AN EXPERIMENTAL INVESTIGATION

OF THE

MAGNETIC CHARACTERS

OF

SIMPLE METALS, METALLIC ALLOYS,

AND

METALLIC SALTS.

BY WILLIAM STURGEON, ESQ.,

Lecturer on Natural and Experimental Science, formerly Lecturer on Experimental Philosophy at the Hon. East India Company's Military Academy, Addiscombe.

(Read April 7th, 1846.)

SECTION I.

1. The subject to which this memoir is directed is one that has been already explored at different periods by many eminent experimental philosophers, who have recorded the results of their labours in various works on science; and as several interesting and well-attested facts have been discovered by those investigations, but little would appear to be wanting at this time to accomplish all the desirable information respecting

the magnetic actions of bodies, whether of a ferruginous or a non-ferruginous character. Under these circumstances, any further investigations of mine, or of any other experimental enquirer, could be productive of nothing more than the developement of a few novel facts in addition to those already recorded, or the application of some of them to novel and useful purposes.

2. It frequently happens, however, in experimental inquiries of this kind, that the different modes of investigation resorted to by different philosophers, are not only productive of new facts, but are the means of developing new laws, and of leading to theoretical views differing considerably from those previously entertained for the explanation of phenomena which had long been grafted into the history of science. And it must be acknowledged that, whether new facts be added to the old stock—the application of any of them to useful purposes discovered—or that novel and more exact views for the explanation of those facts be developed, an additional step in the advancement of science would thus be securely established ; and it is solely from a hope that by *some* of these means the present memoir will

contribute to the progress of scientific knowledge, that I have ventured to offer it to the consideration of this Society.

3. The superlative degree of magnetic action displayed by metallic iron, above that of all other known bodies, has been a theme of almost continuous contemplation and philosophical speculation from remote periods in the history of science till the present day, and continues to be a subject of interest and admiration throughout every part of the scientific world. The ordinary laws of the magnetic action of metallic iron, especially when in masses, are, however, now so satisfactorily established, and the phenomena so well known, that any further notice of them in this place would be foreign to the object of this memoir; more especially as it alludes to the simple magnetic attractions only, whilst illustrating the novel facts it contains, and the mode by which they were developed.

4. Nickel is a metallic body which, next to iron, stands most distinguished for the display of magnetic action: and, indeed, notwithstanding the number of inquiries that have been made respecting the magnetic action of other bodies, and

the talent and expedients that have been employed in the pursuit, little or nothing has been satisfactorily ascertained beyond that which is so conspicuously displayed by those two metals,—iron and nickel. (7—13.)

5. There is something very remarkable, however, respecting the magnetism of these two distinguished metals when in combination with other bodies. Nickel, for instance, is said to lose all its magnetic action when combined with even a small dose of arsenic, and iron has long been understood to suffer the same fate when alloyed with antimony. Beyond these two alloys of nickel and iron, I am not aware that any other have been magnetically investigated, although, as will appear in the sequel, some of the most extraordinary facts that have hitherto appeared in the magnetism of metallic bodies, are displayed by alloys of iron with other metals.*

6. Tiberius Cavallo was amongst the earliest inquirers into the magnetic action of non-ferru-

* At the time this first part of the Memoir was read, I was not aware of these curious and interesting facts. They were subsequently discovered, and are described in the second part.

ginous metals ; but the principal part of his experiments were limited to copper and brass, specimens of both of which he found to be magnetic ; and especially after they had suffered the operation of hammering. The investigating apparatus of this philosopher, like that of many subsequent inquirers, consisted of a delicate magnetic needle, to the poles of which the specimens under examination, to prevent commotion in the air, were slowly and dexterously presented.*

* The following are the conclusions at which Cavallo arrived respecting the magnetism of brass :—

" 1st.—Most brass becomes magnetic by hammering, and loses its magnetism by annealing or softening in the fire, or at least its magnetism is so far weakened by it, as afterwards to be only discoverable when set to float in quicksilver.

" 2nd.—The acquired magnetism is not owing to particles of iron or steel imparted to the brass by the tools employed, or naturally mixed with the brass.

" 3rd.—Those pieces of brass which have that property, retain it without any diminution after a great number of repeated trials, viz., after having been repeatedly hardened and softened.

" 4th.—A large piece of brass has generally a magnetic power somewhat stronger than a smaller piece, and the flat surface of the piece draws the needle more forcibly than the edge or corners of it.

" 5th.—If only one end of a large piece of brass be ham-

7. As brass in an alloy so extensively employed in the construction of magnetic compass-boxes,

mered, then that end alone will disturb the magnetic needle, and not the rest.

"6th.—The magnetic power which brass acquires by hammering has a certain limit, beyond which it cannot be increased by further hammering. This limit is various in pieces of brass of different thicknesses, and likewise of different qualities.

"7th.—Though there are some pieces of brass which have not the power of being rendered magnetic by hammering, yet all the pieces of magnetic brass that I have tried lose their magnetism, so as no longer to affect the magnetic needle, by being made red hot, excepting, indeed, when some pieces of iron are concealed in them, which sometimes occurs; but in this case the piece of brass, after having been made red hot and cooled, will attract the needle more forcibly with one part of its surface than with the rest of it; and hence, by turning the piece of brass about, and presenting every part of it successively to the suspended magnetic needle, one may easily discover in what part of it the iron is lodged.

"8th.—In the course of my experiments on the magnetism of brass, I have twice observed the following remarkable circumstance.—A piece of brass, which had the property of becoming magnetic by hammering and of losing the magnetism by softening, having been left in the fire till it was partially melted, I found upon trial that it had lost the property of becoming magnetic by hammering; but having been afterwards fairly fused in a crucible, it thereby acquired the property it had originally, viz., that of becoming magnetic by hammering.

its magnetic or non-magnetic condition is an important scientific inquiry, which, though for many years in the hands of philosophers, remains at this day as undetermined as when first undertaken. That certain pieces of brass have displayed unequivocal magnetic action is a fact which cannot be questioned, but whether that action was due to the alloy of pure copper and zinc alone, or to portions of iron accidentally present in the metal, different opinions have been entertained.*

"9th.—I have likewise often observed, that a long continuance of a fire so strong as to be little short of melting hot, generally diminishes, and sometimes quite destroys, the property of becoming magnetic in brass. At the same time the texture of the metal is considerably altered, becoming what some workmen call *rotten*. From this it appears that the property of becoming magnetic in brass by hammering, is rather owing to some particular configuration of its parts than to the admixture of any iron; which is confirmed still further by observing that Dutch plate brass (which is made, not by melting the copper, but by keeping it in a strong degree of heat whilst surrounded by *lapis calaminaries)* also possesses that property."

* During the interesting series of experiments carried on by Professor P. Barlow, on the magnetism of ferruginous bodies, the brass compass-box, and several brass screws, belonging to one of the finest looking instruments employed, were found, by that philosopher, to be highly magnetic.—*Barlow's Magnetic Attractions,*—Second Edition, P. 17.

8. It has been supposed by Cavallo and other philosophers, that all bodies, whether metallic or otherwise, are endowed with magnetic powers, which vary considerably in degrees of energy, whilst under the influence of, or operating on, the magnetic needle. But when we meet with such conflicting opinions as those that appear in the writings of philosophers so eminent in this department of physics as Cavallo, Coulomb, Bennet, Haüy, Biot, Becquerel, and others who have entered this field of research, we are necessarily led to infer that the subject has not yet been accurately and satisfactorily determined.

9. The beautiful experiments of M. Arago, and the final developement of magnetic electricity by Dr. Faraday, afford an ample explanation of nearly all those experiments in which vibrations of the magnetic needle, near the bodies under examination, were taken as evidence of their magnetic actions ; as well as in all those cases in which light needles of the bodies examined were vibrated under the influence of powerful magnets. It is reasonable to suppose, also, that thermo-electric currents would influence the results of those experiments which were made previous to the discovery of that branch of electricity by Dr.

Seebeck, especially in those cases in which the bodies under examination were held in the hand whilst presented to the magnetic needle.

10. There are, however, some phenomena on record the explanations of which do not appear to fall within the range of the laws either of magnetic-electricity or thermo-electricity; and, therefore, the cause of their developement is necessarily located in some other source. For instance, when Coulomb employed light, delicately suspended needles of gold, silver, glass, wood, and other substances, both organic and inorganic, he found them obey the polar forces of a magnet in precisely the same manner as needles of iron would do; for after the vibrations had ceased, those needles became arranged, between the north and south poles of powerful magnets, in such manner, that their axis rested in the line of magnetic force, or in a right line joining the magnetic poles employed.

11. It is somewhat remarkable that, when similar experiments were made by M. Becquerel, the results were very different. By employing needles of wood, lac, and some other substances, this philosopher found that the positions they

assumed when at rest directly between the north and south poles of powerful magnets, were invariably at right angles to a right line joining those poles ; and, consequently, at right angles, relative to the magnetic forces, or to the position in which the needles of Coulomb rested. From the results afforded by the experiments of M. Becquerel, that philosopher has been led to consider that the effects produced by a strong magnet on a magnetic needle, or on soft iron, differ essentially from those which take place in all bodies whose original magnetism is very weak. In the former the magnetic axis of each is arranged in its *length ;* but in the latter class of bodies the magnetic axis becomes arranged transversely. M. Becquerel shows, however, that wooden needles assume different positions, with respect to the magnetic poles, according to the distance at which they are placed from them.*

12. In a paper by Dr. Faraday, read before the Royal Society of London, in January last, it is stated, that a variety of bodies, bismuth being the most eminent in this respect, arrange themselves, with regard to powerful magnetic poles,

* Traité Experimental de l' Electricité et du Magnetisme. Tom. II, p. 387.

in precisely the same manner as described by Becquerel; that is, with their longest axis at right angles to the line of magnetic force.

13. Dr. Faraday has attempted a classification of a great number of bodies under the two following heads:—*Magnetics* and *Diamagnetics*. The former class, of which iron is the grand type, become arranged, whilst under magnetic influence, with their longest axis in the magnetic line of force; and the latter class, of which bismuth is the type, become arranged at right angles to the magnetic line of force. In the magnetic class, Dr. Faraday places some of those bodies which, according to M. Becquerel's nomenclature, would be placed in the other class, or amongst those which become arranged at right angles to the line of magnetic force. Such, however, is the condition of this interesting inquiry at the present time, no two of those hitherto engaged in it having arrived at similar results in any series of experiments that have been undertaken.

14. The inquiries that I have made in this department of magnetics have been conducted partly by the employment of magnetic needles, partly by permanent steel magnets, and partly by

electro-magnets, which have afforded different modes of assailing those substances that were the objects of investigation.

15. In all cases where delicate magnetic needles are employed, especially when the suspension is by means of a fibre, and the system astatic, the experiments are exceedingly tedious, and much time is required to allow of the system's repose from its agitations before an attempt can be made to approach it with the specimen to be examined. When, however, a single needle is employed, whose support is a finely pointed pivot, the experiments are less subject to delay than by the other mode, though much caution and some dexterity are still required to enable the experimenter to arrive at satisfactory results. But in whichever way the magnetic needle may be suspended in these delicate investigations, the bodies under examination must either be held immediately in the hand, or indirectly, by means of some other body previously ascertained to have no influence on the needle. If held in the hand, thermo-electric currents are to be suspected; and if attached to the end of a wooden rod, by means of sealing wax, or resinous cement, other electric actions may interfere with the results; or may,

indeed, be the sole cause of any motions that may happen to be observed. Moreover, a delicate magnetic needle does not possess a sufficient degree of power to bring into play the minute portions of magnetism that lie dormant in many bodies. These exiguous sleeping forces can never be roused into a state of activity, and, consequently, can never be discovered by merely presenting the bodies in which they reside to the pole of a feeble magnetic needle. To accomplish their discovery a comparatively powerful magnetic action is absolutely required; for, when thus assailed, their polarization is more easily enforced, and their detection almost certain. The magnetic needle, however, may be usefully employed in cases where the suspected magnetism of a body is of some easily detected amount; and it may be resorted to with advantage, in preliminary trials, under all circumstances, because of the possibility of the specimen under examination possessing a sufficient amount of magnetism to be detected by it, and the more tedious modes of inquiry being thus rendered unnecessary.

16. I have found that a convenient and efficacious mode of examining bodies the magnetic actions of which are very feeble, and others

in which magnetism has but a questionable existence, is by means of an apparatus represented by the accompanying figures.

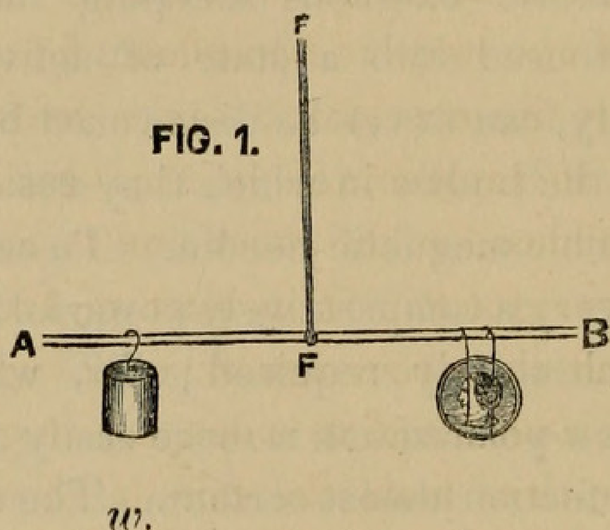


FIG. 1.

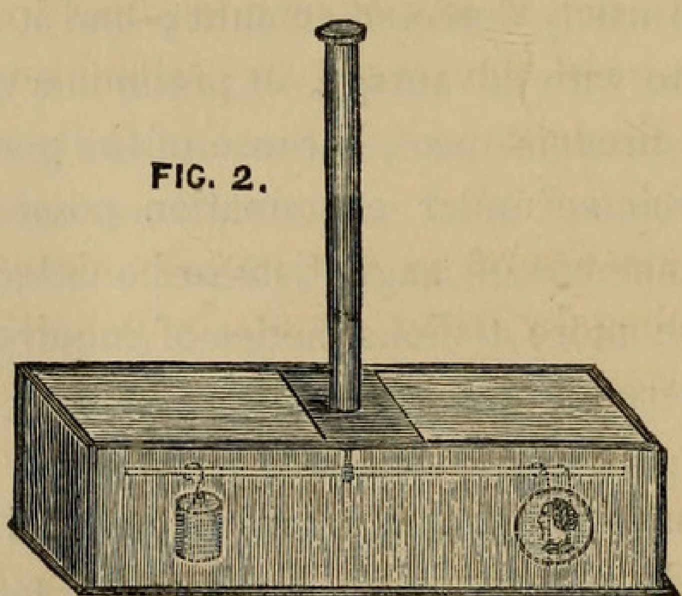


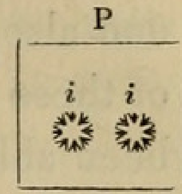
FIG. 2.

Fig. 1 is that part of the apparatus in which the specimens to be examined are placed. It consists of a light cylindrical wooden rod A B, about twelve inches long, and suspended by a few parallel fibres of silk F F, from the cocoon. The end B is furnished with a light slip of card paper and two loops of horse-hair, for the purpose of holding the specimen; say a half-crown, for instance, as represented in the figure, which is counterbalanced at the other end of the lever by a sliding weight *w*. This part of the apparatus is enclosed in a rectangular box, Fig. 2, whose ends, top, and one of its sides, are of glass, and a brass tube rises from the middle of the top, in which hangs the silken fibres. The head of this tube sustains the fibres and their appendages, and can be turned in any horizontal direction for the adjustment of the lever to a parallelism with the sides of the box.

The glass parts of the box are sustained by a light mahogany frame, with a bottom of the same kind of wood. The ends and sides are fixed, but the top, which consists of two sliding parts, can be removed at pleasure, for the purpose of introducing the hands for the adjustment of the apparatus within, and replaced when the specimen has been accurately counterpoised, a process which is still further facilitated by the introduction of the hand at one side of the box, which is opened for that purpose, and afterwards closed by a sliding mahogany door.

When the agitations of the lever have subsided, the sliding door is partially opened for the introduction of the poles of a powerful steel horse-shoe magnet, which is made of a long and narrow shape for the purpose. This magnet is placed on a sliding carriage, by means of which it is made to approach the specimen, or recede from it, with great facility and in the most gentle manner. In consequence of finding decided polarity in some specimens in which no magnetism was previously known to exist, I have been led to the employment of a powerful bar magnet, which I find convenient in those cases where such polarity is suspected. I have also employed electro-magnets, both straight and of the horse-shoe form; but having found that these are troublesome and inconvenient, I have abandoned the use of them altogether in these inquiries.

In cases where extreme nicety is required, I have found the following mode exceedingly useful.



Besides the sliding door which closes one side of the box, I have another sliding piece P, which fits into the same grooves in the side of the box. Through this piece pass two cylindrical rods of soft iron, *i i*, about two inches in length. They are firmly fixed in the wooden slider at their middle parts, and parallel to each other. When this piece is in its place the iron rods are in the same horizontal plane, having one half within and the other half outside the box, and their inner ends presented to the specimen suspended on the lever. When the remaining portion of that side of the box is closed by the sliding door, the specimen is nicely adjusted to the ends of the iron rods by turning the top piece of the tube, until the most trifling space is perceptible between them. When all is at rest the poles of the horse-shoe magnet are made to approach the outer ends of the iron rods, bring them into magnetic action, and thus detect the magnetism of the specimen if any exist in its structure.

17. By the assistance of this apparatus, to which I give the name *Torsion Magnetoscope*, I have examined gold, silver, copper, platinum,

tin, antimony, lead, zinc, bismuth, and mercury; and also some of their alloys and salts. In none of these metals, when in a state of purity, have I been able to discover the slightest trace of magnetic action, though in several specimens of some of them, as they appear in a commercial state, magnetic action is strongly developed.

18. A bar of bismuth, for instance, cast from a mass fused in an earthenware crucible, was found to be highly magnetic, and, for a while, was considered as a good specimen of the magnetic action of that metal; but on examining another bar cast from the remaining portion in the crucible, and finding it still more powerfully magnetic than the former, a suspicion was aroused that either their crystalline structures were different to each other or that the metal was not pure. The experimental inquiries which this suspicion occasioned, led to the detection of localities in the two bars in which the magnetic actions were more powerful than in other parts of them, which gave rise to the determination of *sweating* one of the bars at a low heat, and running out of the crucible the most easily fused portions, before the rest became fluid, which is an excellent process for freeing

pure bismuth from some of the impurities with which it is frequently contaminated in the mercantile state.

19. This purified bismuth having been cast into a bar, was afterwards broken into convenient fragments and tested by the *Torsion Magnetoscope*, previously described (16), but not the slightest trace of magnetism could be detected in any of the pieces.

20. Having satisfied myself that no magnetic action resided in the pure bismuth, the dross left in the crucible was softened by heat and poured on a stone slab, and on being tested developed high magnetic powers. It now became obvious that the whole of the magnetism displayed by the bismuth, when in its first state (17), was due to that portion only which was left as dross in the crucible after the pure metal had been run out.

21. From the results thus arrived at I was induced to fuse other portions of mercantile bismuth, and run out the purest portions of the metal at the lowest degree of fusible heat, by which means I have been enabled to separate the magnetic from the un-magnetic portions, and

thus to arrive at the conclusion that pure bismuth is not susceptible of any *direct* magnetic action by the mere approach of the poles of a powerful magnet, which I consider a test of far greater certainty and exactness than that of a feeble magnetic needle, whatever may be the delicacy of its suspension ; and as a peculiar class of phenomena become displayed by a sudden developement of the powers of an electro-magnet, much misconception might rise from its employment.

22. The most usual impurities of bismuth of commerce are sulphur and arsenic, and, occasionally, a small portion of silver and iron. On subjecting the drossy part (19) to dilute sulphuric acid a portion was dissolved; after which the liquid was reduced almost to dryness by evaporation. The residue being diluted with water, and a solution of ferrocyanuret of potassium being added, it assumed a blue colour, which indicated that a portion of iron had been dissolved from the mass. On dissolving another portion of the dross (19) in dilute sulphuric acid, the presence of iron was again indicated by the addition of bruised gall nut. Hence it was fair to infer that the whole of the magnetic action displayed by the mass was due to the iron it contained.

23. I have examined antimony in the same way, and have found some specimens magnetic, and many others in which magnetic action could not be detected. By thus operating on antimony, however, it would be impossible to form a correct idea of the magnetic, or unmagnetic state of that metal; because, as will appear in the sequel, of its masking, to a considerable extent, the magnetism, of even considerable proportions, of iron, when the two metals form a perfect alloy. Hence, in order to test antimony magnetically, it becomes necessary to ascertain, by chemical processes, that it is perfectly pure, and especially that it is free from iron; for, although antimony will mask the magnetism of iron when in perfect union with that metal, a very trifling proportion of uncombined iron will render the whole mass *apparently* magnetic. By attending to these particulars, pure antimony will not be found to display any magnetic action. (17).

24. It is generally understood, principally I believe, upon the authority of Dr. Seebeck, of Berlin, that iron becomes "completely destitute of magnetic action" when alloyed with four times its weight of antimony.* This, however, does

* Brewster's Magnetism, page 102.

not appear to be correct, for I have formed very perfect alloys of these two metals, in a great variety of proportions, and find that when the iron does not form even a twentieth part of the mass, it is still magnetic, though in a very low degree. When the alloy is of equal parts of iron and antimony, it is highly magnetic. This alloy, when broken, exhibits a dark grey fracture, somewhat glittering. It is easily reduced into powder by the operation of a file, or by pounding in a mortar; and what is very remarkable, it yields an abundance of deep crimson sparks when struck against hard steel.

25. It has already been stated (17), that pure copper is not magnetic; and I must now add that, in a very few cases only, have I detected magnetic action in the copper of commerce, although I have tested a great number of specimens both in the state of sheet and of wire.

26. In the copper coinage of this country, I have never yet met with magnetic action, notwithstanding the number of experiments I have made on the various copper coins that have been struck in the reigns of several Sovereigns.

27. In the gold and silver coinage, however, in which copper forms a constituent part, the case is very different. These alloys are nearly all of them decidedly magnetic, and, probably, none of them entirely free from magnetism. The gold coinage, however, displays much feebler magnetic action than the silver coinage; indeed in many gold coins the existence of magnetism may be considered as questionable, whilst in others, and especially in those of 1844, magnetic action is prominently displayed.

28. The silver coinage, although in some specimens scarcely any magnetic action can be detected, is generally magnetic in a very eminent degree; and I have found that, when any one piece of a particular coinage displays considerable magnetic action, the whole of that coinage, as far as I have examined it, is similarly magnetic. And, on the other hand, when a silver coin has been found to be but very slightly magnetic, I have but rarely met with one of that particular coinage in which any considerable degree of magnetism could be detected.

29. Of the silver coins that have come under my notice, a half-crown of William and Mary,

dated 1691, is the most eminently magnetic. The next, in point of magnetic action, are the half-crowns of 1844 and 1845 ; then one of George IVth, the date of which I have not noted. The half-crowns of George III., of 1819 and 1820, are more slightly magnetic than those last named, and the half-crowns of both coinages in 1817 are still less magnetic than those of 1819 and 1820. Shillings, also, of certain coinages, are magnetic in an eminent degree, and there are but few, if any, that I have examined, that are entirely neutral to the high magnetic powers with which they have been assailed.

30. Silver articles for domestic purposes, such as spoons, prongs, fruit knives, &c., were, in many specimens, found to be much more magnetic than any of thesilver coins that I have examined. I have borrowed several sets of silver tea-spoons from neighbouring families, and, with the exception of one half-dozen of Scotch spoons, of a very old date, all have displayed high magnetic powers, though of very different degrees in different sets. But what is very remarkable, if one individual spoon was found to be highly magnetic, the whole of that particular set, whether it consisted of half a dozen or a dozen spoons,

were highly magnetic also. And, generally, whatever might be the magnetic condition of any individual spoon, the whole number of the set to which that spoon belonged were magnetic alike, or very nearly so. Hence, if the quantity of magnetic action of any individual spoon were to be denoted by q, and the number of spoons in the set denoted by n, the sum total of magnetic action in that set of spoons would be $n\ q$, nearly. Of course, this reasoning applies only to individual sets of spoons which are of uniform make, composition, and structure of metal. It appears, also, as far as my experience has extended, that the same mode of reasoning would give the sum total of all the magnetic action that any individual coinage would display. Suppose, for instance, the magnetism displayed by a half-crown piece were to be taken as the unit of quantity equal q, then the number of pieces being n, the sum total of magnetism which the whole of that coinage would display would be $n\ q$, nearly ; and, similarly, for any other coinage of silver.

31. The difference of magnetic action displayed in the silver coinage and domestic articles of that metal (29,30), led to the supposition that minute portions of iron might accidentally have got

introduced to the alloys whilst in a state of fusion, which had some probability in its favour, from the fact that the metal for silver coinage is fused in cast iron pots,* and, therefore, liable to take up a portion of those vessels. But, on the other hand, if that were always the practice, it would lead to the inference that in all the silver coins the iron would be nearly in the same proportion, and the extent of magnetic action almost the same in all. Whereas, by the tests already described, this is not the case.

32. The current silver coinage of William and Mary became so base, that in the year 1694 it was all called in, and a new coinage issued. From this fact it occurred to me that there was a possibility, at least, that the high degree of magnetic action displayed by the half-crown of 1691 (29), was owing to an undue proportion of copper, or of some other inferior metal. This idea led to the selection of a shilling, in which scarcely a trace of magnetism could be detected, for fusion with an additional portion of copper, also non-magnetic, having been obtained by the electro-type process. These, together with a

* Ure's Dictionary of Arts and Manufactures. Brande's Chemistry, page 1037.

piece of pure silver, were fused in an earthenware crucible, and run out upon a sheet of copper. The copper in this alloy was about one to five of silver, which is more than twice the proportion of that in the standard coinage. On subjecting this mass to the *torsion magneto-scope*, it was found to be more highly magnetic than the old half-crown of William and Mary (29.)

33. This singular result has cost me much thought and a great deal of trouble. The crucible employed was quite clean, having never been used before ; and its contents during the time it was in the fire were the silver and copper, and a mixture of pulverized charcoal and common salt. Similar pieces of charcoal and slices of the same quality of salt have been tested, but no magnetic action could be detected in either. Whence, then, this almost unexpected magnetism in the metallic alloy ? Fragments of a broken crucible similar to that used were found to be slightly magnetic, probably from a portion of iron in the clay of which it was formed : but the magnetic action in the fragment of the crucible was not nearly so great as that displayed by the alloy. Moreover, the pure portion of the silver that entered the alloy had previously been fused in a

similar crucible (one of the same nest,) and with a similar mixture of pulverízed charcoal and salt, and yet showed no trace whatever of magnetic action. Hence, it could hardly be imagined that the magnetism displayed by the alloy was due to iron derived from the crucible.

34. After subjecting a portion of the alloy (32) to dilute nitric acid, and finding no iron in the solution, the surface of the metal was washed in clean water and thrown into dilute sulphuric acid, which, upon the principles of electro-chemistry, took up a portion of the copper; and had iron been present, would have taken it up also. But no indication of that metal appeared by the test of gall nut, nor by that of ferrocyanuret of potassium; but the formation of ferrocyanuret of copper was manifested in an eminent degree, though previously to the introduction of the ferro-cyanuret of potassium, scarcely any colour was perceptible in the liquor.*

35. From the facts above described (32, 33, 34), and, at present, I rest on no other data, I

* Another portion of the alloy has since been analysed, with similar results.

am inclined to think that if any iron could possibly have entered the alloy, its quantity must have been too small to cause the high degree of magnetic action which the specimen exhibited.

36. On comparing this alloy of silver and copper, with the alloy of iron and antimony, in which the weight of the latter metal is only about twenty times that of the iron (24), some very remarkable circumstances present themselves. In the former alloy, where no iron can be detected by the usual chemical tests, we have a metal whose magnetic action is, at least, twice as powerful as that displayed by the alloy of iron and antimony, an alloy of which iron constitutes a very considerable proportion, and whose presence, had it not been previously known, could have been detected by the humblest test for ferruginous matter. These parallel experiments tend to show either that an alloy of pure silver and pure copper is magnetic, or that the magnet is a better test for the presence of minute portions of iron, in such alloys, than any hitherto known in chemical manipulations.

37. I regret that another piece of unmagnetic silver has not yet fallen in my way, to enable me to make further investigations on this curious

subject. But I am in hopes of obtaining unequivocal results before the second part of this memoir is brought before the Society.

38. With respect to brass, one of our most important alloys, I have found it to be highly magnetic in a great number of cases; viz., in all the various states of newly cast brass, brass wire, and sheet brass; as well as in several articles of brass manufacture. But, from the very great difference in the degrees of magnetic action displayed by different specimens of this beautiful alloy, and the total absence of that action in others, there has appeared to me a high degree of probability that the magnetism displayed by brass is due to accidental portions of iron in the alloy.

39. Cavallo discovered that in magnetic brass the action was more powerful in large pieces than in small ones. This fact I have also observed in several specimens that I have examined. The reason seems to be that in the larger pieces a greater quantity of ferruginous matter (if present), is brought into operation than in the small pieces.

40. Cavallo also states, that hammering an un-

magnetic piece of brass will cause it to become magnetic. An instance of this kind I have never yet met with : but I have found that when an unhammered piece has been so slightly magnetic as to have that character but just discernible, hammering it so as to compress its two sides closer together, gives it an increased magnetic action ; which may possibly be a consequence of bringing the whole of its magnetic particles more completely within the range of the testing magnetic influence ; and I am inclined to believe that, had Cavallo's test been more powerful than a magnetic needle, he would have found that those pieces whose magnetism he thought was due to compression alone, were slightly magnetic previously. Still, however, there is a possibility that magnetism might be detected in compressed brass, in which that power is too feeble to be detected whilst the metal is in an uncompressed state, even by powerful magnetic tests.

41. In addition to the advice given by Cavallo, respecting the necessary caution in employing brass in the construction of compass boxes (note to 6,) I should advise the makers of those useful instruments to test every piece of brass, intended to be employed in their construction, by a powerful

magnet, instead of testing them in the usual way by means of a delicate magnetic needle. And if this test be accurately performed when the metal first arrives from the foundry, the detection of any concealed magnetism, even if very feeble, will be almost certain ; and much of that labour and uncertainty, which must always attend examinations by the needle, would be avoided. Unfortunately, however, too much reliance is usually placed on the mere appearance of the brass, or on the character of the foundry whence it is procured, and the consequence is, that but very few brass compass boxes that are in common use are entirely free from magnetic action.

42. The next alloy of importance that I have examined is German silver, in which nickel is one of the principal constituents. In the best kind of German silver, (constituted of copper eight parts, nickel six, and zinc three), a slight magnetic action has been detected, but in the inferior kinds of German silver, into which only about three parts of nickel enter, I have not detected any magnetic action whatever. Hence the magnetism of that portion of nickel is obviously neutralized in that particular alloy.

43. The metallic salts that I have examined, are some of those most frequent in common use. The salts of iron were the sulphate, the yellow and the red ferrocyanuret of potassium, also Prussian blue. These, with the exception of the yellow prussiate, are magnetic; the sulphate of iron in the highest degree of any of them. It is somewhat remarkable that the two kinds of prussiate of potash, where the proportions of iron are so nearly alike, (yellow 15 per cent, red 16 per cent,) should display such a material difference in their magnetic characters. And it is still more singular that Prussian blue, which contains more than 45 per cent of iron, is less magnetic than the red prussiate of potash. The sulphate contains about 33 per cent of iron, and is the most magnetic of the whole.

44. Pure sulphate of copper shows no magnetic action, but that of commerce is highly magnetic, being, as I have ascertained, adulterated with sulphate of iron. Hence, the magnet would be a good and speedy test for the quality of the commercial salt.

45. The following salts appear to be perfectly neutral to magnetic forces :—Common salt, salt-

petre, borax, sulphate of magnesia, sulphate of soda, sulphate of potash, carbonate of potash, and carbonate of soda.

46. Thus far I have attempted to contribute to the list of facts previously known, and to correct some errors which, probably on account of the inefficient modes of investigation, have crept into this particular branch of science. It is possible also, I think, that some of the facts which have now been pointed out, may be an inducement to employ the magnet more extensively than hitherto, in the laboratory of the chemist.

SECTION II.

(Read May 5th, 1846.)

47. In addition to the facts enumerated in the first section of this memoir, further investigations have led to the discovery of others of a no less interesting character. By extending the examination of British silver coins, I find that the whole of them are more or less magnetic. The half-crowns of the present reign, that have come under my observation, are certainly all magnetic, and some of them display considerably high magnetic powers, more especially those of the years 1842, 1844, and 1845; and a Victoria shilling, coined in the year 1842, is still more magnetic than any of the half-crowns.

48. The half-crowns of George the Fourth are, in general, highly magnetic, though but very few of them display such high magnetic powers as some of those of William the Fourth. There is something remarkable in the following fact:—I have not met with any of the half-crowns of

George the Third that are so powerfully magnetic as those of subsequent coinage.

49. With respect to silver ornaments, silver medallions, and silver articles for domestic purposes, they differ materially in their magnetic characters. But, generally, they are more highly magnetic than the British silver coins. (30.)

50. The large silver medal of the Society of Arts, for the year 1825, weighs nearly two and a half ounces; yet it does not display even the slightest degree of magnetic action, by the most severe test to which I have subjected it; whilst a small silver medallion of the Commonwealth, representing Lord Essex on one side, and the two houses of parliament on the other, was found to be more highly magnetic than any of the previously named coins. A small silver medallion of Charles the Second, exhibited a slight degree of magnetic action.* An Indian rupee that I examined, showed no magnetic action whatever.

51. The present gold coinage of this country is, in general, but feebly magnetic. I have met

* For the use of these medallions, and the Indian coin, I am indebted to my friend G. Wareing Ormerod, Esq.

with a few sovereigns of the present reign which are more magnetic than any others that have come under my notice.

52. With respect to jewellery, it is generally more highly magnetic than those articles of silver that have come under my examination. Wedding rings, which contain but a small proportion of copper, have so slight a degree of magnetic action as almost to elude the detection of it: whilst ornamental rings, keepers, &c. which contain a much greater proportion of copper, are, generally, highly magnetic. Some ear-rings that I have examined, are still more magnetic than the finger-rings. Gold watch chains are generally magnetic, especially those containing much copper: also gold spectacle frames, unless they be of what is called fine gold, are magnetic to a considerable extent. In all cases where steel or iron screws, or nails, have been found in the gold articles examined, those parts have been carefully removed previously to the magnetic test being applied.

53. We next come to the consideration of metallic alloys, of which either iron or nickel form no inconsiderable proportions. It has already been shown in the first section of this memoir

(24), that antimony, when alloyed with iron, counteracts the magnetic action of the latter metal in a very eminent degree, rendering it almost undetectable when the iron amounts to little less than a twentieth part of the mass : and I find that when the ferruginous metal amounts to no more than about one fortieth of the mass, its magnetic powers entirely disappear.

54. There are several other metals, besides a number of other bodies, which either partially or wholly neutralize the magnetic actions of iron and nickel. The most eminent of the metals in this capacity is zinc. This metal, which, till these researches were undertaken, was not known to affect the magnetism of iron, neutralizes nearly the whole of that power when alloyed with an equal proportion of the ferruginous metal. And although from an accident with the melting pot I have not yet arrived at the fact, I have no doubt whatever that, when the iron amounts to no more than one quarter of the mass, its alloy with zinc will be perfectly neutral to the magnet.*

* Since this paper was read I have ascertained that an alloy of iron and zinc in the proportion of 1 to 7 respectively, is quite destitute of magnetic action.

55. The neutralization of magnetism in iron by alloying it with zinc is a fact of high importance in the contemplation of metallic magnetism: and especially the magnetism of brass, and other alloys, in which zinc forms a considerable proportion. For it is highly probable, that since zinc smothers the magnetic influence of large proportions of iron, a considerable quantity of the latter metal might enter the composition of brass, without rendering it palpably magnetic. Such in fact, would absolutely be the case, provided the alloy were perfect, and that the copper had no influence on the magnetic condition of the combined iron and zinc.

56. To satisfy myself on this point, I have subjected to chemical analysis, some of those specimens of brass which had been found to be highly magnetic: and, as far as I have proceeded, there appears no reason to suppose that the magnetic powers they displayed were due to iron in their composition. Indeed, I am now inclined to embrace the opinion of Cavallo: (6, note) that the magnetism of brass is not due to ferruginous matter: but depends upon a suitable arrangement of the particles of its proper constituent metals, copper and zinc. Nor do I believe that brass

generally, as it leaves the foundry, contains any notable quantity of iron. I have analysed many specimens, both magnetic and unmagnetic, and the traces of iron, where any were discoverable, were very minute, and as frequent in the one kind as in the other. It is true that some specimens of brass contain more than an average proportion of iron; but it is a curious fact that these specimens are not those which display the greatest magnetic powers.

57. We learn, also, from these facts, that the demagnetizing powers of antimony and zinc will necessarily prevent the detection of small proportions of iron in those metals, even by the aid of powerful magnetic forces, and leave us in uncertainty regarding their purity when examined by this test alone.

58. Lead and iron do not easily unite into a perfect alloy, excepting when the ferruginous metal is in very small proportions; but when thus combined, the iron loses a great part of its natural magnetic qualities.

59. Silver and copper unite very sparingly with iron; but whether the magnetic powers of

the latter are affected by its union with those metals, or not, is not yet known.

60. In order to ascertain the exact quantity of pure metallic iron, that would render a neutral half crown* *apparently* magnetic, to the same extent as another half-crown, was *absolutely* magnetic, I attached to the former, by means of softened gum, new iron filings; and after many trials ascertained that the requisite quantity of filings amounted to about a ten thousandth part of the mass. And on changing the pure iron for the peroxide of iron, a 480th part of the mass was required to render it equally magnetic with the standard half-crown. Now, as more than two-thirds of this oxide is iron, it follows that, in this state, the iron loses a considerable portion of its magnetic powers; and that the proportion of iron required in this case, to produce the standard degree of magnetism to the mass, was little short of a seven hundredth part.

61. Now, if any iron existed in the standard magnetic half-crown, uncombined with the other

* This piece of coin was not entirely devoid of magnetic action, but it approached nearer to a state of neutrality than any other I then had. Its action was very feeble indeed.

metals, it must have been in a state of peroxide,* and that more than an eight-hundredth part of the half-crown must have consisted of iron, if its magnetism were due to the presence of that metal.

62. Again: the magnetic action of this half-crown was considerably more feeble than that of the alloy which has been chemically examined; and in which, if iron were present at all, that metal was in a less proportion than a twenty-thousandth part of the mass, which proportion, in a state of peroxide, and divided as it necessarily must have been through the whole alloy, would scarcely yield the slightest perceptible magnetic action. Moreover, if iron to that amount were even pure or uncombined, its quantity was far too small for the display of those high magnetic powers of which it was obviously possessed. And, as there is a probability, at least, that the magnetic powers of iron become deteriorated by an alloy of that metal with silver or with copper, or both, there is not the slightest reason for supposing that the magnetism of the alloy in question (32) was due to any iron that it could possibly contain. Nor do I believe

* It is possible that the iron, if any, might be in the state of a carburet; but even in this condition much of its magnetic powers would be neutralized.

that the magnetic actions displayed by the coinage are traceable to the presence of iron.

63. It has already been stated (42) that the magnetic action of nickel is considerably neutralized when combined with zinc and copper in the alloy constituting German silver. Since that part of this memoir was read before this society, I have had an opportunity of alloying nickel with zinc alone, and have ascertained than when the zinc is about eight or ten times the quantity of nickel, the alloy is perfectly neutral to the magnet. This alloy has a zinc-coloured fracture, and partially crystallized in the manner of zinc; but it is extremely brittle and easily pulverized in a mortar.

64. Nickel and antimony combine with facility and in an extraordinary manner. If two pieces of the metals, one of each, be placed side by side in the crucible, so as to touch one another, especially at their upper ends, the moment the antimony assumes a dull red heat, even a lower heat than that which commences its fusion when alone, the nickel bursts out into a fine scarlet glow, fuses and spreads over the antimony in a beautiful fluid state, and insinuates itself into the pores of that metal, rendering the whole mass soft like paste or butter. If, whilst in this state, the crucible be

removed from the fire and permitted to cool gradually, the fracture of the button of this alloy, when broken, is of a much lighter colour than that of antimony. It is of a light grey, and very imperfectly crystallized. It is not so brittle as antimony, though still pulverable in a mortar. When one-fourth of the mass is nickel, the fracture is very compact, and not unlike that of fine steel, but of a lighter colour. With these proportions the alloy is somewhat malleable, and can be cut by a cold chisel.

65. From a retrospection of the facts developed by these researches in connection with those previously known, we are led to observe a material difference in the magnetic characters of bodies when in their simplest or natural conditions; and that these natural magnetic characters become considerably modified when the simple or elementary bodies are variously combined; some simple bodies losing their natural magnetic properties, and others displaying a new magnetic action of which, before combination, they appeared to be destitute. Under these circumstances it would be difficult to ascertain the line of demarcation between those bodies that are naturally and separately magnetic and those that are not. Probably the safest way would

be to allow all bodies to possess, more or less, of the magnetic character; and to classify them into those that are *palpably* magnetic, like iron and nickel: and those that are but obscurely magnetic, or whose magnetism is not detectable in their individual states, but which become magnetic by combination.

66. Provisionally, therefore, we might venture to call the former class *Sapho* magnetics*, and the latter class *Asapho† magnetics.*

67. *Sapho-magnetics* might be conveniently subdivided into *Mono‡ magnetics* and *Suno§ magnetics*, accordingly as they consist of individual or of compound bodies. Then, as we have many bodies which counteract the highest magnetic powers of simple bodies, these might be called *Kato-magnetics*,‖ because many of them, if not all, have the power of completely neutralizing the magnetic actions of other bodies.

* Σαφα. Clearly, manifestly.

† Ασαφῶς. Indistinctly, without clear evidence or marks.

‡ Μονος. Alone, single.

§ Συν. Together, or, Συναιρω. To co-operate.

‖ Κατα. Opposite to, to make disappear.

68. The *Mono-magnetics* at present known are but few in number, iron being the grand type. Next to iron is nickel. Cobalt is also a mono-magnetic body, and, at present, completes the list of this class of magnetics.

69. In the *Suno-magnetic* class I place alloys of copper and silver, copper and gold, and copper and zinc; and, although these three are the only ones with which we are yet acquainted, I have no doubt that many more alloys will soon find a place among suno-magnetics.

70. The *Kato-magnetics* are very numerous, as this class includes all bodies which, by combination, impair the magnetism of other bodies. Amongst the metallic *Kato-magnetics*, zinc is the most powerful hitherto ascertained. Next to zinc is antimony. Then lead and tin. Arsenic, probably, stands very high in this class, but I have had no opportunity of ascertaining its proper place. The non-metallic *Kato-magnetics* are sulphur, oxygen, cyanogen, chlorine, carbon, and the generality of those bodies which combine with the metals.

71. In proposing this classification of magnetics

I have aimed at nothing further than an abstract of that which absolutely takes place in nature. The whole rests upon facts, most of which have their analogies in electricity. All bodies are known to possess electric properties, but differing in degrees of power, and the compounds display very different electric powers to those of the simple constituents. The electro-magnetic powers differ in different bodies, both simple and compound, as decidedly as the powers which are purely electric. Therefore this classification may be considered as supplying a small portion of an extensive nomenclature that has long been wanting in this region of science.