XVII. *On the magnetic powers of Soft Iron. By Mr.* Francis Watkins. *Communicated by* J. G. Children, *Esq. Sec. R.S.*

Received April 16,—Read April 25, 1833.

1. A STRAIGHT bar of soft iron, when placed in the vicinity of the poles of a real or artificial magnet, acquires the properties of a magnet; but this power conferred by induction is of a temporary nature, for we find that when the soft iron is withdrawn all its magnetic effects cease.

2. None of those processes which are employed to form permanent steel magnets, will induce a magnetic state on a straight soft iron bar capable of being retained by the bar.

3. When an electric current traverses a copper conducting wire coiled around a piece of soft iron, a powerful temporary magnet is obtained; but when the flow of the electric current ceases, the magnetism developed by the soft iron ceases also.

4. These I believe to be the notions of most persons having a knowledge of magnetism. According to these notions, soft iron can only exhibit magnetic powers when immediately under the influence of induction; consequently soft iron has little or no retentive power within itself, that faculty belonging exclusively to hardened steel.

5. I have, however, noticed that soft iron, under certain conditions, not only possesses the power of retaining magnetism, but that this power does not appear to be weakened by time.

6. Although the fact itself, abstractedly considered, may not be thought of much consequence, yet, perhaps, viewed in conjunction with many others on the same subject already before the world, and with other facts probably still to be revealed, it may be of use in a future classification of magnetic phenomena.

7. The experiments were principally made with four pieces of soft round bar iron, eighteen inches long, and one inch in diameter; each bent into the form of a horse-shoe, and furnished with a keeper of soft iron. About twenty

feet of copper wire, one-fifteenth of an inch thick, was wound around each of the soft iron horse-shoes in a single helix. Compound helices would certainly have made the horse-shoes more magnetic; but as the object was simply to try whether the magnetic principle were permanent, I was content to obtain a certain force, and endeavour to discover whether the intensity of that force remained undiminished after a lapse of time; which I found to be really the case.

8. One of the soft iron horse-shoes, above described (7.), was submitted to the influence of an electric current, by the ends of the copper helix which encircled it being connected with the metallic elements of a voltaic battery of a single pair of plates. While the current traversed the helix, the soft iron supported one hundred and twenty-five pounds. Without breaking the connexion between the copper helix and the battery, the weights were reduced to fifty-six pounds, and then the battery was taken away altogether. The soft iron horse-shoe still supported firmly the fifty-six pounds. The weight was then removed, at the same time special care being taken not in the least to disturb the keeper. Every day the sustaining power of the soft iron horse-shoe was tested, and it was found that it would hold fifty-six pounds suspended by its keeper, just as firmly at the end of ten days as it did when tried in the first instance. The soft iron horse-shoe being required for other purposes, the keeper was violently removed after the last experiment; and then all the magnetism disappeared.

9. When a compass needle was made to approach towards the extreme ends of the branches or poles of the soft iron horse-shoe, while connected with its keeper, a polar state in the soft iron was distinctly marked by the respective attractions and repulsions of the ends of the needle, as they agreed or disagreed in polarity with those of the soft iron. In short, the attractions and repulsions were precisely like those which take place when a compass needle is placed within the sphere of influence of the poles of permanent horse-shoe magnets.

10. One of the soft iron horse-shoes (7.) was saturated with magnetism, by means of the electric current traversing the copper helix around it. The weight supported, while the current was present, amounted to seventy-eight pounds. Twenty-eight pounds were appended to its keeper, and the flow of electricity stopped; attention being paid (as in the first case,) that the union

between the keeper and the poles should in no degree be interfered with. In the absence of the voltaic battery, the soft iron still supported the twenty-eight pounds; and when tried day after day, for nearly a fortnight, was found, like its companion (8.), to be as powerful on the last day as on the first.

I notice this experiment, in order to show that, although one piece of soft iron may not be so susceptible of the magnetic virtue as another, still one of inferior power will retain its virtue like another whose power is superior; the absolute quantity of magnetism being the only difference between them.

11. At the suggestion of Mr. Christie, I had two pieces of soft round bar iron, one inch in diameter, bent into semicircles, so that when their filed flat ends were placed together, the two formed a circle of about six inches internal diameter. Each of the semicircular pieces of soft iron had a copper wire wound around it one-fifteenth of an inch in diameter and fifteen feet in length, in the order of a single helix. Each coil of the helices commenced and terminated as closely to the ends of the semicircles as could be effected with safety to their being retained there.

12. When a circle was formed by the two pieces of soft iron, and an electric current was passing along one of the helical systems of copper wire, a polar arrangement was instantly made manifest, by the action produced upon a suspended compass needle placed within the circle, the opposite magnetic states being observed nearly about the junction of the semicircles, as was anticipated, in consequence of the helix transmitting the electric current, commencing and terminating at those points. The suspended compass needle, in obeying the magnetic influence of the polarity of the circle, arranged itself with its poles opposite dissimilar poles in the circle; and this effect took place whatever situation the poles of the circle occupied as regarded the magnetic meridian.

13. While one half of the circle was rendered magnetic by the presence of an electric current in the helical coil which enveloped it, the other half was attached, and was powerfully attracted. Under these conditions, the flow of the electric stream was interrupted: the attraction still continued, and a weight of twenty-one pounds was upheld, on being hung to the lower half of the circular arrangement, and the magnetic power remained undiminished, so long as the semicircles were not separated.

14. The polar arrangement in the soft iron circle is apparently different while the electric current passes along the helix, enveloping one half, and after the electrical influence is withdrawn: in the first case, in spite of the intervention of a thin plate of mica between each junction of the semicircular pieces, so long as the electric current is present in either helix, the extremities of the semicircles, in approximation, develop *similar* polarities; in other language, the contiguous ends are either both north or both south poles; whereas, on interrupting the transmission of the electric current, the ends in approximation are found to be respectively in opposite states, being north opposed to south, and vice versâ. Similar phenomena are exhibited by electro-magnets of all shapes and sizes, provided the exciting current be very intense; but if it be feeble, the common law obtains whether the electric current be present, or whether it be absent. Of course it is here understood that no rupture has taken place.

15. Several weeks after one of the pieces of soft iron (7.) had been magnetized by the electric current, it was found to be equal in strength to what it was when first it acquired its magnetism. Its original keeper was gently slid off its poles; at the same time a new but similar kind of keeper was progressively slid on; the precaution, of course, being taken that the first keeper was not completely removed before the new keeper was well seated in its place. The soft iron was then tried as to its magnetic power, and it proved full as powerful after the change of keepers as it did before any alteration had been made. Many experiments have been made upon this branch of the subject, and the results found to be uniform in all cases.

16. A straight cylindrical rod of soft iron, ten inches long, and three quarters of an inch in diameter, had eight feet of copper wire wound around it one-fifteenth of an inch in diameter. While an electric current was passing along the copper wire, the rod of soft iron evinced magnetic powers, and kept suspended at its extremities or poles, pieces of soft iron. The ends of a piece of well-annealed iron wire were bent at right angles, so that they could attach themselves to the extremities of the cylindrical rod of soft iron, when it was made into a magnet by the agency of the electric current. On interrupting the electric circuit, it was observed that the arms of the bent wire still adhered to the poles of the cylindrical rod. When iron filings were presented to the

bent portions of the wire, they were attracted and adhered to them. A compass needle was next placed in the vicinity of both poles (successively) of the cylindrical rod, and it became affected in the same manner as when applied to a straight bar steel magnet. When the bent wire was disconnected from the cylindrical rod of soft iron, no appreciable magnetism could be discovered in either the wire or the rod.

17. One of the soft iron horse-shoes (7.) has been allowed to remain charged with magnetism since the middle of last November, and it is now as powerful, if not rather more so, as when first it received the magnetic virtue. Unfortunately, no record was taken at the time as to the precise weight it would uphold. It has, after a lapse of fifteen weeks, frequently supported thirty pounds; and from the force found necessary to slide its keeper through a small space along the surfaces of the poles, it is presumed that its powers are much beyond those here quoted; but being fearful of separating the keeper, the sustaining power of this soft iron magnet has not as yet been put to a severer test than thirty pounds*.

18. A piece of soft bar iron, nineteen inches long, and one inch square, was bent into the form of a horse-shoe, and magnetized by the same procedure as that followed in forming permanent steel magnets, called "touching or rubbing." The exciting magnet was a powerful electro-magnet, and after the square iron horse-shoe had been rubbed some few times backwards and forwards, and withdrawn carefully, to prevent any disturbance between its poles and keeper, it was observed that the square iron horse-shoe would sustain a weight of more than thirty pounds. This power resided in the piece of iron as long as the union between its poles and keeper was uninterrupted; when a rupture took place between them, all magnetism disappeared.

19. At another time, the above-mentioned piece of square bar iron was

* At a Soirée which I had the honour of attending at Kensington Palace on the 27th of April, it was tried, in the presence of H. R. H. the Duke of Sussex and many noblemen and gentlemen, what was the greatest weight the above-mentioned soft iron horse-shoe magnet could support; and it was found that although nearly six months had elapsed since it received the magnetic virtue, yet it was capable of upholding 100lbs.; but the moment the keeper was separated from the poles, almost all the magnetism disappeared. So trifling, indeed, was the residual magnetism in the soft iron horse-shoe, that when the keeper was again applied to the poles, there was not attractive force sufficient even to support the keeper.

rubbed with a steel permanent magnet, and it was found to be equally susceptible, and equally retentive of the magnetic virtue it received from the steel magnet, as it was with that impressed by the electro-magnet. When the keeper was disunited from the poles, magnetism was no longer apparent either in the square bar iron, or in its keeper.

Hence it is clear, that the magnetism conferred on soft iron, by the process of "touching or rubbing," is retained with the same energies as that impressed by electric currents.

20. Another method was adopted to illustrate the powers of soft iron to retain magnetism. One of the pieces of soft round bar iron, bent into the form of a horse-shoe (7.), was stripped of its single helix of copper wire, and in lieu thereof, had sixty feet wound around it in six separate helices, after the fashion recommended by the American philosophers. This soft iron horse-shoe was then fitted up with the necessary apparatus, to show the electric spark by magneto-electricity. It was found, that for days after the magnetism was conferred on the soft iron horse-shoe, when its keeper was suddenly disengaged from the poles, an electric spark was evolved. The spark was not so brilliant as it would have been had the rupture been made while the soft iron was directly under the influence of the electric current; but still the electric spark was displayed by magnetic agency, and it is well known that there must be a considerable concentration of magnetism to exhibit electrical light. This very interesting experiment has been repeated many times with perfect success. The mechanical arrangement of the apparatus necessary to show the electric spark is not here adverted to, because the evolution of electricity by magnetic agency is not the immediate object of the paper; but it may be cursorily noticed, that soft iron magnets are decidedly to be preferred for the exhibition of magneto-electric phenomena, and for showing the electrical light evolved by soft iron magnets: those made of the common English iron of commerce are the best.

21. A horse-shoe of soft iron, with a copper helix (7.), was magnetized by an electric current. Between the poles and the keeper a thin lamina of mica was interposed. While the current was present in the wire, the magnetic powers of the soft iron enabled it to support fifty-five pounds suspended to its keeper. The weights being removed, and the connexion between the voltaic

battery and the copper coil interrupted, the horse-shoe of soft iron retained sufficient magnetic power to support twenty pounds, in spite of the interference of the mica, between the poles and the keeper. The horse-shoe of soft iron was tried, day after day, for nearly two months, and the magnetic force it displayed seemed to be undiminished; so that it was here evident, the mica screen in no degree interfered with the retaining power of the soft iron, although it decidedly did in respect to the weight it would uphold.

22. To ascertain how far the screening effects of thin plates of mica might be extended, so as partially, if not wholly, to overcome the attractive force exerted between the poles of the soft iron magnet and its keeper, and thus destroy all sustaining power, the following experiments were made. On each separate experiment an additional plate of mica was added to that already interposed between the poles and the keeper, and the zinc element of the voltaic battery was well cleansed each time to secure, if possible, equal inducing effects from the electric current. One of the soft iron horse-shoes (7.) was employed, and while the electric current was being transmitted along the copper coil of wire which enveloped it, the horse-shoe supported, with one plate of mica placed between its poles and the keeper, forty-nine pounds; with two plates, forty pounds; three plates, twenty-six pounds; four plates, seventeen pounds; five plates, thirteen pounds; six plates, eight pounds; seven plates, four pounds and a half; eight plates, two pounds and a half; nine plates, two pounds; ten plates, one pound and a half; eleven plates, one pound; twelve plates, three quarters of a pound; thirteen plates, half a pound; fourteen plates, the keeper only; fifteen plates, nothing.

23. While the electric current was traversing the copper wire, coiled around one of the horse-shoes of round bar iron (7.), a piece of common writing-paper was placed between the poles and the keeper; still twenty-eight pounds were supported by the horse-shoe of soft iron. When the voltaic battery was removed without at all meddling with the keeper, and the magnetism of the horse-shoe tried, it was evident a sustaining power existed, for several pounds weight were upheld. Further, in successive trials, for days afterwards, the same power still remained; but when endeavouring to ascertain the exact weight the horse-shoe would support, the keeper broke from it, and the magnetism disappeared. Many experiments of this nature were made, and varied

as regarded the screening substances; but as the results accorded generally with those detailed in this and the preceding paragraph, it has not been considered worth while to particularize them.

24. The magnetism developed by soft iron, when immediately under the inductive influence of an electric current, is eminently useful in the formation of artificial magnets. The magnetism it confers on the steel is equal, if not superior, in intensity to that bestowed by a permanent steel magnet; and when it is remembered, that a soft iron magnet of immense power can be commanded at all times, through the aid of a small voltaic battery, it is clear that a soft iron magnet affords not only the most excellent but the most economical and ready source of magnetism that could be desired.

I have for some time been in the habit of employing soft iron magnets to magnetize both simple and compound hardened steel horse-shoe as well as straight bars; and by paying strict attention to the procedure proper on these occasions, I have been enabled to obtain magnetism in a high state of concentration, in the hardened steel which I submitted to the action of the soft iron magnet.

25. If the steel bar be round and small, no better method can be pursued for imparting the magnetic principle to it, than that of enveloping it in a copper wire helix, and passing a voltaic current through the helix. This procedure was suggested by M. ARAGO and Sir HUMPHRY DAVY, about the same time, in 1821.

26. When performing the experiments whence the preceding results were obtained, it very frequently happened that a separation was effected between the keeper and the poles of the soft iron, sometimes designedly, at others unintentionally; but it was observed in all cases, that separation, whether made immediately after the soft iron had been saturated with magnetism, or after it had retained its magnetism for weeks, still the greatest portion, indeed nearly the whole, of the magnetism of the soft iron was destroyed almost instantaneously; the soft iron retaining only as much as would enable it to support the keeper, and frequently not that, even when the keeper was immediately replaced after a rupture.

This slight retentive property of the soft iron for magnetism, after a rupture, I conceive not properly to belong to the iron itself, but to be caused by the

iron being mixed more or less with steel. The fact of iron retaining a trifling portion of magnetism has long been known to those engaged in the science of electro-magnetism, as also its capriciousness in developing magnetic energies. Among those who, I know, have particularly noticed these facts, I ought to mention my friends, Dr. DAUBENY, Mr. MARSH, and Mr. STURGEON.

27. When I first undertook to perform the series of experiments, the results of which have been briefly detailed, I had in view a different object from that I have since obtained; for I thought the soft iron with its keeper resembled in a manner a closed voltaic circuit. But subsequent observations have led me to conclude, that the whole phenomenon resolves itself simply into a novel case of complex induction. As thus, the horse-shoe of soft iron is made a strong magnet, by the inducing effects of the electric current transmitted along the helical coils of copper surrounding it. The keeper, being a bar of soft iron, is made a magnet by the inductive influence of the magnetism, active at the time in the soft iron horse-shoe, and becoming powerful by the poles of opposite denomination in the soft iron horse-shoe conspiring, equally, to induce opposite poles in the ends of the keeper. Consequently, the great sustaining power possessed by the soft iron horse-shoe (7.) and its keeper, is the result of combined efforts; or in other words, we have two magnets, placed end to end, with dissimilar poles in approximation; which position is well known to increase magnetic effects very considerably, and also to preserve the magnetism.

28. From what has been said and experimentally proved, it appears that when two pieces of soft iron, the extremities or poles of which are so disposed that the one pole of one piece has the power of inducing a dissimilar pole on the end opposite to it in the other piece, the magnetic effects are very considerable, and, what is very singular, are inclined to be permanent, that is, so long as the two pieces are very near to each other; and thus situated they resemble a hardened steel magnet with its keeper.

29. That induction, of a complex kind, is the cause of the phenomena noticed in this paper, there can be little doubt; for it is clear, by experiments 13. and 14., that an appreciable interval existed by the intervention of the mica and writing paper, so that nothing like a continuous flow of electricity or magnetism could have prevailed in the system formed by the soft iron horse-shoe and its keeper. Besides, it was observed in one case, that when the keeper of

one of the soft iron horse-shoes (7.), which, when connected, had occasionally supported twenty-eight pounds for many days after saturation, was disengaged, a coat of rust covered not only the flattened surfaces of the poles of the soft iron horse-shoe, but also the keeper. These surfaces were quite clean when the soft iron horse-shoe received its magnetism, and the rust was produced by its being hung accidentally (when charged,) over a place where a galvanic battery, in a high state of excitement, was perpetually brought into operation. Here again there was an interval, of some extent, between the smooth portion of the poles and the keeper; so that nothing like a continuous circuit could here have been established; and yet, in this condition, the soft iron horse-shoe and its keeper, by their reciprocal action, had the power of resisting a separating force equal to a weight of twenty-eight pounds.

30. I have frequently noticed, when experimenting with electro-magnets which would support from four to five hundred pounds weight, that when the keeper was slid backwards and forwards upon the flattened poles of the electro-magnets, only one or two faint streaks were visible, either upon the poles or the keeper; consequently, there could have been metallic contact only in the parts where those streaks were produced; and yet the surfaces were as perfect as they could be made by hand. Hence the sustaining power of the electro-magnet was dependent upon complex induction; in short, it appears evident, that all magnetic phenomena belonging to this class of effects have their origin in that influence termed induction, but which, when both magnetic states operate, is properly called complex induction.

5, *Charing Cross*,
March 16, 1833.