APPENDIX.*

On the application of the principle of the galvanic multiplier to electro-magnetic apparatus, and also to the developement of great magnetic power in soft Iron, with a small galvanic element;† by Prof. Joseph Henry, of the Albany Academy.‡

For a long time after the discovery of the principal facts in electro-magnetism, the experiments in this interesting department of science could be repeated only by those who were so fortunate as to possess a large and expensive galvanic apparatus. Mr. Sturgeon, of Woolwich, did much towards making the subject more generally known, by shewing that when powerful magnets are used, many of the most interesting experiments can be performed with a very small galvanic combination. His articles of apparatus, constructed on this principle, are of a much larger size, and more convenient, than any before used. They do not however, form a complete set, as it is evident, that strong magnets cannot be applied to every article required, and particularly to those intended to exhibit the action of terrestrial magnetism on a galvanic wire, or the operation of two galvanic wires on each other.

In a paper, published in the Transactions of the Albany Institute, June, 1828, I described some modifications of apparatus, intended to supply this deficiency of Mr. Sturgeon, by introducing the spiral coil on the principle of the galvanic multiplier of Prof. Schweiger, and this I think is applicable in every case where strong magnets cannot be used. The coil is formed by covering copper wire, from $\frac{1}{16}$ to $\frac{1}{25}$ of an inch in diameter, with silk; and in every case, which will permit, instead of using a single conducting wire, the effect is multiplied by introducing a coil of this wire, closely turned upon itself. This will be readily understood by an example: thus, in the experiment of Ampere, to shew the action of terrestrial magnetism on a galvanic current, instead of using a short single wire suspended on steel points; 60 feet of wire, covered with silk, are coiled so as to form a ring of about 20 inches in diameter, the several strands of which are bound together by wrapping a narrow silk ribbon around them. The copper and zinc of a pair of small galvanic plates are attached to the ends of the coil, and the whole suspended by a silk fibre, with the

* This article arrived too late for insertion in its proper place: its importance induces us to give it in an appendix.

† The term galvanic element is used in this paper to denote a single pair of galvanic plates.

‡ In a former number of this Journal, Prof. Henry, was *erroneously* mentioned as being connected with the Rensselaer School at Troy.

galvanic-element hanging in a tumbler of diluted acid. After a few oscillations, the apparatus never fails to place itself at right angles to the magnetic meridian. This article is nothing more than a modification of De la Rive's ring on a larger scale.

Shortly after the publication mentioned, several other applications of the coil, besides those described in that paper, were made in order to increase the size of electro-magnetic apparatus, and to diminish the necessary galvanic power. The most interesting of these, was its application to a developement of magnetism in soft iron, much more extensively, than to my knowledge had been previously effected by a small galvanic element.

A round piece of iron, about ¼ of an inch in diameter, was bent into the usual form of a horse-shoe, and instead of loosely coiling around it a few feet of wire, as is usually described, it was tightly wound with 35 feet of wire, covered with silk, so as to form about 400 turns; a pair of small galvanic plates, which could be dipped into a tumbler of diluted acid, was soldered to the ends of the wire, and the whole mounted on a stand. With these small plates, the horse-shoe became much more powerfully magnetic, than another of the same size, and wound in the usual manner, by the application of a battery composed of 28 plates of copper and zinc, each 8 inches square. Another convenient form of this apparatus was contrived, by winding a straight bar of iron 9 inches long with 35 feet of wire, and supporting it horizontally on a small cup of copper containing a cylinder of zinc, when this cup, which served the double purpose of a stand and the galvanic element, was filled with dilute acid, the bar became a portable electro-magnetic magnet. These articles were exhibited to the Institute in March, 1829.

The idea afterwards occurred to me, that a sufficient quantity of galvanism was furnished by the two small plates, to develope, by means of the coil, a much greater magnetic power in a larger piece of iron. To test this, a cylindrical bar of iron, ½ an inch in diameter, and about 10 inches long, was bent into the form of a horse-shoe, and wound with 30 feet of wire; with a pair of plates containing only 2½ square inches of zinc, it lifted 14 lbs. avoirdupois. At the same time, a very material improvement in the formation of the coil suggested itself to me, on reading a more detailed account of Prof. Schweiger's galvanometer, and which was also tested with complete success upon the same horse-shoe; it consisted in using several strands of wire, each covered with silk, instead of one:—agreeably to this construction, a second wire, of the same length as the first, was wound over it, and the ends soldered to the zinc and copper in such a manner that the galvanic current might circulate in the same direction in both, or, in other words, that the two wires might act as one; the effect by this addition was doubled, as the horse-shoe, with the same plates before used, now supported 28 lbs.

With a pair of plates 4 inches by 6, it lifted 39 lbs., or more than 50 times its own weight.

These experiments conclusively proved that a great developement of magnetism could be effected by a very small galvanic element, and also that the power of the coil was materially increased by multiplying the number of wires, without increasing the length of each.

The multiplication of the wires, increases the power in two ways; first, by conducting a greater quantity of galvanism, and secondly, by giving it a more proper direction, for since the action of a galvanic current is directly at right angles to the axis of a magnetic needle, by using several shorter wires, we can wind one on each inch of the length of the bar to be magnetized, so that the magnetism of each inch will be developed, by a separate wire; in this way the action of each particular coil becomes very nearly at right angles to the axis of the bar, and consequently, the effect is, the greatest possible. This principle is of much greater importance when large bars are used. The advantage of a greater conducting power from using several wires might in a less degree be obtained by substituting for them one large wire of equal sectional area, but in this case the obliquity of the spiral would be much greater and consequently the magnetic action less; besides this, the effect appears to depend in some degree on the number of turns which is much increased by using a number of small wires.*

In order to determine to what extent the coil could be applied in developeing magnetism in soft iron; and also to ascertain, if possible, the most proper length of the wires to be used—

A series of experiments were instituted jointly by Dr. Philip Ten-Eyck and myself. For this purpose 1060 feet (a little more than $\frac{1}{5}$ of a mile) of copper wire of the kind called bell wire, .045 ($\frac{45}{1000}$) of an inch in diameter, were stretched several times across the large room of the Academy.

Experiment 1. A galvanic current from a single pair of plates of copper and zinc 2 inches square, was passed through the whole length of the wire, and the effect on a galvanometer noted;—From the mean of several observations, the deflection of the needle was 15°.

Exp. 2. A current from the same plates was passed through half the above length (or 530 feet) of wire, the deflection in this instance was 21°.

By a reference to a Trigonometrical table, it will be seen that the natural tangents of 15° and 21° are very nearly in the ratio of the square roots of 1 and 2, or of the relative lengths of the wires in these two experiments.

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* Several small wires conduct more common electricity from the machine than one large wire of equal sectional area; the same is probably the case though in a less degree, in galvanism.

The length of the wire forming the galvanometer may be neglected, as it was only 8 feet long. This result agrees remarkably with the law discovered by Mr. Ritchie and published in the last No. of the Journal of the Royal Institution of Great Britain.

Exp. 3. The galvanometer was now removed, and the whole length of the wire attached to the ends of the wire of a small soft iron horse-shoe, ¼ of an inch in diameter and wound with about 8 feet of copper wire with a galvanic current from the plates used in Exps. 1 and 2; the magnetism was scarcely observable in the horse-shoe.

Exp. 4. The small plates were removed and a battery composed of a piece of zinc plate 4 inches by 7 surrounded with copper, was substituted, when this was attached immediately to the ends of the 8 feet of wire wound round the horse-shoe, the weight lifted was 4½ lbs.; when the current was passed through the whole length of wire (1060 feet) it lifted about half an ounce.

Exp. 5. The current was passed through half the length of wire (550 feet,) with the same battery, it then lifted 2 oz.

Exp. 6. Two wires of the same length as in the last experiment were used, so as to form two strands from the zinc and copper of the battery; in this case the weight lifted was 4 oz.

Exp. 7. The whole length of the wire was attached to a small trough on Mr. Cruickshank's plan, containing 25 double plates, and presenting exactly the same extent of zinc surface to the action of the acid as the battery used in the last experiment. The weight lifted in this case was 8 oz., when the intervening wire was removed and the trough attached directly to the ends of the wire surrounding the horse-shoe it lifted only 7 oz. From this experiment, it appears that the current from a galvanic trough is capable of producing greater magnetic effect on soft iron after traversing more than ⅕ of a mile of intervening wire, than when it passes only through the wire surrounding the magnet. It is possible that the different states of the trough, with respect to dryness, may have exerted some influence on this remarkable result; but that the effect of a current from a trough, if not increased, is but slightly diminished in passing through a long wire is certain. A number of other experiments would have been made to verify this had not our use of the room been limited, by its being required for public exercises.

On a little consideration however, the above result does not appear so extraordinary as at the first sight, since a current from a trough possesses more projectile force, to use Prof. Hare's expression, and approximates somewhat in intensity to the electricity from the common machine. May it not also be a fact that the galvanic fluid, in order to produce the greatest magnetic effect, should move with a small velocity, and that in passing through one fifth of a mile, its velocity is so retarded as to produce a greater magnetic action? But be this as it may, the fact, that the magnetic action of a current from a trough is, *at least*, not sensibly diminished by passing through a long wire, is directly applicable to Mr. Barlow's project of forming an electro-magnetic telegraph, and also of material consequence in the construction of the galvanic coil. From these experiments, it is evident that in forming the coil we may either use one very long wire or several shorter ones as the circumstances may require; in the first case, our galvanic combinations must consist of a number of plates so as to give projectile force; in the second, it must be formed of a single pair.

In order to test on a large scale, the truth of these preliminary results, a bar of soft iron, 2 inches square and 20 inches long, was bent into the form of a horse-shoe, 9½ inches high, the sharp edges of the bar were first a little rounded by the hammer, it weighed 21 lbs.; a piece of iron from the same bar weighing 7 lbs. was filed perfectly flat on one surface for an armature or lifter; the extremities of the legs of the horse-shoe were also truly ground to the surface of the armature: around this horse-shoe 540 feet of copper bell wire were wound in 9 coils of 60 feet each; these coils were not continued around the whole length of the bar, but each strand of wire, according to the principle before mentioned, occupied about two inches and was coiled several times backward and forward over itself; the several ends of the wires were left projecting and all numbered, so that the first and the last end of each strand might be readily distinguished. In this manner, we formed an experimental magnet on a large scale, with which several combinations of wire could be made by merely uniting the different projecting ends. Thus, if the second end of the first wire be soldered to the first end of the second wire, and so on through all the series, the whole will form a continued coil of one long wire. By soldering different ends, the whole may be formed into a double coil of half the length, or into a triple coil of one third the length, &c. The horse-shoe was suspended in a strong rectangular wooden frame 3 feet 9 inches high and 20 inches wide, an iron bar was fixed below the magnet so as to act as a lever of the second order; the different weights supported, were estimated by a sliding weight in the same manner as with a common steelyard. See the sketch of the magnet.

In the experiments immediately following,* a small single battery was used, consisting of two concentric copper cylinders, with zinc between them; the whole amount of zinc surface exposed to the acid from both sides of the zinc was ⅖ of a square foot; the battery required only half a pint of dilute acid for its submersion.

Exp. 8. Each wire of the horse-shoe was soldered to the battery in succession, one at a time; the magnetism developed by each was just sufficient to support the weight of the armature, weighing 7 lbs.

* All the weights in this series of experiments are avoirdupois.

Exp. 9. Two wires, one on each side of the arch of the horse-shoe, were attached; the weight lifted was 145 lbs.

Exp. 10. With two wires, one from each extremity of the legs, the weight lifted was 200 lbs.

Exp. 11. With three wires, one from each extremity of the legs, and the other from the middle of the arch, the weight supported was 300 lbs.

Exp. 12. With four wires, two from each extremity, the weight lifted was 500 lbs. and the armature; when the acid was removed from the zinc, the magnet continued to support, for a few minutes, 130 lbs.

Exp. 13. With six wires, the weight supported was 570 lbs.; in all these experiments, the wires were soldered to the galvanic element; the connexion, in no instance, was formed with mercury.

Exp. 14. When all the wires, (nine in number,) were attached, *the maximum weight lifted was* 650 *lbs.* and this astonishing result, it must be remembered, was produced by a battery containing only $\frac{2}{5}$ of a square foot of zinc surface, and requiring only half a pint of diluted acid for its submersion.

Exp. 15. *A small battery, formed with a plate of zinc* 12 *inches long and* 6 *wide, and surrounded by copper, was substituted for the galvanic element used in the last experiment; the weight lifted in this case was* 750 *lbs.* This is probably the maximum of magnetic power which can be developed in this horse-shoe, as with a large calorimoter, containing 28 plates of copper and zinc, each 8 inches square, the effect was not increased, and indeed we could not succeed in making it lift as much as with the small battery.

The strongest magnet of which we have any account, is that in the possession of Mr. Peale, of Philadelphia; this weighs 53 lbs. and lifted 310 lbs. or about six times its own weight. Our magnet weighs 21 lbs. and consequently lifts more than thirty five times its own weight; it is probably, therefore, the most powerful magnet ever constructed.

This, however, is by no means the maximum, which can be produced by a small galvanic element, as in every experiment we have made the power increases by increasing the quantity of iron; with a bar similar to the one used in these experiments, but of double the diameter, or of 8 times the weight, the power would doubtless be quadruple, and that too without increasing the size of the galvanic element.

Exp. 16. *In order to ascertain the effect of a very small galvanic element on this large quantity of iron, a pair of plates, exactly one inch square, was attached to all the wires; the weight lifted was* 85 *lbs.*

The following experiments were made with wires of different lengths, on the same horse-shoe.

Exp. 17. With 6 wires, each 30 feet long, attached to the galvanic element; the weight lifted was 375 lbs.

Exp. 18. The same wires used in the last experiment, were united so as to form 3 coils of 60 feet each; the weight supported was 290 lbs. This result agrees nearly with that of Exp. 11, though the same individual wires were not used; from this it appears, that 6 short wires are more powerful than 3 of double the length.

Exp. 19. The wires used in Exp. 10, but united so as to form a single coil of 120 feet of wire, lifted 60 lbs., in Exp. 10, the weight lifted was 200 lbs., this is a confirmation of the result in the last experiment.

Exp. 20. The same wires used in the last Exp., were attached to a small compound battery, consisting of 2 plates of zinc and 2 of copper, after the plan of Prof. Hare, and containing exactly the same quantity of zinc surface, as the element in the last Exp., in *this case* the weight lifted was 110 lbs., or nearly double of that in the last. This result is in strict accordance with that of Exp. 7, the two plates having more projectile force, and thus produce a greater effect with a long wire.

In these experiments a fact was observed, which appears somewhat surprizing, when the large battery was attached and the armature touching both poles of the magnet, it was capable of supporting more than 700 lbs. but when only one pole is in contact it did not support more than 5 or 6 lbs., and in this case we never succeeded in making it lift the armature (weighing 7 lbs.). This fact may perhaps be common to all large magnets, but we have never seen the circumstance noticed of so great a difference between a single pole and both.

A number of experiments were also made with reference to the best form of the iron to receive magnetism, but no very satisfactory results were obtained; of these however, the following are considered as not uninteresting.

Exp. 21. A cylindrical bar of iron weighing 13 oz. 4½ drachms, and bent into a horse-shoe, was covered with 2 coils of wire each 60 feet long; with the small battery used in the last Exp., it lifted 42 lbs.

Exp. 22. A rectangular flat bar $\frac{15}{16}$ of an inch wide, and $\frac{1}{5}$ of an inch thick, also bent into a horse-shoe, weighing 9 oz. 3 dr., and of exactly the same surface as the bar used in the last Exp., lifted, with the same wires and battery, 35 lbs.

Exp. 23. A piece of a gun barrel, little less than an inch in diameter and about 8 inches long, and from $\frac{1}{12}$ to $\frac{1}{13}$ of an inch thick, weighing 8 oz. 3¾ dr. with the wires and battery as before, lifted 40 lbs.

From the last Exp., it appears that a given quantity of iron in the form of a hollow cylinder, is capable of receiving more magnetism than that of a solid cylinder of less diameter, but it is evident from Exp. 21, that a solid bar of the same diameter as the gun barrel, and of greater weight would have lifted more; perhaps the gun barrel was not sufficiently thick for the full developement of magnetism, which, according to Barlow's experiments, resides near the surface.*

A series of experiments† were separately instituted by Dr. Ten Eyck in order to determine the maximum developement of magnetism in a small quantity of soft iron; from these the following interesting results were obtained.

Experiment 1. A horse-shoe of round iron $\frac{56}{100}$ of an inch in diameter, 4 inches long, weighing 2314 grains and wound with 23 ft. copper-wire diameter $\frac{45}{1000}$ of an inch, with a pair of ouc inch plates, lifted 19 lbs. 5oz. 6 dwt. 16 grs.; with a pair of 4 inch plates, lifted 25lbs. 6 oz. 5 dwt.; with the cylindrical element used in Exps. 8, 9 and 10 of former series, it lifted 42 lbs. 6 oz. 8 dwt. 8 grs., or 105 times its own weight.

Exp. 2. A horse-shoe of round iron $\frac{1}{4}$ inch in diameter, $3\frac{1}{2}$ inches in length weighing 310 grains, and wound with 15 ft. copper wire, diameter $\frac{45}{1000}$ inch, with a pair of one inch plates, lifted 3 lbs. 11 oz. 7 dwt. 22 grs.; with 4 inch plates it lifted 5 lbs. 5 oz. 12 dwt. 12 grs.; with the cylindrical element 8 lbs. 2 oz. 8 dwt. 18 grs., or 152 times its own weight.

Exp. 3. A horse-shoe formed of a flat bar $2\frac{1}{10}$ inches long $\frac{3}{10}$ broad and $\frac{6}{100}$ thick, weighing 84 grains, and wound with 16 ft. of brass wire, $\frac{2}{100}$ of an inch in diameter, with a pair of one inch plates, lifted 5 lbs. 2 oz. 3 dwt. 8 grs.; with 4 inch plates, lifted 2 lbs. 10 oz. 2 dwt. 12 grs.; with the cylindrical element 2 lbs . 10 oz. 13 dwt. 2 grs., or 198 times its own weight.

Exp. 4. A horse-shoe of round iron slightly flattened, one inch in length, diameter, (before flattening) $\frac{8}{100}$ inch, weight 6 grains and wound with 3 feet brass wire same diameter as that of No. 3. with a pair of one inch plates, lifted 2 oz. 15 d. 1 gr.; with four inch plates, lifted 3 oz. 17 dwt. 10 gr.; with the cylindrical element 5 oz. 5 dwt. 4 grs., or 420 times its own weight.

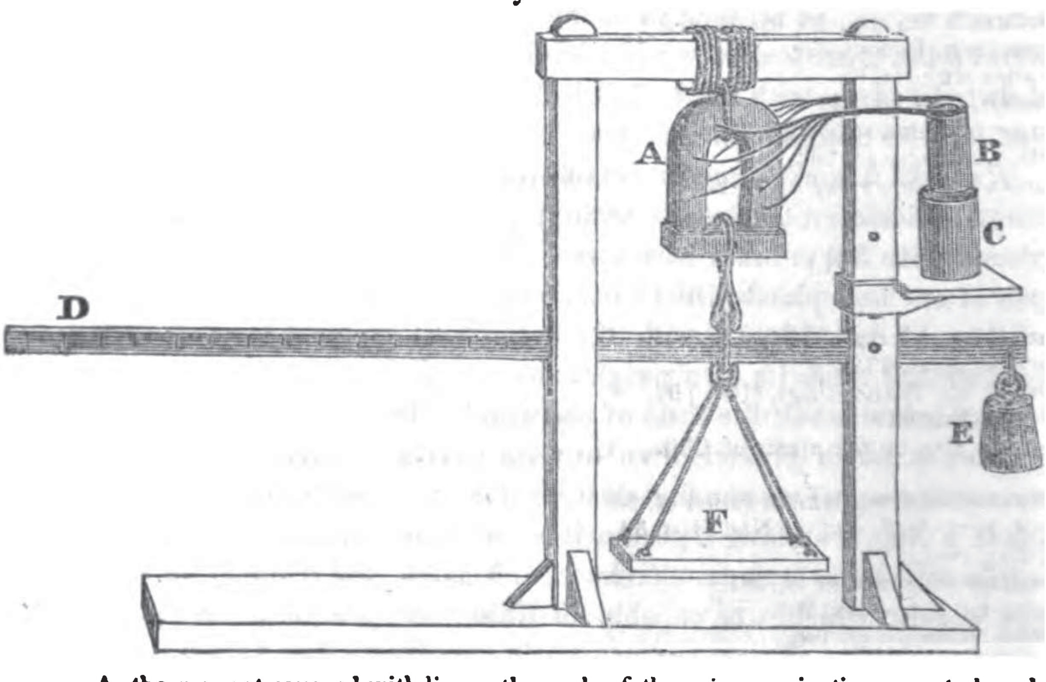
In this last result the ratio of the weight lifted, to the weight of the magnet is much greater than any we have ever seen noticed; the strongest magnet we can find described is one worn by Sir Isaac Newton in a ring, weighing 3 grains, it is said to have taken up 746 grs. or nearly 250 times its own weight. M. Cavallo has seen one of 6 or 7 grs. weight which was capable of lifting 300 grs. or about 50 times its own weight. From these experiments it is evident, that a much greater degree of magnetism can be developed in soft iron by a galvanic current, than in steel by the ordinary method of touching.

Most of the results given in this paper, were witnessed by Dr. L. C. Beck, and to this gentleman we are indebted for several sugges-

* See Barlow's Essay on Magnetic attractions, page 50.
† Troy weight is used in these experiments.

tions, and particularly that of substituting cotton well waxed for silk thread, which in these investigations, became a very considerable emit of expense; he also made a number of experiments with iron bonnet wire, which, being found in commerce already wound, might possibly be substituted in place of copper:—the result was that with very short wire the effect was nearly the same as with copper, but in coils of long wire with a small galvanic element it was not found to answer; Dr. Beck also constructed a horse-shoe of round iron, one inch in diameter, with four coils on the plan before described; with one wire it lifted 30 lbs., with two wires 60 lbs., with three wires 85 lbs., and with four wires 112 lbs.

While engaged in these investigations, the last No. of the Edinburgh Journal of Science was received, containing Prof. Moll's paper on Electro-Magnetism, some of his results are, in a degree, similar to those here described: his object, however, was different, it being only to induce strong magnetism on soft iron with a powerful galvanic battery. The principal object in these experiments was to produce the greatest magnetic effect, with the smallest quantity of galvanism. The only effect Prof. Moll's paper has had over these investigations, has been to hasten their publication: the principle on which they were instituted was known to us nearly two years since, and at that time exhibited to the Albany Institute.



A, the magnet covered with linen, the ends of the wires projecting so as to be soldered to the galvanic element B. C, a cup with dilute acid on a moveable shelf. D, a graduated lever. E, a counterpoise. F, a scale for supporting weights; when a small sliding weight on the lever is not used; a second galvanic element is attached to the appparatus so that the poles of the magnet can be instantly reversed, this is omitted in the figure.

By inverting the large magnet, it sets in motion a very large revolving cylinder of March and Ampère.