possibly take place in the one without a corresponding and simultaneous vicissitude in the character of the other,—it follows that the revolving wire will uniformly proceed in *one* and the *same* direction, whatever may be the nature of the electric stream; and that no vicissitudes in the direction of motion can possibly be accomplished by any similar arrangement.

Now, as the direction in which the wire revolves will be determined by the direction in which the spirals encompass the iron, it is plain that the apparatus may be so constructed as to perform its revolutions in any direction the experimenter may think proper to select: but the selection once made, and the standard spiral determined on, the apparatus becomes incapable of exhibiting that beautiful diversity of revolving motions which proceed from various combinations of the electric and magnetic forces.

If, however, the electric current were not to be continuous from one of the extreme cups to the other, the apparatus might then be made to perform the usual variety of electro-magnetic rotations; because in that case one current might be employed to give polarity to the iron, whilst another could be transmitted in any required direction through the pendent revolving wire.

Upon the same principle a bar of soft iron, properly connected, will rotate on its axis with an astonishing velocity; the direction of motion being always determined by the character of the helical conductor. The apparatus which I use for the exhibition of this interesting phenomenon is similar to that by means of which I showed the rotation of a steel magnetic bar on its axis, by the influence of two electric currents (Phil. Mag. vol. lxiv. p. 246); the transient electro-magnet in this case being substituted for the permanent steel magnet in the other experiment. The manner in which the spiral is arranged will be understood by contemplating fig. 2. The ends of the spiral are soldered to the cylindrical bar of iron at the points *a a*, and to the centre is soldered a short wire with a descending point for the purpose of maintaining an uninterrupted connection with an annular mass of mercury in  
which

Fig. 2.



which it revolves. The direction of motion is constantly the same whatever may be the nature of the galvanic connections.

It does not appear that any very extensive experiments were attempted to improve the lifting powers of electro-magnets from the time that my experiments were published in the Transactions of the Society of Arts, &c. for 1825, till the latter part of 1828. Mr. Watkins, Philosophical Instrument-maker, Charing Cross, had, however, made them of a much larger size than any which I had employed; but I am not aware to what extent he pursued the experiment.

In the year 1828 Professor Moll of Utrecht, being on a visit to London, purchased of Mr. Watkins an electro-magnet weighing about five pounds; at that time I believe the largest which had been made. It was of round iron, about one inch in diameter, and furnished with a single copper wire twisted round it 83 times. When this magnet was excited by a large galvanic surface, it supported about 75 pounds.

Professor Moll afterwards prepared another electro-magnet, which when bent was  $12\frac{1}{2}$  inches high,  $2\frac{1}{2}$  inches in diameter, and weighed about 26 pounds; prepared like the former with a single spiral conducting wire. With an acting galvanic surface of 11 square feet, this magnet would support 154 pounds, but would not lift an anvil which weighed 200 pounds.

The success of these experiments, which established the first grand step in exalting the attractive powers of electro-magnets, gave a new impulse to the inquiry, which the American philosophers have pursued to an extent that will not be very easily surpassed. By dividing about 800 feet of conducting wire into 26 strands, and forming it into as many separate coils round a bar of soft iron about 60 pounds in weight, and properly bent into the horse-shoe form, Professor Henry has been enabled to produce a magnetic force which completely eclipses every other in the whole annals of magnetism; and no parallel is to be found since the miraculous suspension of the celebrated Oriental impostor in his iron coffin\*.

This electro-magnet is said to have supported nearly two tons when excited by about five square feet of galvanic surface, an extent comparatively trifling, when compared to the prodigious magnetic force which it is capable of calling into action.

The largest electro-magnet which I have as yet exhibited in my lectures weighs about 16 pounds. It is formed of a square bar of soft iron,  $1\frac{1}{2}$  inch across each side; the poles

\* Silliman's Journal.

are separate from each other  $1\frac{1}{4}$  inch; the cross piece which joins the poles is from the same rod of iron, and about  $3\frac{3}{4}$  inches long.

Twenty separate strands of copper wire, each strand about 50 feet in length, are coiled round the iron one above another, from pole to pole, and separated from each other by intervening cases of silk; the first coil is only the thickness of one ply of silk from the iron, the twentieth or outermost about half an inch distant from it. By this means the wires are completely insulated from each other without the trouble of covering them with thread or varnish. The ends of the wires project about two feet, for the convenience of connection.

With one of my small cylindrical batteries, exposing about 150 square inches of total surface, this electro-magnet supports 400 pounds. I have tried it with a larger battery, but its energies do not appear to be so materially exalted as might have been expected by increasing the extent of galvanic surface. Much depends upon a proper acid solution: good nitric or nitrous acid, with about six or eight times its quantity of water, answers very well. With a new battery of the above dimensions, and a strong solution of salt and water at a temperature of about  $190^{\circ}$  Fahr., the electro-magnet supported between 70 and 80 pounds, when the first 17 coils only were in the circuit. With the three exterior coils alone in the circuit, it would just support the lifter or cross piece. When the temperature of the solution was between  $40^{\circ}$  and  $50^{\circ}$ , the magnetic force excited was comparatively very feeble. With the innermost coil alone, and a strong acid solution, this electro-magnet supports about 100 pounds: with the four innermost wires, about 250 pounds. It improves in power with every additional coil until about the twelfth, but not perceptibly any further: therefore the remaining eight coils appear to be entirely useless; although the last three of them, independent of the innermost seventeen, and at the distance of half an inch from the iron, produce in it a lifting power of 75 pounds.

It is evident from these results, that the exciting power of this miniature battery becomes improved by multiplying the number of conducting wires as far as twelve at least, although the greater part of them be at some considerable distance from the iron; and it is highly probable, although the experiments which I have made on this bar do not satisfactorily prove the fact, that by employing a larger galvanic surface, a much further addition to the number of conducting wires may be advantageously introduced into the circuit for the excitation of  
the



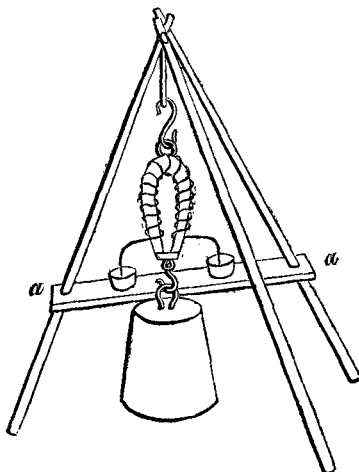
the magnetic energies of soft iron. Perhaps the best arrangement would be to have a separate small battery to each wire.

Mr. Marsh has fitted up a bar of iron much larger than mine, with a similar distribution of the conducting wires to that devised, and so successfully employed, by Professor Henry. Mr. Marsh's electro-magnet will support about 560 pounds when excited by a galvanic battery similar to mine\*. These two, I believe, are the most powerful electro-magnets yet produced in this country.

A small electro-magnet, which I also employ on the lecture-table, and the manner of its suspension, is represented by fig. 3. The magnet is of cylindric rod iron, and weighs four ounces: its poles are about a quarter of an inch asunder. It is furnished with six coils of wire in the same manner as the large electro-magnet before described, and will support upwards of 50 pounds.

I find a triangular gin very convenient for the suspension of the magnet in these experiments. A stage *aa* of thin board, supporting two wooden dishes, is fastened at a proper height to two of the legs of the gin. Mercury is placed in these vessels, and the dependent amalgamated extremities of the conducting wires dip into it; one into each portion. The vessels are sufficiently wide to admit of considerable play for the wires in the mercury without interruption of contact, which is sometimes occasioned by the swinging of the magnet and attached weight: the circuit is completed by other wires, which connect the battery with these two portions of mercury. When the weight is supported as in the figure, if an interruption be made by removing either of the connecting wires, the weight instantaneously drops on the table. The large magnet I suspend in the same way on a larger gin; the weights which it supports are placed one after another on a square board, suspended by means of a cord at each corner from a hook in the cross piece, which joins the poles of the magnet.

Fig. 3.



\* See the Report of Proceedings at the Royal Institution, in our present Number.—EDIT.

With a new battery, and a solution of salt and water at a temperature of 190° Fahr., the small electro-magnet supports 16 pounds.

I noticed in some of my earliest experiments, that a bar of soft iron which had been intensely magnetized by galvanic action, retained a considerable degree of polarity when the exciting cause had been long removed,—a phænomenon now more conspicuously displayed by the employment of larger masses; nor does it appear to be an easy matter to subdue, entirely, this residual polarity. The poles may be reversed as frequently as we please; but still some, and frequently a considerable degree of polarity remains unneutralized. If the cross piece be permitted to remain attached to the poles when the galvanic connection is broken, the residual polarity will still keep them together with an astonishing force; as is manifest by the very great weight which the magnet continues to support before the cross piece is disengaged from its poles. A residual polarity, however, still remains; but so enfeebled are its energies by the slightest interruption of polar contact, that the cross piece will seldom be supported a second time without a renewed excitation by the battery.

The vigorous residuum of polarity which retains the cross piece to the magnet arises from a continued mutual attraction between the two; for whilst the battery operates upon the magnet, and excites it to action, the latter in its turn also excites the magnetism of the iron connecting its poles, which iron becomes as decidedly polar as the magnet itself; a *north pole* being determined in that end of it which is in connection with the south pole of the magnet, and a *south pole* in the other end, which is connected with the north pole of the magnet. The four magnetic poles thus brought into play, and in vigorous operation on each other, will, if not separated, retain their positions at the points of connection, even though the first exciting cause be entirely withdrawn. But if the connection of the two pieces of iron be in the least interrupted, their magnetism immediately recedes from the extremities, and becomes equally distributed in the metal; the vigour of the poles vanishes, and their magnetism becomes totally incapable of keeping them attached to each other.

Precisely the same kind of reasoning will explain the cause of that well known deterioration of magnetic force which invariably takes place by removing the cross piece from a highly excited steel magnet. The excitation in this case, whether it be performed by the operation of a magnet, or by the more gradual process of adding small weights to those already suspended, is carried on whilst the poles and the cross piece are in contact; and both become excited at the same time. The magnet

magnet and cross piece now operate on each other with a gradually increasing vigour; the poles of the one becoming more and more energetic as the power of the opposing poles of the other become further exalted. And this reciprocal increase of action will be exercised on each other till a maximum of mutual attraction is obtained, at which time the magnet will support its greatest load. If more weight be added, the mutual attractive forces of the magnet and cross piece will be overpowered, and the two will separate. The magnetism of the iron no longer displays polarity, and that of the steel partially recedes from its extremities; but in consequence of the character of the metal, a considerable polarity is still displayed by the magnet: its energies, however, are very much diminished; and when the cross piece is replaced at the poles, the effort to stimulate it to polarity is proportionably diminished. The reciprocal attractions now operate with impaired forces, and consequently the load which can be supported is much less than before.

A compound steel magnet in my possession weighs 9 pounds, which, when well magnetized will support 120 pounds; but if weights be added till the cross piece falls off, the power is reduced to about 75 pounds.

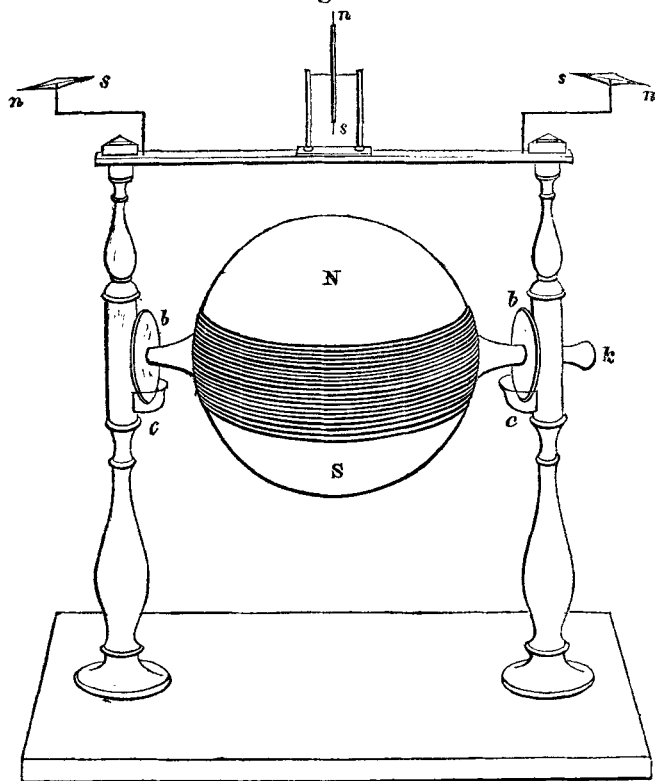
Fig. 4. is a representation of an electro-magnetic sphere, mounted on a mahogany frame, consisting of a stout base board and two upright pillars, to the upper extremities of which is fixed a cross piece or stage. On the centre of the stage, and directly over the sphere, is placed a dipping needle; and near to the extremities are inserted the lower ends of two wires bent twice at right angles, as seen in the figure; the upper extremities of these wires are finely pointed, and support two horizontal needles.

The sphere NS is a cast-iron shell, about 8 inches in diameter, and weighs about 68 pounds. Its surface is divided into three parts, which for convenience may be called *tropical* and *polar*, having one of the former and two of the latter. The tropical region is covered with four coils of copper wire in separate strata, insulated from each other, and also from the metallic sphere, by means of slips of silk; the exterior coil, being uncovered, is seen in the figure. The coils are prevented from slipping towards the poles by means of stout iron rings soldered to the sphere, one at each tropical circle.

The two sets of extremities of the conducting wires are soldered, one to each of the two copper discs or wheels *bb*, through the centres of which the extremities of the horizontal axis of the sphere pass. The lower edges of the wheels dip into portions of mercury placed in two semicircular vessels *cc*, which slide into the side of the pillars a little below the holes which receive the axis of the sphere.

By this arrangement the extremities of the wires which encircle the globe will constantly be in connection with the mercury in the two cups, in whatever position the poles may be placed. The connections with the battery are accomplished by two wires joining its plates, and the two portions of mercury in the vessels *c c*.

Fig. 4.



If this apparatus be so placed, before the battery be attached, that the needles stand at right angles to the vertical plane of the frame, and the dip of the central needle is counterbalanced, they will be arranged nearly parallel to each other, as their distance prevents them being affected by the ball.

If the axis joining the poles of the sphere be now brought into a horizontal position, by turning the key *k*, which enters the horizontal axle, the equator will be directly under the dipping needle. With this position of the apparatus, make the galvanic connections so that the pole of the sphere which faces the north may assume north polarity, or that species of polarity  
which

which is natural to the northern regions of the earth. The two horizontal needles will deviate from their former positions, having their north ends drawn towards the sphere: the central needle being placed on the equator will remain undisturbed. If the north pole of the sphere be now gradually turned upwards, the horizontal needles will be directed still more towards this pole, and the north end of the central needle will incline. The angles of deviation and dip will increase more and more as the north pole of the sphere advances towards the zenith; and when it has arrived at that point, those angles will have arrived at their maximum. The central needle will stand vertically, exhibiting a dip of  $90^\circ$  over the pole; and the two horizontal needles will point almost directly towards it. By permitting the sphere to resume its first position as gradually as it left it, the needles which are influenced by it will be observed to recede as gradually to their former positions.

If now the galvanic connections be reversed, the whole of the needles become reversed also, because of a change in the polarity of the sphere; and the dipping needle, after a few oscillations, will settle in a horizontal position.

By experimenting in this way with various positions of the sphere, it will be found to operate on the needle in a manner highly imitative of the earth's magnetism on different parts of its surface.

The two polar regions of the sphere exhibit a diffused polarity, the centres of which are nearly, perhaps exactly, in the poles of its equator. There are, however, in the polar regions several points which exhibit distinct polarity; and although of the same character as the general pole in which they are situated, will draw a delicate needle held near to them, from the direction which it takes when held at a greater distance from the action of the general or aggregate pole of that particular region. These local poles, I imagine, arise from a want of uniformity in the character of the iron. There are on the earth's surface aberrations of this kind arising from the local attractions of certain islands, and from causes not easily determined; which, as it happens, these accidental poles may serve to imitate.

## XXVI. *Letter from Dr. Henry on a Modified Disinfecting Apparatus.*

*To the Editors of the Philosophical Magazine and Annals.*

Gentlemen,

**I**T was my intention to have postponed any further communication respecting disinfection, until a series of experiments, which I had hoped would, ere this, have been made by