A

TREATISE

ON

MAGNETISM,

IN

THEORY AND PRACTICE,

WITH

ORIGINAL EXPERIMENTS.

BY

TIBERIUS CAVALLO, F.R.S.

LONDON:
PRINTED FOR THE AUTHOR;
And sold by C. DILLY, in the Poultry; P. ELMSLY, in the Strand; and J. STOCKDALE, in Piccadilly.

M.DCC.LXXXVII.

THE

PREFACE.

THE importance of the ſubject of magnetiſm, principally in navigation, and the obſcurity of the cauſe which produces its wonderful phenomena, has, from ages, excited the attention of very able philoſophers and mathematicians, who, with diligent aſſiduity, and profound conſideration, have examined the properties of the magnet, and have framed hypotheſes for their explanation. Several of thoſe labours, though not crowned with diſcoveries, are nevertheleſs exceedingly ingenious, and deſerve ſome attention.

To arrange thoſe obſervations in a proper order, to deſcribe the various hypotheſes, and the manner in which the phenomena of magnetiſm have been attempted to be mathematically deducible from them, was the author's original intention; but when the work was nearly accompliſhed, its great bulk, and the intricacy of the mathematical part, incompatible with the genius of the generality of readers, and even with the patience of mathematicians; conſidering that thoſe calculations were ſeldom productive of remarkable conſequences; the original

original plan of the work was relinquiſhed, and much labour was beſtowed in diveſting it of the abſtruſe part, and contracting it into the form in which it is now made public.

The object then of the following Treatiſe is to exhibit a comprehenſive view of the preſent ſtate of knowledge relative to magnetiſm; the author having diſpoſed the various particulars in that order which ſeemed moſt likely to lead the reader from the ſimpleſt to the moſt intricate and depending part of the ſubject, by the plaineſt and ſhorteſt ways.

The firſt Part treats of the laws of magnetiſm, *viz.* of thoſe properties, and their limits, which have been aſcertained by a great number

ber of experiments and obſervations, and which are independent on any hypotheſis.

In order to diſtinguiſh the knowledge of certain facts from the ſuppoſition of their cauſes, and the improbability of moſt of thoſe ſuppoſitions, the ſecond, and by far the ſhorteſt, Part of the book, has been allotted to the hypotheſes of magnetiſm.

The third Part treats of the practice of the ſubject, *viz.* it contains a ſeries of ſuch experiments as are neceſſary, and ſufficient to demonſtrate the certainty of the laws mentioned in the firſt Part, and to employ them for the various purpoſes to which they are ſubſervient.

The fourth, and laſt Part, contains

tains the various experiments made by the author himſelf, relating to magnetiſm.

There will be alſo found interſperſed throughout the work, various remarks and hints, uſeful to thoſe who may be willing to promote the farther inveſtigation of the ſubject; but, on the other hand, the author has thought proper to omit ſeveral trifling particulars, which might be eaſily ſuggeſted by the ingenuity of the reader, and divers experiments, which ſeemed to be only variations of thoſe inſerted in the book.

Laſtly. To render the work more perſpicuous and uſeful, two copper-plates and a copious index have been added to it.

THE

CONTENTS.

PART I.

LAWS OF MAGNETISM.

PART II.

PART III.

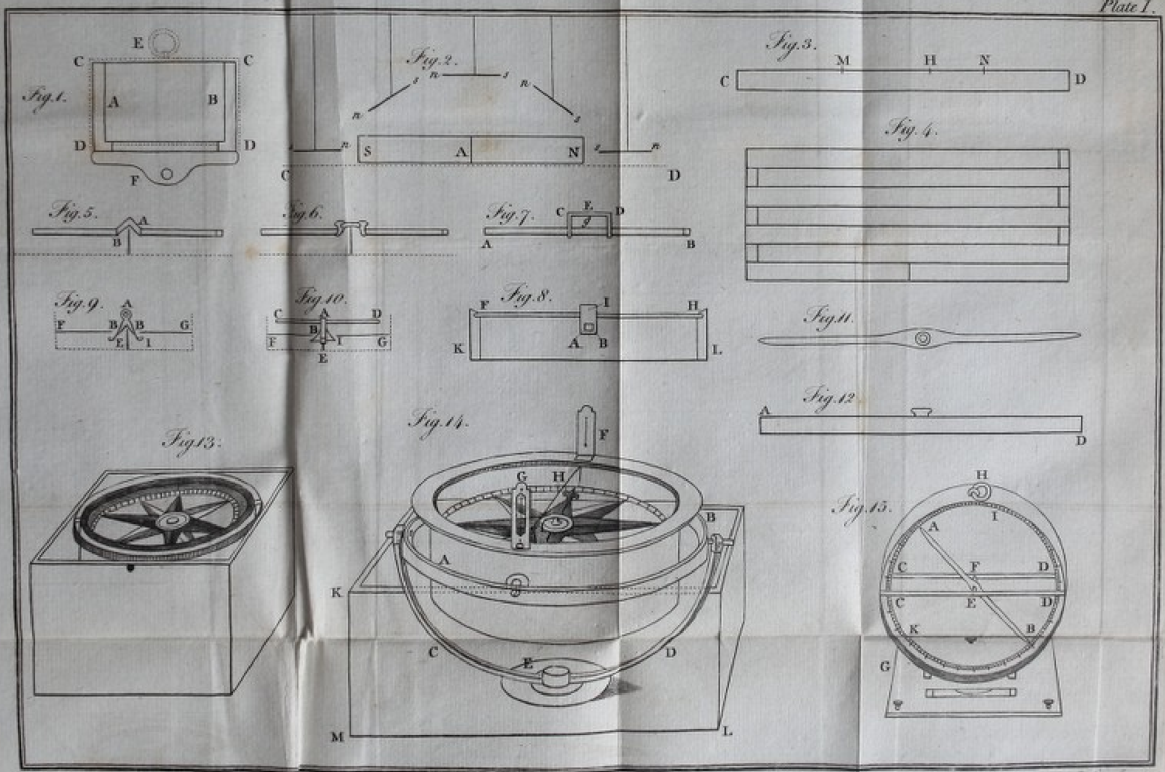
PART IV.

APPENDIX.

ERRATA.

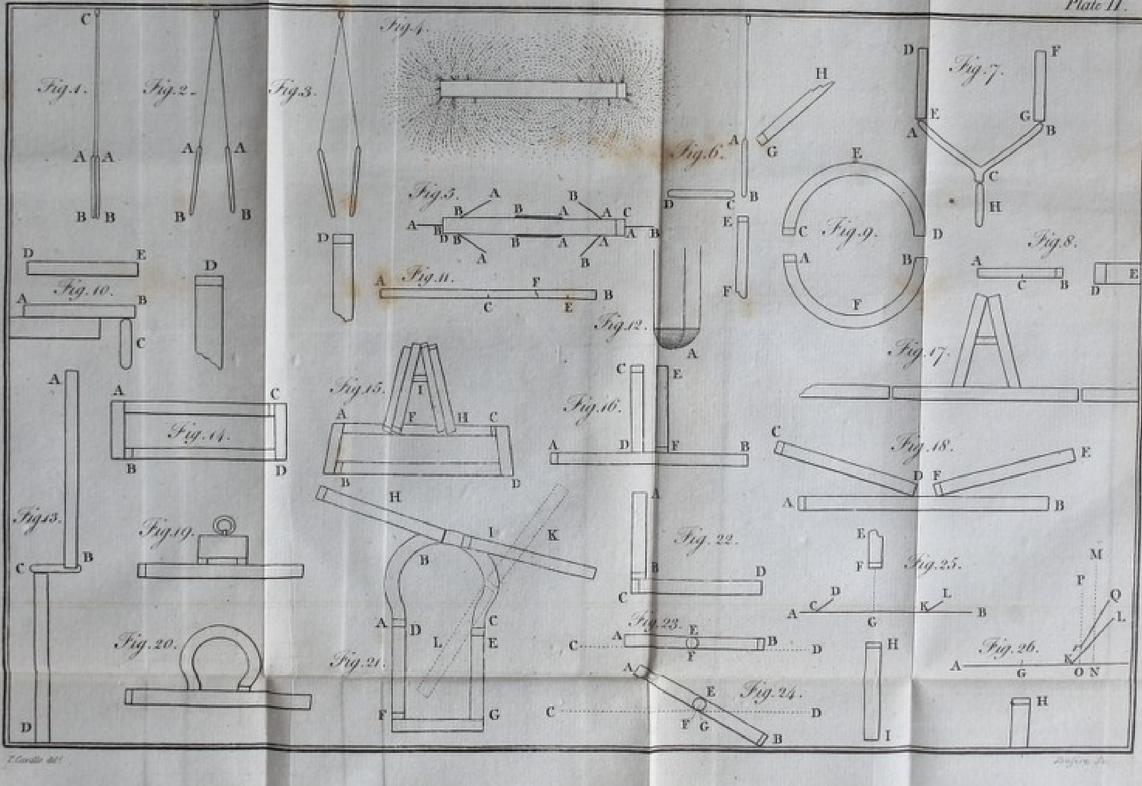
Page 4, line 7, *for* north *read* south.
Page 68, line 17, *for* attracted *read* are attracted.
Page 166, line 24, *for* E F *read* I K.
Page 175, line 9, *for* round the *read* round to the.
Page 239, last line, *for* 20 *read* 21.
Page 258, line 6, *for* vane *read* vanes.
Page 282, line 20, *for* invalidates *read* strengthens.

Plate I.



T. Cavallo del. Basire sc.

Plate II.



T. Cavallo del.

Basire Sc.

PART I.

LAWS OF MAGNETISM.

CHAPTER I.

Containing a general idea of Magnetiſm, and the explanation of the technical words.

A SOLID mineral body, which has the property of attracting iron, or ferruginous ſubſtances, beſides other properties peculiar to itſelf, has been called a *natural magnet*, or *load-ſtone* *. And, as the

* The word *magnet*, by ſome ancient writers, is derived from the name of a ſhepherd, by whom they ſuppoſe the magnet to have been firſt diſcovered on mount Ida. It has been more commonly called *lapis Heracleus*, by Pythagoras, Ariſtotle, Euripides, and others,

the ſame properties may be communicated to iron, ſteel, and other ferruginous ſubſtances; thoſe bodies, after having acquired the magnetical properties, are called *artificial magnets*.

A magnet, whether natural or artificial, is always poſſeſſed of the following characteriſtic properties, which are inſeparable from its nature; ſo that a body cannot be called a magnet unleſs it be poſſeſſed of all thoſe properties at the ſame time: neither is there any inſtance of a magnet's being produced, which had only one or a few of thoſe properties, without ſhewing any of the reſt.

1. A magnet attracts iron and other ferruginous ſubſtances.

2. When a magnet is placed ſo as to be at liberty to move itſelf eaſily, as, if it be ſuſpended by a thread, &c. it turns one, and conſtantly the ſame part of its

others, from Heraclea, a city of Magneſia, a part of ancient Lydia, where it is ſuppoſed to have been firſt found. It has likewiſe been called *lapis nauticus*, from its uſe in navigation; and *ſiderites*, from its property of attracting iron, which metal is called σίδηρος in Greek.

ſurface

ſurface towards the north pole of the earth, or towards a point not much diſtant from it; and of courſe it turns the oppoſite part of its ſurface towards the ſouth pole of the earth, or towards a point not much diſtant from it. Theſe parts on the ſurface of a magnet are therefore called its *poles*, the former being denominated its *North pole*, and the latter its *South pole*. The property itſelf is called *the magnet's directive power*, or *magnetic polarity*; and when a magnetic body places itſelf in that direction, it is ſaid to *traverſe*. A plane perpendicular to the horizon, and paſſing through the poles of a magnet when ſtanding in their natural direction, is called the *magnetic meridian*: and the angle made by the magnetic meridian and the plane of the meridian of the place where the magnet ſtands, is called *the declination of the magnet*, or more commonly *the declination of the magnetic needle*; becauſe the artificial magnets, moſtly uſed for obſerving this property, are generally made ſlender, and ſomewhat in the ſhape of a needle; or becauſe real ſewing needles themſelves have been often uſed for this purpoſe.

3. When two magnets are placed ſo that the north pole of one is oppoſite to the ſouth pole of the other, then they attract each other; but if the ſouth pole of one magnet be placed oppoſite the ~~north~~ South pole of the other magnet, then they repel each other. In ſhort, magnetic poles of the ſame name repel one another, whereas thoſe of a different name attract each other.

4. When a magnet is placed ſo as to be at liberty to move itſelf very eaſily, it generally inclines one of its poles towards the horizon, and of courſe it elevates the other pole above it. This property is called the *inclination* or *dipping* of the magnet, or more commonly, *of the magnetic needle*, for the reaſon above-mentioned.

5. Laſtly; Any magnet may, by proper methods, be made to impart thoſe properties to iron, ſteel, or, in ſhort, to moſt ferruginous ſubſtances.

The experience and induſtry of mankind have gradually diſcovered, examined, aſcertained, and employed for various uſeful purposes, those magnetical properties; and it is the object of this work to describe, in a concise and perspicuous manner, the laws, which have been ascertained by those innumerable observations, and the uses to which they have been rendered subservient. Those laws and their uses are methodically laid down in the following pages, there being allotted to each chapter those particulars, which were most connected with each other: but, as the whole action of magnetism seems to be confined solely or principally to iron, and to those bodies which contain that metal in some state or other, it will be necessary to premise the natural history and chymical properties of that substance, at least such as may be deemed necessary for the comprehension of the subject, or likely to open the way to farther discoveries.

CHAPTER II.

The natural hiſtory and principal properties of Iron; and of the natural Magnet, or Loadſtone.

IRON is, of all the metals, the moſt ſubſervient to human life; and, at the ſame time, it is very remarkable, that its nature is far from being perfectly underſtood, or ſufficiently inveſtigated. It is reckoned amongſt the imperfect metals, on account of its being ſubject to ruſt or calcination; and its ſpecific gravity, though ſubject to a little variety, yet is ſeldom, if ever, leſs than 7,6, or exceeds 8 times the weight of diſtilled water.

Iron is found almoſt in any place, and is extracted from the bowels of the earth, it being therein found either by itſelf in a metallic ſtate, which is called *native iron*, or mixed with various other ſubſtances; which compounds, when the iron or martial part contained in them is in a conſiderable proportion, are called iron ores.

The

The iron ores defcribed by the lateft mineralogifts, and their principal names, are the following:

1. *The fteel ore*, which confifts of a brown calx of iron mixed with iron in its metallic ftate.

2. *The magnet*.

3. A mixture of the brown calx of iron and plumbago.

4. *The white* or *fparry iron ore*; being the brown calx of iron united to the white calx of manganefe.

5. *The magnetic fand*.

6. *Hæmatites*; confifting of the red calx of iron indurated, and combined with a little argill, and frequently with manganefe.

7. *Hæmatitical yellow, red, and brown ochres*; confifting of hæmatites in a loofe form, mixed with a confiderable proportion of argill.

8. A combination of the red calx of iron with plumbago.

9. *Torften*; being a mixture of the red calx mixed with a fmall proportion of the brown and indurated calx of iron.

10. *Emery.*

11. *The grey iron ore*; consisting of the red calx united to siderite.

12. The argillaceous iron ores; the two species of which are, the highland argillaceous ore, *minera ferri ochreacea*; and the swampy argillaceous ore, *minera ferri lacustris vel subaquosa.*

13. *The red calcareous iron ore.*

14. *The siliceous iron ore.*

15. *The muriatic iron ore.*

16. *The martial calamine.*

17. *Martial pyrites,* which consist of iron mineralized by sulphur.

18. *The white, grey, or blueish-grey pyrites. Marcassite*; being iron mineralized by sulphur and arsenic.

19. *Mispickel*; consisting of iron mineralized by arsenic alone.

20. *Combustible iron ore.*

21. *Green vitriol,* being iron mineralized by vitriolic acid.

22. Iron mineralized by the phosphoric acid; the two species of which are, *the siderite,* and *the native Prussian blue*; the lat-

ter

ter of which consists of iron, phosphoric acid, and argillaceous earth *.

In extracting the metal from the various iron ores, two objects must be considered, *viz.* the state of the iron, which is in a more or less metallic state, and the extraneous substances which are mixed with it. On those accounts, it is almost impossible to prescribe the most advantageous method of extracting the iron from a certain ore, without making particular experiments upon it. However, the principal agents in this operation are, a strong heat, and the admixture of substances capable of furnishing the inflammable principle.

The iron, after being extracted from the ore, and being reduced into the metallic form, is not always of the same nature; and its various species, the principal of which we shall now enumerate, are possessed of peculiar and very remarkable properties.

Cast iron, viz. iron after having been fused by the action of a strong heat, is very

* See Bergman's mineralogy, Kirwan's mineralogy, and my mineralogical tables.

hard

hard and brittle, ſo that it cannot be formed into any required ſhape by hammering, nor even by filing.

The malleable iron is formed from the caſt iron, by expoſing it to a ſtrong blaſt of air for ſome hours, whilſt it ſtands in a red or rather white heat. It is remarkable, that in this proceſs a quantity of liquid matter comes out of the iron, which when cold is in the form of black cinders, called *finery cinders*, from the name of the furnace employed for the proceſs *.

The malleable iron is of two ſorts, *viz.* that called *red ſhort iron*, which has the property of being malleable when cold, but brittle when hot; and that called *cold ſhort iron*, which is malleable when red hot, but brittle when cold.

Steel is formed from iron, by expoſing the iron to a ſtrong heat for ſeveral hours, whilſt it is ſurrounded by ſubſtances that contain a great deal of the inflammable principle, as charcoal, oleaginous ſubſtances, &c.: hence it is generally believed,

* See Prieſtley's experiments relating to various branches of nat. phil. vol. iii. ſect. xxiv.

that

that the iron becomes ſteel only in conſequence of its acquiring a greater quantity of the inflammable principle, called *phlogiston* by the chymiſts; but there is ſome ſort of malleable iron which will never become ſteel; and I am informed by a very ingenious chymiſt, that this effect is owing to the want of the ſemi-metal called manganeſe; this gentleman having found, that the iron, which is wont to be capable of becoming ſteel, contains ſome portion of manganeſe; whereas, that ſort of iron which is incapable of becoming ſteel is quite free from any admixture of that ſemi-metal.

By the tranſition from iron into ſteel, the weight of the metal is not at all, or very little, increaſed; but it acquires ſeveral remarkable properties. Steel is generally harder than malleable iron; it may be hammered when cold, but incomparably better when red hot; it may be fuſed; and it is capable of acquiring various degrees of hardneſs. Hammering will harden it to a certain degree; but if it be made red hot, and in that ſtate be plunged into cold

water,

water, or other cold liquor, ſo as to cool it ſuddenly, it becomes exceedingly hard and brittle, ſo that it can neither be hammered nor filed; and, the greater the difference between its degree of heat and that of the liquor, in which it is plunged, the greater is the degree of hardneſs it acquires. The ſteel, after having been thus hardened, may be ſoftened to any required degree, by expoſing it to a proper heat, which operation is called *tempering*. The ſoftening by this means is accompanied by a gradual change of colour; which colour, however, is merely ſuperficial, but remains as long as the ſteel is not rubbed with ſomething capable of ſcraping off part of the metal. Thus, if the hardened piece of ſteel be laid upon a red-hot iron, or be heated in any other manner, it will firſt acquire a reddiſh, then a yellowiſh or ſtraw colour, which will gradually deepen, and change into blueiſh, deep blue, and laſtly, the ſteel becomes red hot. Now, if the piece of ſteel be removed from the heat juſt when it has acquired the ſtraw-colour, it is then ſoftened a little, and juſt

ſufficiently

ſufficiently to ſerve for points of drills, and ſome other tools; hence this degree of ſoftening is called *drill temper*. If the piece of ſteel be removed from the heat as ſoon as it becomes blue, it will be found to be ſoftened ſufficiently to ſerve for ſprings; hence that degree of ſoftening is called *ſpring temper*. If the ſteel be ſuffered to become red hot before it be removed, it will be found to have loſt all the hardneſs which it had acquired in the firſt proceſs.

By repeated hardening and ſoftening, a piece of ſteel becomes leſs and leſs fit for nice work: but even in ſteel newly formed, there occurs a conſiderable variety; and that ſort is reckoned the beſt, which in its fractures exhibits a ſmall, uniform, and ſilvery granulated appearance.

All the above-mentioned ſpecies or ſtates of iron are capable of calcination, *viz.* of being reduced to ruſt, and of courſe, to various intermediate ſtates between that of good metal, and that of red calx. This change, according to the

more

more general opinion, is occaſioned by the eſcape of the inflammable principle; and in fact, if the calx of iron be expoſed to a ſtrong heat whilſt it is ſurrounded by charcoal-duſt, or other ſubſtance abounding with phlogiſton, the calx will become iron again.

In the following pages, for the ſake of brevity, we ſhall comprehend all the above-mentioned ſtates or ſpecies of iron under the general appellation of *ferruginous ſubſtances*; adding the word *metallic* to thoſe which are in a metallic ſtate, and the word *calcined* to thoſe which are in a calcined ſtate.

A remarkable phænomenon happens in the calcination of this as well as of other metals, which is, that the metal acquires weight by being calcined, and the calx loſes weight by being reduced again into metal. Thus it has been obſerved, that 100 grains of the brown calx of iron will produce about 85 grains of iron; and 100 grains of the red calx will produce about 75 grains of iron: and, on the contrary, the above-mentioned quantities of iron will

produce

produce 100 grains of the brown or red calx reſpectively.

This increaſe of weight has been aſcertained to be owing to a certain permanently elaſtic fluid or ſort of air, which combines with the calx in a greater or ſmaller proportion, according as the calcination is more or leſs perfect; and the diminution of weight obſerved in the reduction of the calx into metal, to be owing to the eſcape of that ſame elaſtic fluid from the calx. Upon theſe grounds, ſome ingenious perſons have imagined, that the calcination of a metal, or the reduction of the calx into metal again, had nothing to do with the inflammable principle or phlogiſton of the chymiſts; but that it was all to be explained by the loſs or acquiſition of the ſaid permanently-elaſtic fluid.—Various arguments and experiments ſeem to favour each opinion; but the nature and limits of the preſent work not permitting me to expatiate on this ſubject, I muſt refer thoſe readers, who are deſirous of examining it farther, to other books, where they may be informed not only of the above-mentioned ſubject,

ſubject, but likewiſe of the particulars concerning the elaſtic fluids which may be obtained from the ſolution of iron, and of other properties relating to this moſt uſeful metal *.

The metallic ferruginous ſubſtances are ſoluble in all acids, though not with equal facility; and if any vegetable aſtringent be added, the ſolution will become black; but if phlogiſticated alkali be added, inſtead of the vegetable aſtringent, then the ſolution will become blue.

The natural magnet, mentioned at the beginning of this chapter, is an ore of iron; and it contains a greater quantity of iron, either in the metallic ſtate or not much dephlogiſticated, than moſt other iron ores. However, though every magnet ſeems to contain ſome iron in a metallic ſtate, yet it does not follow that every ore, which contains the iron in that ſtate, is magnetic; there having been found many iron ores,

* Hiſt. de l'Acad, ſince the year 1778.—Prieſtley's Experiments and Obſervations relating to the different ſorts of Air, &c.—Rozier's Journal de Phiſ. for September 1786—and my Treatiſe on Air and Permanently Elaſtic Fluids.

which had all the appearance of good magnets, but were not poſſeſſed of the magnetic properties *.

Beſides the iron particles, the natural magnets often contain a portion of quartz and argill, and probably ſome ſulphur, becauſe when made red hot they generally have a ſulphureous ſmell; beſides which, many other ſubſtances may be found in them, though not ſo frequently as thoſe mentioned above.

Magnets differ in ſpecific gravity according to the proportion and nature of the other ingredients that are mixed with the iron or martial part, but generally they are about ſeven times heavier than diſtilled water.

Their colour is moſtly a dull browniſh black; though, as may be imagined,

* Some old writers on magnetiſm make mention of certain load-ſtones ſo light as even to ſwim upon water. But as iron is ſo univerſally ſpread throughout the works of nature, it is not improbable that ſome light, ſpungy, vulcanic productions may contain a quantity of iron particles with ſome veſtiges of magnetiſm, ſufficient to give the name of magnet to the whole maſs.

a conſiderable difference is often occaſioned by the admixture of heterogeneous ſubſtances, and by the ſtate of the iron contained in them. The magnets which are found in Arabia are reddiſh, thoſe of Macedonia are blackiſh, and thoſe found in Hungary, Germany, Britain, and Italy, have moſtly the colour of unwrought iron.

The hardneſs of magnets is ſuch as juſt to afford ſparks when ſtruck with ſteel; but it is extremely difficult to turn them in a lathe or to ſhape them by a file.

It has been obſerved, that generally thoſe magnets, which have a fine cloſe grain, are more powerfully magnetic, and retain the virtue much longer, than thoſe which are of a coarſer grain; and even longer than the artificial magnets which are made of ſteel.

They are found in many parts of the world, and almoſt wherever there is a good iron mine. In Europe they are met with pretty frequently, in the mines of Germany, in the Apennines, in France, in the iſlands of the Mediterranean Sea, in Britain, in Ire-

land,

land, and in various other places. Aſia does likewiſe abound with magnets; neither are the other parts of the world without them, though not very copiouſly; or perhaps for want of ſufficient examination ſo great a quantity of magnets has not been found in them as in Europe and Aſia.—They are not found of any particular ſhape or ſize.

CHAPTER III.

Of Magnetic attraction and repulſion.

THE various ſorts of attraction hitherto diſcovered may be reduced to five: *viz.* 1ſt. The attraction of gravitation, or that power, by which bodies fall towards the centre of the earth, and by which the immenſe bodies of our planetary ſyſtem are retained within their proper orbits. 2. The attraction of cohesion, which takes place when the parts of bodies are put in cloſe contact, as when two ſmooth, and like ſurfaces of metal, glaſs, marble, or other ſubſtance, are preſſed one upon the other. 3. The chymical attraction, or affinity, which occaſions an intimate mixture, and alteration of two or more ſubſtances of different natures. It requires the immediate contact of the parts of the bodies, in order to take place. Such is the attraction between acids and alkalies, between acids and metals, &c. 4. The attraction of electricity, poſſeſſed by all ſorts of bodies when electrified; which acts on ſubſtances of every kind, and extends its ſphere of action to a conſiderable diſtance. 5. Laſtly; The attraction of magnetiſm, which acts only upon iron, or upon thoſe bodies which contain that metal in ſome ſtate or other; hence, beſides other obvious peculiarities, this ſort of attraction may be eaſily diſtinguiſhed from the reſt.

A piece of iron, or ſteel, or other ferruginous ſubſtance, being brought within a certain diſtance of one of the poles of a magnet, is attracted by it, ſo as to adhere to the magnet, and not ſuffer to be ſeparated without an evident effort. This at-

traction

traction is mutual; ſo that the iron attracts the magnet as much as the magnet attracts the iron; for if they be placed on pieces of wood, ſo as to float upon the ſurface of water, it will be found that the iron advances towards the magnet, as well as the magnet advances towards the iron; or if the iron be kept ſteady, the magnet will move towards it.

The ſtrength or degree of magnetic attraction varies according to different circumſtances; namely, the ſtrength of the magnet, the weight and ſhape of the body preſented to it, the magnetic or unmagnetic ſtate of that body, the diſtance between it and the magnet, &c.: which particulars we ſhall now examine in their order.

A magnet attracts a piece of ſoft and clean iron more forcibly than any other ferruginous body of the like ſhape and weight. The iron ores, amongſt which the natural magnet is comprehended, are attracted more or leſs forcibly, in proportion as they contain a greater or leſs quantity of metallic particles, as that quantity is in a more or leſs perfect metallic ſtate, and as it is of a ſofter or harder nature; but they are all, as well as hard iron and ſteel, attracted leſs forcibly than ſoft iron.

If a piece of iron be preſented ſucceſſively to the various parts of the ſurface of a magnet, it will be found that the attraction is ſtrongeſt at the poles of the magnet (*viz.* thoſe parts of the ſurface which, when the magnet is freely ſuſpended, are directed towards the north and the ſouth); that the attraction diminiſhes in proportion as the part of the ſurface to which the iron is preſented recedes from the poles; and is very little or not at all perceivable about thoſe parts of the ſurface, which are equidiſtant from the poles.

The attraction is ſtrongeſt near the ſurface of the magnet, and diminiſhes as it recedes from it: *viz.* if a piece of iron be placed in contact with one of the poles of a magnet ſufficiently ſtrong, they will adhere to each other, and there is required a certain force to ſeparate them; but if the ſame piece of iron be kept at an inch diſtance from the ſame pole of the magnet, there will alſo be perceived an endeavour to attract it; but the force required to prevent the iron running to the magnet will be found to be much ſmaller, than that which was required to ſeparate them in the firſt caſe; and if the iron be held at a diſtance greater than one inch, the attraction will be found to be ſtill weaker; and ſo on.

Though the attraction between the magnet and the iron, or other ferruginous body, is ſtronger within a ſhort diſtance than farther off, yet the law of that diminution has not yet been aſcertained, notwithſtanding the repeated endeavours of the greateſt geniuſes philoſophical and mathematical. For inſtance, it is not known whether, at a given diſtance, the attraction of a magnet in general is twice, three times, or any other number of times greater than at double that diſtance. The analogy of other energies, which being propagated from a centre, and expanding into a ſphere, have their denſities diminiſhed in the proportion of the ſquares of the diſtances would eaſily perſuade one to expect the ſame law in magnetics; but experience does not ſhew it. Various accurate experiments, made by different philoſophers, have been attended with different reſults. In ſome, the attraction ſeemed to decreaſe in the inverſe ratio of the diſtances, with ſufficient regularity; but in others it decreaſed much faſter, or in different proportions at different diſtances: ſo that the only general concluſion, which may be inferred from them, is, that the decreaſe of magnetic attraction is not ſlower than the inverſe ratio of the diſtances; *viz.* at double the diſtance the attraction is half as ſtrong, or rather leſs; at treble the diſtance the attraction is one third as ſtrong, or rather leſs; and ſo on *.

In order to give the reader an idea of the above-mentioned irregularity reſpecting

* From ſome other experiments made with magnetic needles, which will be conſidered in the ſequel, it appears that the attraction decreaſes in the ratio of the cubes of the diſtances.

magnetic attraction, and alſo of the diſtance to which it may extend itſelf, I ſhall ſubjoin four experiments, accurately made by the learned Muſſchenbroek *.

EXP. I. A cylindrical magnet, two inches long, and weighing 16 drams, was ſuſpended to one ſcale of an accurate balance, and under it there was placed, upon a table, a cylinder of iron, which was exactly of the ſame bulk and ſhape. Things being thus prepared, the cylinder of iron was ſucceſſively placed at different diſtances from the magnet, and at each diſtance the degree of attraction between the iron and the magnet was aſcertained by weights put in the oppoſite ſcale of the balance. The reſults were as follow, *viz.*

Diſtance in inches.				Attractions in grains.
6	—	—	—	3
5	—	—	—	$3\frac{1}{2}$
4	—	—	—	$4\frac{1}{2}$
3	—	—	—	6
2	—	—	—	9
1	—	—	—	18
0	—	—	—	57

* Introduction to Natural Philoſophy, chap. xix.

EXP.

EXP. II. A ſpherical magnet, of the ſame diameter as the cylindrical one uſed before, but of greater ſtrength, was affixed to one of the ſcales of the balance; and the cylindrical magnet, uſed in the preceding experiment, was placed upon the table, with its ſouth pole upwards, and facing the north pole of the ſpherical magnet. In this diſpoſition of the apparatus the attractions were found to be as follows:

Diſtance in inches.				Attractions in grains.
6	—	—	—	21
5	—	—	—	27
4	—	—	—	34
3	—	—	—	44
2	—	—	—	64
1	—	—	—	100
0	—	—	—	260

EXP. III. Inſtead of the cylindrical magnet, the cylinder of iron was placed upon the table, and under the globular magnet. The reſult was as follows:

Diſtance in inches.				Attractions in grains.
6	—	—	—	7
5	—	—	—	$9\frac{1}{2}$
4	—	—	—	15
3	—	—	—	25
2	—	—	—	45
1	—	—	—	92
0	—	—	—	340 *

EXP. IV. Inſtead of the iron cylinder, a globe of iron of the ſame diameter as the ſpherical magnet was placed upon the table, and the attractions were found to be as follows:

Diſtance in inches.				Attractions in grains.
8	—	—	—	1
7	—	—	—	2
6	—	—	—	$3\frac{1}{4}$
5	—	—	—	6
4	—	—	—	9
3	—	—	—	16
2	—	—	—	30
1	—	—	—	64
0	—	—	—	290

* The ſame magnet was found to attract a ſhorter cylinder of iron with leſs force, but in the ſame ratio.

From the ſecond and third experiments it appears, that, when in contact, a magnet attracts another magnet with leſs force than a piece of iron. This has been confirmed by many other experiments. But the attraction between two magnets begins from a greater diſtance than between the magnet and iron; hence it muſt follow a different law of decrement.

The attraction between a given magnet and a piece of iron is ſubject to a variation ariſing from the weight and ſhape of the iron; there being a limit, in the weight and ſhape of the iron, in which the magnet will attract it more forcibly than either a greater or a ſmaller one: but this moſt advantageous weight and extenſion of the piece of iron can only be determined by actual experiment, it being various according to the various nature, ſtrength, and ſhape of the magnet, as well as of the iron.

Magnetic attraction takes place between the magnet and ſuch ferruginous bodies as were not magnetic before, or between the contrary poles of two magnets: but when

two

two magnets are placed with their poles of the ſame name toward each other, then, inſtead of attracting, they repel each other. However, it often happens, that though the north pole of one magnet be placed near the north pole of another magnet, or the ſouth pole of the one be placed near the ſouth pole of the other, yet they attract each other: and ſometimes they ſhew no attraction nor repulſion.

In order to reconcile this apparent contradiction, it is neceſſary to mention firſt another phenomenon, which takes place whenever a piece of ferruginous ſubſtance is brought near a magnet; and which indeed is the foundation of, and ſerves to explain, a great many other appearances, otherwiſe unintelligible, in the ſcience of magnetiſm.

The phenomenon, in ſhort, is this: *viz.* When a piece of iron, or any other ſubſtance that contains iron, is brought within a certain diſtance of a magnet, it becomes itſelf a magnet, having the poles, the attractive power, and in ſhort every property of a real magnet. That part of it

which

which is nearest to the magnet, acquires a contrary polarity: thus, if an oblong piece of iron, A B, be brought within a proper distance of a magnet, so that the extremity A of the iron may be opposite the north pole of the magnet, then this same extremity A will become a south pole, and the other extremity B will become a north pole.—This law will be rendered very evident by the experiments in the Third Part of this treatise.

The magnetism acquired by being placed within the influence or the sphere of activity of a magnet, in soft iron lasts only whilst the iron continues in that situation, and when removed from the vicinity of the magnet, its magnetism vanishes immediately; but with hard iron, and especially with steel, the case is quite different; for the harder the iron or the steel is, the more permanent is the magnetism which it acquires from the influence of a magnet; but it will be in the same proportion difficult to render it magnetic. If, for instance, a soft piece of iron and a piece of hard steel, both of the same shape and size, be be brought within the influence of a magnet at the ſame diſtance, it will be found that the iron will appear much more magnetic than the ſteel; but if the magnet be removed, the ſoft iron will inſtantly loſe its magnetiſm, whereas the hard ſteel will preſerve it for a long time.

From theſe obſervations two conſequences are evidently deduced, *viz.* firſt, that there is no magnetic attraction but between the contrary poles of two magnets; for the iron, or other ferruginous body, that is preſented to a magnet, muſt become itſelf a magnet before it be attracted: and ſecondly, it appears why a magnet muſt attract a piece of ſoft iron more forcibly than hard iron, and much more than hard ſteel, *viz.* becauſe the hard iron, and more eſpecially the hard ſteel, does not become ſo ſtrongly magnetical as ſoft iron, when preſented to a magnet.

We may now reſume the ſubject of magnetic repulſion, and ſhew why the magnetic poles of the ſame name may repel, attract, or not act at all upon one another.

Indeed,

Indeed, the law of repulſion being always exerted between magnetic poles of the ſame name, nearly as ſtrong as the attraction between thoſe of different name, remains certain and immutable; but it often happens, that one of the magnets, being more powerful than the other, will change the pole of that other magnet, in the ſame manner as it gives magnetiſm to any other piece of iron which is expoſed to its influence, and then an attraction will take place apparently between magnetic poles of the ſame names; though in fact it is an attraction between poles of different name, becauſe one of them has been actually changed. Thus, ſuppoſe that a powerful magnet be placed with its north pole very near the north pole of a weak magnet; it will be found that inſtead of repelling they will attract each other, becauſe that part of the weak magnet, which before was a north pole, has been changed into a ſouth pole by the action of the ſtrong magnet.

As thoſe bodies which are poſſeſſed of any magnetiſm cannot be very readily affected by the influence of another magnet,

for

for the very ſame cauſe which renders them capable of retaining any magnetiſm at all, namely their hardneſs; and, as the power of a magnet diminiſhes in proportion to the diſtances from its ſurface, it follows, that when the north or ſouth pole of a weak magnet is from a conſiderable diſtance gradually brought near the like pole of a powerful magnet, the pole of the weak magnet cannot be changed very eaſily; hence, beyond a certain diſtance, *viz.* before the ſaid pole be changed, the two magnets muſt exert a repulſion againſt each other; but when the ſmall magnet has been brought ſo near the powerful one as that its pole may begin to be changed, then neither an attraction nor a repulſion will take place; and when the two magnets are approached nearer than that limit, then, the pole of the weak one being changed, an attraction will enſue.

After theſe obſervations, the ingenious reader may eaſily imagine that the decreaſe of repulſion between homogeneous magnetic poles muſt be at leaſt as much if not more irregular than the decreaſe of the attraction at different distances. It is likewise evident, that many objects must be had in view in attempting to investigate the law of that decrease.

Neither the attraction nor the repulsion of magnetism is sensibly affected by the interposition of bodies of any sort, except iron or ferruginous bodies in general. Thus, suppose that when a magnet is placed at an inch distance from a piece of iron, there is required an ounce of force to remove it; or, which is the same thing, suppose that the attraction towards each other is equal to one ounce; it will be found that the said degree of attraction remains constantly unaltered, *viz.* always equal to one ounce, though a plate of other metal, or of glass, or paper, or other body, be interposed between the magnet and the iron, or though they be inclosed in separate boxes of glass or other matter. Neither the absence or presence of air has any effect upon them. In short, no other substance besides iron, or those bodies which contain that metal in any of its metallic states, does sensibly affect the attraction or repulsion of magnetism.

Heat weakens the power of a magnet; and a white heat deſtroys it entirely, or at leaſt in a great meaſure. Hence it appears, that from this cauſe alone, beſides others which may concur, the power of a magnet muſt be continually varying.

The attractive power of a magnet may be increaſed conſiderably by gradually adding more and more weight to it; for by this means it will be found that the magnet will keep ſuſpended on one day a little more weight than it did the preceding day; which additional weight being added to it on the following day, or ſome time after, it, will be found that the magnet can keep ſuſpended a weight ſtill greater, and ſo on as far as a certain limit.

On the contrary, by an improper ſituation, or putting a very ſmall weight of iron to it, the magnet may gradually loſe much of its ſtrength.

It has been ſaid by various authors, that in theſe northern parts of the world the north pole of a magnet generally has an attractive power ſomewhat ſtronger than the ſouth pole, but in the ſouthern parts of the earth the ſouth pole of the magnet is ſaid to poſſeſs the greateſt attractive power. This law, however, has not been yet properly aſcertained.

The holding of a piece of iron of ſome magnitude to one pole of a magnet, increaſes the attraction of the other pole, ſo as to enable it to lift a greater weight.

It has been obſerved, that amongſt the natural magnets, the ſmalleſt generally poſſeſs a greater attractive power, in proportion to their ſize, than thoſe which are larger. There have been often ſeen natural magnets, not exceeding the weight of 20 or 30 grains, which could lift a piece of iron that weighed 40 or 50 times more than themſelves. Mention is made of a ſmall magnet wore in a ring, which weighed about three grains, and was capable of taking up 746 grains, or nearly 250 times its own weight; and I have ſeen one which could not weigh more than ſix or ſeven grains, and was capable of lifting a weight of about 300 grains. But magnets of above two pounds weight, ſeldom lift up 10 times their own weight of iron.

It often happens, that a natural magnet, cut off from a larger load-ſtone, will itſelf be capable of lifting a greater weight of iron than the original large load-ſtone from which it was cut off. This muſt be imputed to the heterogeneous nature of the large load-ſtone; for, ſuppoſe that one part of it contains a good quantity of pure metal ſtrongly magnetical, the reſt of it being impure, or mixed with other ſubſtances, it is plain that the impure part can only obſtruct the action of the purer part; hence this latter, being ſeparated from the reſt, muſt act more powerfully than the whole together did.

As both magnetic poles together attract a much greater weight than a ſingle one, and as the two poles of a magnet are generally in oppoſite parts of its ſurface, in which ſituation it is almoſt impoſſible to adapt the ſame piece of iron to them both at the ſame time; therefore it has been commonly practiſed to adapt two broad pieces of ſoft iron to the poles of a load-ſtone, and to let them project on one ſide of the magnet, becauſe in that caſe, the pieces of iron being rendered themſelves magnetic, another piece of iron could be conveniently adapted to their projections, ſo as to let both poles act at the ſame time. Thoſe pieces of iron are generally held faſt upon the magnet by means of a braſs or ſilver box. The magnet in this caſe is ſaid to be *armed*, and the pieces of iron are called the *armature*.

In fig. 1ſt of plate I. A B repreſents the magnet; C D, C D repreſent the armature or pieces of iron, the projections of which are D D, and to which the piece of iron F is made to adhere. The dots E C D C D repreſent the braſs box, having a ring E at its upper part, by which the armed magnet may be ſuſpended. Thus the two poles of the magnet, which are at A and B, are made to act at D D, where the ſtraight piece of iron F may be conveniently applied.

For this purpoſe, and to avoid the armature, artificial magnets have been made in the ſhape of a horſe-ſhoe, having their poles in the truncated extremities; for which reaſon they have more power than the ſtraight magnetic bars.

CHAP. IV.

Of the Magnet's directive property, or polarity.

IT is an invariable law in magnetics, that no magnet is without a ſouth and a north pole; but it often happens, that the ſame magnet has more than two poles, *viz.* ſome of one name, and ſome of the other. The figure, and alſo the heterogeneous nature of the magnets, is the principal cauſe of their often having more than two poles. It is impoſſible to determine the number and ſituation of the poles in a magnet without actual trial; and the method of aſcertaining them is, to preſent the various parts of the ſurface of the magnet in queſtion to one of the poles of another magnet that is freely ſuſpended; for thoſe parts of the magnet, which repel the other ſuſpended one, have the ſame polarity, and thoſe, which attract it, have a different polarity. For inſtance, if the magnet be preſented to the north pole of the other ſuſpended magnet, then thoſe parts of the former which repel the latter are poſſeſſed of a north polarity; and thoſe, which attract it, are poſſeſſed of a ſouth polarity.

Two laws may be remarked, with reſpect to magnets that have more than two poles. The firſt is, that the parts adjacent to one pole are poſſeſſed of a contrary polarity; and the ſecond is, that the number of poles of one denomination in a magnet is either equal to, or differs from the number of poles of the other denomination by one. Thus, if the magnet has four ſouth poles, then it will have either four, or three, or five, north poles.

Good magnets, of an uniform texture and properly ſhaped, have only two poles: and they lie in oppoſite parts of their ſurfaces; ſo that a line drawn from the one to the other paſſes through the centre of the magnet*.

In

* Here it muſt not be underſtood, that the polarity of a magnet reſides only in two points of it; for, in truth, it is the half, or a great part of the magnet, that

is

In ſuch magnets, the line between the two poles is called the *axis*; and a line formed all round the ſurface of the magnet by a plane, which divides the axis into two equal parts, and is perpendicular to it, is called *the equator of the magnet*. It appears, therefore, that philoſophers have appropriated to the magnet the poles, the equator, and the meridian, in imitation of the terraqueous globe; but, to complete the ſimilarity, magnets have been often made of a ſpherical ſhape, with the poles and equator marked on their ſurfaces. When ſo ſhaped they have been called *terrellas*, that is *ſmall earths*.

If a magnet be broken into two or more parts, each part is a perfect magnet of itſelf, having two, and ſometimes more poles; though not every one of the parts has always the ſame number of poles.

is poſſeſſed of one polarity, *viz.* has the property of repelling the contrary pole of another magnet, and the reſt of the magnet is poſſeſſed of the other polarity: the poles then are thoſe points in which that power is the ſtrongeſt.

The

The poles of the fragments generally, but not always, anſwer to the poles which were neareſt to them in the original magnet.

When a magnet can move itſelf freely, as, if it be ſuſpended by a fine thread, or if it be made to float on water by means of a piece of wood, or if it be poiſed on a point, and provided it be not diſturbed by the vicinity of iron, &c. it will place itſelf ſo as to direct its north pole towards the north, and the ſouth pole towards the ſouth. Beſides, it depreſſes one of its poles below the horizon, at the ſame time that the other pole is elevated above it.—Of this latter property or inclination, we ſhall treat in the next chapter, and ſhall examine the former only in the preſent.

When a magnet, that is freely ſuſpended, has only two poles, it will place itſelf very readily in the magnetic meridian, or in that plane in which other good magnets are wont to place themſelves: but when it has more than two poles, it may happen, that thoſe poles are ſo ſituated as

that

that the magnet will not traverſe, that is, it will have no directive power, and yet it will attract, repel, &c. Suppoſe, for inſtance, that an oblong magnet poſſeſſes a north polarity equally ſtrong at each extremity, and a ſouth polarity in the middle; it is plain, that as each of the extremities has an equal tendency towards the north, neither of them can be directed towards the north in preference to the other; conſequently the magnet cannot traverſe *. Indeed, when both extremities have the ſame polarity, it happens very ſeldom that they are preciſely of the ſame ſtrength; and therefore, excepting this caſe, the magnet will always traverſe; however, as the caſe has happened ſometimes naturally, and it may, though with difficulty, be effected by art, it is proper that the young experimenter be apprized of it, in order to prevent ſurpriſe and miſtakes.

* It is hardly neceſſary to obſerve, that if this ſame magnet be broken in two pieces, the parts will traverſe very readily.

The

The directive property of the magnet is the moſt wonderful, and altogether the moſt uſeful part of the ſubject. By it the mariners are enabled to conduct their veſſels through vaſt oceans, out of the ſight of land, in any given direction; by it the miners are guided in their works below the ſurface of the earth; and travellers are conducted through deſerts, otherwiſe impaſſable. The uſual method is, to keep an oblong piece of magnetic ſteel (*i. e.* an artificial magnet) ſuſpended ſo as to move very freely; which will place itſelf always in the plane of the meridian, or not much diſtant from it, *viz.* with one and the ſame end towards the north, and with the oppoſite end towards the ſouth; then, by looking upon the direction of this magnet, or magnetic needle, they direct their courſe ſo as to make any required angle with it, *viz.* to go in any required direction with reſpect to the parts of the world. Thus, ſuppoſe that a veſſel ſetting off from a certain place, muſt go to another place which is exactly weſtward of the former; in that caſe,

case, the veſſel muſt be directed ſo that its courſe may be always at right angles with the ſituation of the magnetic needle, and ſo as to let the north end of the needle be on the right hand ſide, and the ſouth end on the left hand ſide of the veſſel; for, as the magnetic needle lies north and ſouth, the direction of eaſt and weſt, which is the courſe of the veſſel, is exactly perpendicular to it.— A little reflection will eaſily ſhew how the veſſel may be ſteered in any other direction.

An artificial ſteel magnet fitted for this purpoſe, in a proper box, is called the *mariner's compaſs*, or *ſea compaſs*, or ſimply the *compaſs* *.

Though

* The magnet's attractive power has been known to the remoteſt antiquity; it being mentioned by Homer, Pythagoras, Ariſtotle, Plato, and others. The Jews were acquainted with it. See Kircher *de magnete*, lib. i. cap. v. But the earlieſt knowledge of its directive property, or the diſcovery of the uſe ofthe magnetic needle in Europe, was not known before the 13th century.

Th

Though the north pole of the magnet, in every part of the world, is directed nearly towards the north, yet it happens very seldom that it points exactly towards it, and, of course, that the south pole of the magnet

The honour of this invention has been much contended for; but by the consent of most writers it seems, that a certain Flavio or John de Gioja, or Giova, or Gira, a Neapolitan, who lived in the 13th century, has the best title to the discovery. Dr. Gilbert, an English writer of the 16th century, in his book *de magnete*, affirms, that Paulus Venetus brought the invention of the compass to Italy in the year 1260; having learned it of the Chinese. Ludi Vertomanus asserts, that when he was in the East-Indies, about the year 1500, he saw a pilot direct his course by a magnetic needle fastened and formed like those now in use. And Mr. Barlow, in his Navigator's Supply, anno 1597, relates, that in a personal conference with two East-Indians, they affirmed, that, instead of our compass, they used a magnetic needle of about six inches in length, suspended upon a pin in a dish of white china earth filled with water, in the bottom of which there were marked two cross lines to indicate the principal winds; the rest of the divisions being left to the skill of their pilots. But these two last observations, being of a date much posterior to the use of the magnetic needle in Europe, conclude nothing with respect to its original discovery; since the use of that magnet points exactly towards the south. In other words, the magnetic meridian does seldom coincide with the meridian of the place, and generally declines a few degrees eastward or westward of it. This declination is different in different places, on

that magnetic property might have been introduced into Asia by some European.

P. Duhalde, in his General History of China, vol. i. in the annals of the Chinese monarchy, speaking of the Emperor *Hoangti*, when he gave battle to *Tchi Yeou*, says, "He perceiving that thick fogs saved the "enemy from his pursuit, and that the soldiers "rambled out of the way, and lost the course of the "wind, he made a carr, which shewed them the four "cardinal points: by this method he overtook *Tchi* "*Yeou*, made him prisoner, and put him to death. "Some say there were engraved in this carr, on a plate, "the characters of a rat and a horse, and underneath "was placed a needle to determine the four parts of "the world. This would amount to the use of the "compass, or something very near it, being of great "antiquity and well attested."

And, in another part of the same book, speaking of certain ambassadors, says, "After they had their au-"dience of leave, in order to return to their own coun-"try, *Tcheou Kong* gave them an instrument, which on "one side pointed towards the north, and on the oppo-"site on land as well as at ſea; and is alſo continually varying in the ſame places. For inſtance, the declination in London is not the ſame as at Paris, or as at the Cape of Good Hope; and the declination in London, or at ſome other place, is not the ſame now

" ſite ſide towards the ſouth, to direct them better on " their way home, than they had been directed in " coming to China. This inſtrument was called " *Tchi Nan*, which is the ſame name as the Chineſe " now call the ſea compaſs by: This has given oc" caſion to think, that *Tcheoû Kong* was the inventor " of the compaſs."—This happened in the 22d cycle, above 1040 years before Chriſt.

Renaudot adduces ſtrong reaſons againſt the knowledge of the mariner's compaſs amongſt the ancient people of China, and of Arabia. See Kircher *de magnete*, lib. i. cap. v.

Sir G. Wheeler ſays, that he had ſeen a book of aſtronomy older than the year 1302, which mentions the uſe of the needle in aſtronomy, but not in navigation. And in an old French poet, named Guyot de Provins, who wrote about the year 1180, there is expreſs mention made of the load-ſtone and the compaſs; but their uſe in navigation is obliquely hinted at.

The Spaniſh jeſuit Pineda, and Kircher, affirm that Solomon knew the uſe of the compaſs, and that his ſubjects did actually uſe it in their navigations.

Notwithnow as it was 20 years ago, or ſome time ago. The change or variation of the declination may be obſerved even in one hour's time; or, more properly ſpeaking, the magnetic meridian, in one and the ſame part of the world, is continually ſhifting its ſituation.

This variation cannot be owing to any imperfection in the conſtruction of the magnetic needles, or to the various ſtrength of different magnets, becauſe all the magnets or magnetic needles, that are kept in the ſame place, ſhew exactly the ſame declination, provided they be freely ſuſpended, and not placed within the influence of each other, or of other ferruginous bodies *.

The

Notwithſtanding the foregoing remarks, it is ſtill very doubtful whether the uſe of the compaſs in navigation, or even the traverſing property of the loadſtone, was known by any people before the Europeans began to uſe it, in or about the 13th century; in which time the above-mentioned Flavio, or John de Gioa, if not the inventor, was at leaſt the firſt who uſed it for the guidance of veſſels in the Mediterranean.

* The diſcovery of the declination of the magnetic needle is generally attributed to Sebaſtian Cabot, a Venetian, who is ſaid to have diſcovered it in the year

 1500;

The uncertainty of this declination in different parts of the world, is one of the greateſt impediments againſt the perfection of navigation; and therefore philoſophers have ſpared no pains in endeavouring to inveſtigate its cauſe, and, if poſſible, to correct the errors that neceſſarily ariſe from it; but human induſtry has not yet been able to elucidate this obſcure part of the ſubject of magnetiſm.

Ever ſince the diſcovery of the declination of the magnetic needle, ingenious perſons, both at ſea and on land, have aſſiduouſly endeavoured to aſcertain its quantity in different places; and their obſervations have been not only regiſtered in books, but are alſo ſet down in good ſea charts, for the uſe of future navigators: however, thoſe obſervations can ſerve for a few years only, on account of their being

1500; though in truth it was Columbus who, as is mentioned in his life, diſcovered it, in his firſt voyage to America in 1492; but the variation of the declination, or the variation of the declination in the ſame place, but at different times, was diſcovered by Mr. Gellibrand, a profeſſor in Greſham College, about the year 1625.

inconſtant

inconſtant and fluctuating in the ſame places; nor has it yet been diſcovered that this variation or fluctuation is ſubject to any law or period; though various hypotheſes have been framed for its explanation.

When the compilation of the preſent work was firſt begun, my deſign was to inſert in it all the obſervations relating to the declination of the magnetic needle, which had been made in different parts of the world, and at different times, for the uſe of thoſe perſons who might wiſh to inveſtigate the cauſe or period of that variation; but, after having extracted the obſervations of divers navigators and other obſervers from the accounts of voyages, &c. it appeared that the bulk of thoſe obſervations alone, independent of any other part of the ſubject, would require a volume larger than the preſent. Conſidering, therefore, that this additional volume could be of uſe only to a few ſpeculative perſons (and probably it would not be productive of any uſeful theory; ſince, as will be particularly mentioned in the ſequel, the cauſe, upon which the declination and its variation are likely to depend, ſeems to be itſelf very fluctuating and irregular) I have contented myſelf with ſubjoining only a liſt of a few obſervations made in various parts of the world, together with the obſervations made at different times in London. After which I ſhall conclude this chapter with ſome general obſervations relating to the declination, and a ſpecimen of the daily variation.

N. B. By the declination being eaſt or weſt, is meant, that the north extremity of the magnetic needle is on the eaſtern or weſtern ſide of the meridian of the place.

Latitude, North. °	′	Longitude, Weſt. °	′	Declination, Eaſt. °	′	Years in which the obſervations were made.
70.	17.	163.	24.	30.	21.	1779.
69.	38.	164.	11.	31.	0.	1778.
66.	36.	167.	55.	27.	50.	
65.	43.	170.	34	27.	58.	
63.	58.	165.	48.	26.	25.	
59.	39.	149.	8.	22.	54.	
58.	14.	139.	19.	24.	40.	
55.	12.	135.	0.	23.	29.	
53.	37.	134.	53.	20.	32.	

Latitude,

Latitude, North. °	′	Longitude, West. °	′	Declination, West. °	′	Years in which the observations were made.
50.	8.	4.	40.	20.	36.	1776.
48.	44.	5.	0.	22.	38.	
40.	41.	11.	10.	22.	27.	
33.	45.	14.	50.	18.	7.	
31.	8.	15.	30.	17.	43.	
28.	30.	17.	0.	14.	0.	
23.	54.	18.	20.	15.	4.	
20.	30.	20.	3.	14.	35.	
19.	45.	20.	39.	13.	11.	
16.	37.	22.	50.	10.	33.	
15.	25.	23.	36.	9.	15.	
13.	32.	23.	45.	9.	25.	
12.	21.	23.	54.	9.	48.	
11.	51.	24.	5.	8.	19.	
8.	55.	22.	50.	8.	58.	
6.	29.	20.	5.	9.	44.	
4.	23.	21.	2.	9.	1.	
3.	45.	22.	34.	8.	27.	
2.	40.	24.	10.	7.	42.	
1.	14.	26.	2.	5.	35.	
0.	51.	27.	10.	4.	59.	
0.	7.	27.	0.	4.	27.	
South.						
1.	13.	28.	58.	3.	12.	
2.	48.	29.	37.	2.	52.	
3.	37.	30.	14.	2.	14.	
4.	22.	30.	29.	2.	54.	
5.	0.	31.	40.	1.	26.	
6.	0.	32.	50.	0.	6.	

Latitude, South. °	′	Longitude, West. °	′	Declination, East. °	′	Years in which the observations were made.
6.	45.	33.	30.	00.	35.	1776.
				West.		
7.	50.	34.	20.	00.	7.	
8.	43.	34.	20.	00.	15.	
				East.		
9.	1.	34.	50.	00.	44.	
				West.		
10.	4.	34.	49.	00	38.	
				East.		
12.	40.	34.	49.	1.	12.	
13.	23.	34.	49.	1.	1.	
14.	11.	34.	49.	1.	9.	
15.	33.	34.	40.	1.	15.	
16.	12.	35.	20.	2.	4.	
18.	30.	35.	50.	3.	2.	
20.	8.	36.	1.	5.	26.	
21.	37.	36.	9.	3.	24.	
24.	17.	36.	8.	3.	24.	
26.	47.	34.	27.	3.	44.	
28.	19.	32.	20.	1.	58.	
30.	25.	26.	28.	2.	37.	
				West.		
33.	43.	16.	30.	4.	44.	
35.	37.	9.	30.	5.	51.	
38.	52.	23.	20.	22.	12.	
		East.		East.		
40.	36.	173.	34.	13.	47.	
42.	4.	167.	32.	13.	17.	
				West.		
44.	52.	155.	47.	9.	28.	
46.	15.	144.	50.	14.	48.	
48.	41.	69.	10.	27.	39.	

Declination observed in London at different times.

Years.	Declination. °	′	
1576.	11.	15.	
1580.	11.	11.	
1612.	6.	10.	East.
1622.	6.	0.	
1633.	4.	5.	
1634.	4.	5.	
1657.	0.	0.	
1665.	1.	22½.	
1666.	1.	35½.	
1672.	2.	30.	
1683.	4.	30.	
1692.	6.	0.	
1700.	8.	0.	
1717.	10.	42.	
1724.	11.	45.	
1725.	11.	56.	
1730.	13.	00.	West.
1735.	14.	16.	
1740.	15.	40.	
1745.	16.	53.	
1750.	17.	54.	
1760.	19.	12.	
1765.	20.	00.	
1770.	20.	35.	
1774.	21.	3.	
1775.	21.	30.	
1780.			
1785.			

When the variation of the magnetic needle was firſt diſcovered, it was to the eaſt of the meridian of London, and of ſeveral other places on the continent. It has been ſince that time advancing continually towards the weſt, ſo that in the year 1657, the magnetic needle pointed due north and ſouth; and, at preſent, its variation is about 22° weſt. This gradual advance of the needle's variation from the eaſt to the weſt, has been obſerved in various other places; but in ſome parts of the world the variation has neither moved with the ſame celerity, nor towards the ſame way. The rate of its increaſe has neither been very regular, *viz.* if the variation increaſed was 10 minutes in one year, it did not keep conſtantly increaſing 10 minutes more for every ſubſequent year; though ſometimes it has ſhewn a conſiderable degree of regularity for a few years. In ſhort, the obſervations and theories hitherto made, relating to the variation of the magnetic needle, do not point out any way, by which the declination in a given place, and for a given time, may be foretold with any degree of certainty.

The daily variation is evidently affected by the heat and cold; though their not being always proportionate to each other, ſhews, that heat is not the only cauſe upon which it depends.

I ſhall now add, as a ſpecimen of the daily variation, the obſervations made at different hours of one and the ſame day, and alſo, the mean variation for each month in the year, according to the obſervations of the late ingenious Mr. Canton *.

* Phil. Tranſ. vol. li.—If the reader be deſirous of examining farther the obſervations made concerning the variations of different places, and at different times, he may conſult the Phil. Tranſ.—the Hiſtory de l'Academie de Paris—almoſt all the Acts of other academies—the obſervations made in the courſe of Capt. Cook's voyages, and publiſhed by Mr. Bayly and Mr. Wales.—&c. &c.

The

The declination observed at different hours of the same day.

June 27th, 1759.

	Hours.	Minutes.	Declination West. °	′	Degrees of Fahrenheit's thermometer.
Morning.	0.	18.	12.	2.	62.
	6.	4.	18.	58.	62.
	8.	30.	18.	55.	65.
	9.	2.	18.	54.	67.
	10.	20.	18.	57.	69.
	11.	40.	19.	4.	68½.
Afternoon.	0.	50.	19.	9.	70.
	1.	38.	19.	8.	70.
	3.	10.	19.	8.	68.
	7.	20.	18.	59.	61.
	9.	12.	19.	6.	59.
	11.	40.	18.	51.	57½.

The mean variation for each month in the year.

	′	″
January — —	7.	8.
February — —	8.	58.
March — —	11.	17.
April — —	12.	26.
May — —	13.	0.
June — —	13.	21.
July — —	13.	14.
August — —	12.	19.
September — —	11.	43.
October — —	10.	36.
November —	8.	9.
December —	6.	58.

CHAP-

CHAPTER V.

Of the magnet's inclination, or dipping needle.

TAKE a globular magnet, or, which is more eaſily procured, an oblong one, like S N, fig. 2. of plate I; the extremity N of which is the north pole, the other extremity S, the ſouth pole, and A is its middle or equator. Place it horizontally upon a table C D; then take another ſmall oblong magnet *n s* (a common ſmall ſewing needle, made magnetic, anſwers perfectly well for this purpoſe), and ſuſpend it, by means of a fine thread tied to its middle, in ſuch a manner as to remain in a horizontal poſition, when not diſturbed by another magnet, &c. Now, if the ſaid ſmall magnet, being held by the upper part of the thread, be brought juſt over the middle of the large magnet, within two or three inches of it, you will find, that this ſmall magnet will turn itſelf ſo as to direct its ſouth pole *s* towards the north pole N of the large magnet, and

its

its north pole *n* towards the ſouth pole S of the large one; agreeably to the magnetical law mentioned in the preceding pages, *viz.* that poles of different name attract each other. It will be farther obſerved, that the ſmall magnet, whilſt kept juſt over the middle A of the large one, will remain parallel to it, and conſequently in a horizontal ſituation; the reaſon of which is, becauſe the poles of the ſmall magnet, being equally diſtant from the contrary poles of the large one, are equally attracted. But if the ſmall magnet be moved a little nearer to one end than to the other of the large magnet, then one of its poles, namely that which is neareſt to the contrary pole of the large magnet, will be inclined downwards; and of courſe the other pole will be elevated above the horizon. It is evident that this inclination muſt be greater according as the ſmall magnet is placed nearer to one of the poles of the large magnet, becauſe the attraction of the neareſt pole will have more power upon it. Farther, if the ſmall magnet be brought juſt oppoſite

one

one of the poles of the other, it will turn the contrary pole towards it, and will place itſelf in the ſame ſtraight line with the axis of the large magnet.—— Obſerve the fig.

After comprehending this very eaſy experiment, the reader, in order to underſtand the phenomena of the magnetic inclination or dipping needle upon the ſurface of the earth, needs only imagine that the earth is the large magnet, and that the magnetic needle, or any other magnet, is the ſmall magnet of the preceding experiment; for, admitting that the north pole of the earth is poſſeſſed of a ſouth magnetic polarity, and that the oppoſite pole is poſſeſſed of a north magnetic polarity, it appears, as is confirmed by actual experience, that when a magnet, properly ſhaped and ſuſpended, is kept near the equator of the earth, it muſt remain in a horizontal ſituation; that if it be removed nearer to one of the poles of the earth, it muſt incline one of its extremities, namely that which is poſſeſſed of the contrary magnetic polarity;

rity; that the ſaid inclination muſt increaſe in proportion as the magnet or magnetic needle recedes from the equator of the earth; and laſtly, that when brought juſt upon either of the poles of the earth, it muſt ſtand perpendicular to the ground, *viz.* in the ſame ſtraight line with the axis of the earth. The direction of the dipping needle, in any place, is called the *magnetical line*.

My reader muſt not be ſurpriſed to hear, that a ſouth magnetiſm is attributed to the north pole of the earth; it being only meant, that it has a magnetic polarity contrary to that end of the magnetic needle which is directed towards it; and, as we call that ſame end of the needle a north magnetic pole, we muſt of neceſſity attribute a contrary polarity, that is, a ſouth magnetic polarity, to the north pole of the earth. With a proper change of names, the ſame remark muſt be underſtood of the ſouth pole of the earth, which therefore muſt be conſidered to be poſſeſſed of a north magnetic polarity.

That the whole body of the earth acts like

a real

a real magnet, is a ſuppoſition, not only ſuggeſted by the ſimilarity between the phenomena of the dipping needle and the above-mentioned experiment; but is confirmed by many other experiments and obſervations, ſo that it would be ſcepticiſm indeed to doubt of it: we ſhall, however, examine this ſubject more at large in the next Part.

If the poles of the earth, *viz.* the extremities of the axis, about which it performs the diurnal rotation, coincided with its magnetic poles, or even if the magnetic poles were always at a fixed diſtance from them, the inclination of the magnetic needle would be regular, and navigators could derive great advantage from it; for it would not be difficult to determine, by mathematical means, the degree of the inclination of the needle in any given latitude; and conſequently, by obſerving the actual inclination of the dipping needle in any required place, the mariners could thereby aſcertain the latitude of that place. The caſe, however, is far different; for the magnetic poles of

the

the earth are continually ſhifting ſituation, and that without any known regularity or period: hence, the inclination, as well as the horizontal direction, of the needle is continually changing in the ſame place, and generally it changes very little in one place, and a great deal or nothing in another; ſo that the exact degree of its inclination, in any given place, can only be aſcertained by actual experiment.—Here follow a few obſervations of the inclination of the needle in various places.

Latitude, North.		Longitude, East.		The north end of the needle below the horizon.		Years in which the obſervations were made.
°	′	°	′	°	′	
53.	55.	193.	39.	69.	10.	1778.
49.	36.	233.	10.	72.	29.	
		West.				
44.	5.	8.	10.	71.	34.	1776.
38.	53.	12.	1.	70.	30.	
34.	57.	14.	8.	66.	12.	
29.	18.	16.	7.	62.	17.	
24.	24.	18.	11.	59.	0.	
20.	47.	19.	36.	56.	15.	
15.	8.	23.	38.	51.	0.	
12.	1.	23.	35.	48.	26.	
10.	0.	22.	52.	44.	12.	
5.	2.	20.	10.	37.	25.	
South.						
0.	3.	27.	38.	30.	3.	

Latitude,

Latitude, South. °	′	Longitude, East. °	′	The north end of the needle below the horizon. °	′	Years in which the obſervations were made.
4.	40.	30.	34.	22.	15.	1776.
7.	3.	33.	21.	17.	57.	
11.	25.	34.	24.	9.	15.	
		Eaſt.		South end below.		
16.	45.	208.	12.	29.	28.	
19.	28.	204.	11.	41.	0.	
21.	8.	185.	0.	39.	1.	1777.
35.	55.	18.	20.	45.	37.	1774.
41.	5.	174.	13.	63.	49.	1777.
45.	47.	166.	18.	70.	5.	1773.

Two principal obſervations may be made with reſpect to the dipping needle: the firſt is, that its inclination does not alter regularly in going from north to ſouth, or from the latter to the former, along any meridian; and the ſecond is, that its alteration in the ſame place, at different times, is very ſmall: Thus, in London, about the year 1576, the north pole of the dipping needle ſtood 71°. 50′. below the horizon; and in the year 1775 it ſtood at 72°. 3′, the alteration of the inclination in ſo many years amounting to leſs than a quarter of a degree, which may be even attributed to the error of the inſtruments, ſince, as will appear in the ſequel, thoſe inſtruments are far from having attained to any perfection, even in the preſent age.

CHAPTER VI.

Of the various bodies which are attracted by the magnet.

PROPERLY ſpeaking, the magnet attracts only iron, in whatever ſtate that metal may be; but, as moſt natural bodies contain too ſmall a quantity of iron to be called ferruginous, and yet they are attracted by the magnet, it is proper to enumerate them in this chapter, not only to ſhew the great diſperſion of iron throughout the works of nature, but alſo, becauſe thoſe obſervations ſeem likely to open the way to farther diſcoveries in other branches of philoſophy as well as magnetiſm.

The liſt of thoſe bodies is very comprehenſive;

prehenſive; there being hardly any ſubſtance, but which, if not naturally, at leaſt by ſubjecting it to the action of fire, may be rendered, in ſome meaſure, capable of being attracted by the magnet.

Iron is attracted with different degrees of force, according to the different ſtates of its exiſtence; but it never becomes quite inſenſible to the magnetic power. Even the pureſt calx, or the compleateſt ſolution, that has been produced of that metal, when properly examined, is found to be in ſome degree attracted by the magnet.

Soft iron, clean and of an uniform texture, is attracted more forcibly than the hard, or any other ſort of iron. Steel, eſpecially when hardened, is attracted much leſs forcibly than iron. The ſcales which are ſeparated from the ſurface of red-hot iron when hammered, and the particles of burned ſteel that are produced from the colliſion of a flint and ſteel, are attracted by the magnet about as well as pieces of good iron that equal them in bulk.

The black calx of iron is attracted very weakly. The red calx, or ruſt, whether it be produced by the action of acids, of fire, or of expoſure to the atmoſphere, is attracted very little; but it never becomes quite inſenſible of the magnet's action, though it be repeatedly waſhed and purified.

When the particles of iron are in the form of black ſcales, or even in that of red calx, they are often of ſuch a nature, perhaps owing to their hardneſs, as to acquire a weak but ſenſible polarity from the influence of a ſtrong magnet; ſo that, by changing the pole of the magnet that is preſented to them, they may be made to turn accordingly; though, in general, they are attracted alike on every ſide.

Beſides the different ſtates of purity, the attraction between the iron and a magnet is ſubject to a conſiderable variation, ariſing from the ſize of the iron; for a ſingle piece of iron of a certain bulk, which, as was obſerved in the 3d chapter, muſt be determined by experiment in any magnet, is attracted more forcibly than either a larger or a ſmaller piece, or than many pieces,

pieces, which, taken all together, are equal to it in weight; hence it follows, that a quantity of iron is attracted with the leaſt force, when reduced into the ſmalleſt bits, or fineſt powder.

The ores of iron are attracted more or leſs readily, according as they contain a greater or ſmaller quantity of metal, and as that metal is in a more or leſs perfect metallic ſtate; but they are always attracted, even thoſe which contain ſo ſmall a quantity of metal as hardly to deſerve the name of ores.

By the action of fire, the iron ores are generally put in a ſtate of being much more readily attracted, which is evidently owing to their acquiring more of the inflammable principle, or to their approaching nearer to the perfect metallic ſtate. In fact, if thoſe ores which are very weakly attracted, be expoſed to the action of fire, when they are ſurrounded by ſubſtances that abound with the inflammable principle, they are thereby rendered much more capable of being attracted, than if they be expofed to an open fire, and to the current of air, by themfelves.

The ores of other metals are generally, though weakly, attracted by the magnet, which fhews their containing fome iron; fuch are the ores of lead, of tin, and of copper. Native cinnabar is likewife attracted; but the factitious cinnabar is not *.

The pure metals are not attracted; and it is very fingular, that though pure lead is not attracted in the leaft by the magnet, yet its calx is a little attracted. The calx of tin is likewife attracted, but even in a fmaller degree †.

Of the femi-metals, zinc, bifmuth, and particularly cobalt, as well as their ores, are almoft always attracted by the magnet. Antimony is not attracted unlefs it be firft expofed to a gentle fire. Arfenic is not attracted at all.

* This remark fhews, that the colour of a mineral is not always a fure indication of its containing iron; for both forts of cinnabar have the fame red colour.

† See Brugman de affinit. magnet. § xxxix.

A certain

A certain ſort of biſmuth is ſaid to poſſeſs a very ſingular property, which is, that the magnet repels it on every ſide *.

Whoever conſiders the vaſt diſperſion of iron throughout the world, and its being always capable of attraction towards the magnet, will eaſily believe, that there is hardly any ſubſtance in nature, which, if not in its uſual ſtate, at leaſt by burning, may be rendered capable of being in ſome meaſure attracted by the magnet.

The other minerals beſides the metallic, are almoſt all attracted by the magnet, at leaſt after having been expoſed to the action

* "Biſmutum colore albo, argenteo, nitente, tra-
" hitur a magnete, creſcitque illius attractio ex igne
" ſemimetallum hoc in calces vertente ; ſed biſmu-
" tum cujus colori magis obſcuro quid de violaceo
" inhærebat ſingulare admodum phænomenon exhi-
" buit. Ejus ſcilicet portio, circello chartaceo aquæ
" innatanti immiſſa lente, ab utroque magnetis polo
" in omnem plagam repellebatur. Huic ſimile quid
" me ſemel tantum, et caſu, inter millena experi-
" menta magnetica, obſervaſſe memini, in molecula
" exigua ex lapide noſtro molari excuſſa. Repulſio
" hæc biſmuti ſingularis in attractionem ignis ope
" mutatur perquam tamen continuo exiguam."
Brugman de affinit. magnet. § xl.

of fire *. Of the pure earths, the calcareous is leſt or not at all, and the ſiliceous the moſt frequently, attracted. Sand is generally attracted, eſpecially the black ſea-ſand, which evidently contains a good deal of martial earth, or rather half-formed iron.

Amber and other combuſtible minerals are generally attracted by the magnet, eſpecially after burning.

Of the precious ſtones, thoſe which are pellucid, as the diamond, and cryſtals, are not attracted. The amethyſt, topaz, chalcedony, and generally thoſe which are de-

* When ſubſtances are to be burned, or, as it is called by ſeveral mineralogiſts, are to be roaſted, for the ſake of rendering them more eaſily capable of being attracted; it has been recommended by various ingenious perſons, to ſurround them with what they call a *reducing flux*, *viz.* with ſubſtances that contain abundance of phlogiſton, in order to revivify, as much as poſſible, the ſmall quantity of iron calx which is in the ſubſtances to be examined; but care ſhould be had, that, in this operation, ſome quantity of iron be not imparted to thoſe ſubſtances by the reducing flux itſelf.—A common earthen crucible, though itſelf magnetic, yet it has been found that it imparts no iron to the ſubſtances that are expoſed in it to the fire.

prived

prived of their colour by fire, are not attracted. The other precious ſtones are all attracted; *viz.* the ruby, eſpecially the oriental, the chryſolite, and the tourmalins. The emerald, and particularly the garnet, are not only attracted, but frequently acquire an evident polarity from the influence of a ſtrong magnet, ſo that afterwards they are attracted from one ſide and repelled from the other. The opal is but weakly attracted.

Almoſt every part of animal or vegetable bodies, after combuſtion, is in great meaſure attracted by the magnet. The fleſh, and eſpecially the blood, after burning, are attracted moſt, but the bones are attracted leſs powerfully. The vegetables, after burning, are almoſt all, though not all with equal force, attracted by the magnet. But unburned and freſh animal or vegetable ſubſtances very ſeldom, if ever, ſhew any perceptible attraction towards the magnet.

It is very remarkable, that even ſoot, and the duſt which uſually falls upon whatever is left expoſed to the atmoſphere, are ſenſibly attracted by the magnet.

Thus

Thus it appears that iron, though divided into exceedingly ſmall particles, is in ſome ſtate or other mixed with every ſubſtance; that it is to be found in animals, in vegetables, in minerals, and even in the air; that in every ſtate of exiſtence it always ſhews ſome attraction towards the magnet; and that its exiſtence in ſeveral ſubſtances can be diſcovered by no other known method beſides the magnet. But a judicious enquirer might aſk, Why muſt we conclude that a ſubſtance contains iron, only becauſe it is in ſome meaſure attracted by the magnet? and when he is told, that the magnet attracts only iron, he might again aſk for a demonſtration of that law.—Indeed it ſeems almoſt certain, that ſome bodies, independent of iron, are attracted by the magnet; but, as the proofs of this aſſertion depend upon ſome of the author's own experiments, which will be related in the laſt Part of this work; it ſeems not proper to admit the above-mentioned aſſertion as a law in this place.

CHAP.

CHAPTER VII.

Of communicated Magnetiſm.

WHEN a piece of iron or ſteel, or, in ſhort, of any ferruginous body, is preſented to a magnet, within a proper diſtance of one of its poles, it becomes inſtantly magnetic, the part of it, which is neareſt to the magnet, acquiring the contrary polarity, &c.

This acquired magnetiſm is ſtrongeſt with ſoft iron, and weakeſt with hardened ſteel, or with the brittle ſort of caſt iron; the other ſorts of iron or ferruginous bodies acquiring a ſtronger or weaker power, according as they approach the hardneſs of the latter or the ſoftneſs of the former. But the permanency of the acquired magnetiſm follows juſt the reverſe of this rule; ſo that the hardeſt ſteel retains it for many years with little or no diminution; whereas very ſoft iron loſes it entirely the moment it is removed from the influence of the magnet; the other ferruginous bodies preſerving it for a longer or ſhorter time, according as they participate more of the nature of hard ſteel, or of that of ſoft iron. Hence it may be deduced, that, in general, the beſt method of making artificial magnets, conſiſts in applying one or more powerful magnets to pieces of the hardeſt ſteel, becauſe thoſe pieces will thereby acquire a conſiderable power, and will retain it for a long time; taking care, in this operation, that the north pole of the magnet or magnets be applied to that extremity of the piece of ſteel which is required to be made the ſouth pole, and that the ſouth pole of the magnet be applied to the oppoſite extremity.—In the ſame manner as a piece of ſteel or iron is rendered magnetic, a weak magnet may be rendered more powerful, or its power may be reſtored when loſt.

It is evident, that in this method the operator ſhould have one or more magnets, by the application of which the ſteel, or other ferruginous body, may be rendered magnetical; therefore it may be aſked, By what means is magnetiſm originally given, to ſuch artificial magnets as are ſaid to have

that

that power imparted without the interference of any magnet?—The anſwer to this queſtion is, that no magnetiſm at all can be communicated to any ferruginous body whatever, without the action of another magnet; and that, in the method vulgarly called, of giving magnetiſm to ſteel, *&c.* without the aid of a magnet, the beginning of the magnetic power is communicated from the earth, which is a real magnet; and therefore there is no magnetiſm communicated but by the action of another magnet.

The experiment which ſhews the magnetiſm of the earth in the cleareſt manner poſſible, and by which means the beginning of that power is communicated in the above-mentioned method, is the following:

Take a ſtraight bar of ſoft iron (one of two or three feet in length, and about three quarters of an inch in diameter, will anſwer perfectly well), and, in theſe parts of the world, if you keep it in a vertical poſition, that is, with one end A towards the ground, and with the other end B upwards,

you

you will find that the bar is magnetic; the extremity A being a north pole, capable of repelling the north pole of a magnetic needle, and the upper end B being a ſouth pole, capable of repelling the ſouth pole, and of attracting the north pole, of the magnetic needle.—If you invert the bar, placing it with the extremity B downwards, its polarity will be inſtantly reverſed, B becoming the north, and A the ſouth pole *. The explanation of this curious phenomenon is eaſily deduced from the foregoing obſervations; for, ſince in theſe northern parts the earth is poſſeſſed of a ſouth magnetic polarity, the loweſt part of the iron bar, by being neareſt to it, muſt acquire the contrary, namely the north polarity; the other extremity of the bar becoming a ſouth pole.

It follows likewiſe (and it is confirmed by actual experiment) that in the ſouthern parts of the earth the loweſt part of the bar

* An iron bar of four or five feet in length, and above an inch thick, in this ſituation, will be capable of attracting a ſmall bit of iron, or a common ſewing-needle.

acquires

acquires the ſouth polarity; that on the equator the bar muſt be kept horizontal, in order to let it acquire any magnetiſm from the earth; and that, even in theſe parts of the earth, the moſt advantageous ſituation of the bar is not the perpendicular, but that a little inclined to the horizon. In ſhort, in every part of the world it muſt be placed in the magnetical line, *viz.* in the direction of the dipping needle *.—If the iron bar, inſtead of being kept in the magnetical line, be placed in a direction perpendicular to it, then it will acquire no magnetiſm, becauſe in that ſituation the actions of both poles of the earth upon each extremity of the bar are equal. If, inſtead of the above-mentioned two directions, the bar be placed in any other poſition, then it will acquire more or leſs magnetic power, according as it approaches nearer to the former or to the latter of the ſaid two directions.

A bar of hard ſteel, or of hard iron, does not acquire any magnetiſm from

* See the fifth chapter of this Part.

the

the earth, like the bar of ſoft iron, becauſe the magnetic power of the earth is weak, in proportion to that which is required in order to render a ſteel bar magnetic.

Having thus deſcribed the general phenomena of communicated magnetiſm, we muſt now proceed to enumerate the particular laws, which have been aſcertained concerning them.

A magnet, by communicating magnetiſm to other ſubſtances, not only loſes nothing of its power, but has it rather improved.

A magnet can never communicate a greater power than itſelf poſſeſſes, or even an equal degree of it; but ſeveral magnets, of nearly an equal degree of magnetiſm, when joined together, have a ſtronger power than one of them ſingly; hence, in order to impart a ſtrong magnetic power to a given body A, by means of a weak magnet B, one muſt firſt render ſeveral bodies C, D, E, F, &c. weakly magnetic, and then, by properly joining C, D, E, F, &c. together, he may communicate

municate to another body, or ſeveral other bodies, a ſtronger magnetiſm, till, at laſt, he will be able to communicate to A the required degree of magnetic power.

It is almoſt ſuperfluous to mention, that when the ferruginous body is applied in contact with the magnet, it acquires a ſtronger power than if it be placed at ſome diſtance from its ſurface.

When a ferruginous body is expoſed to the influence of a magnet, though it acquires the greateſt part of the power at the very firſt perceptible inſtant; yet, in order to acquire the utmoſt degree, of which that body may be capable, it muſt remain in that influence for a conſiderable time. Soft iron acquires the maximum of magnetic power very readily; but, according as the nature of the ferruginous body is harder, ſo the maximum of the power is communicated ſlower.

Agreeably to thoſe laws, it has frequently been obſerved, that bars, and other pieces of iron, by having remained a long time in one ſituation, have become magnetic *. Sometimes iron bars, which were not capable of a permanent magnetiſm on account of their ſoftneſs, have in time, and by being left expoſed to the atmoſphere in a due ſituation, acquired a conſiderable degree of magnetiſm; but it has been alſo remarked, that thoſe bars have, at the ſame time, become harder; which is, perhaps, owing to a partial calcination, or to ſome other hitherto unaſcertained change in the nature of the iron.

The polarity thus communicated by the earth to iron bars, is more or leſs permanent, in proportion to the degree of hardneſs of the iron, the time of their remaining in one ſituation (the moſt proper being that of the dipping needle), and laſtly, the ſhape of the iron, or the proportion between the thickneſs and length of the pieces.

An oblong piece of iron made red hot, and then left to cool in the magnetical

* It is frequently found mentioned in books, that ſome pieces of iron, which had remained in one ſituation for many centuries, were become as ſtrongly magnetic as good natural magnets.

line, acquires thereby a degree of magnetiſm, which is more or leſs permanent, according to the nature of the iron. The reaſon of which is, becauſe, whilſt red hot, the iron is ſoft, and therefore the earth can render it magnetic more eaſily; but, when cooled, it becomes harder, and conſequently more tenacious of the acquired power.

In drilling, filing, hammering, and, in ſhort, in all thoſe caſes in which iron, ſteel, &c. is put into violent action, ſome of the pieces concerned frequently acquire a conſiderable degree of magnetiſm; the origin of which muſt be derived from the earth, and from the changeable nature of the metal, or the viciſſitudes of heat, cold, and vibratory motion, in which it is accidentally put.

It ſeems that, for the ſame reaſons, magnetiſm is in certain caſes produced by means of electricity; the particulars obſerved, concerning which, are the following, and they were aſcertained by means of the moſt powerful electrical machine that has been yet made. — They in a great meaſure, coincide with thoſe made with other machines.

When the bar or needle is laid horizontally in the magnetic meridian, whichever way the ſhock of an electric jar or battery enters, the end of the bar that ſtands towards the north will acquire the north polarity, *viz.* the power of turning towards the north when freely ſuſpended; the other end acquiring the ſouth polarity. If the bar, before it receives the ſhock, has ſome polarity, and is placed with its poles contrary to the uſual direction, then its original polarity is always diminiſhed, and often reverſed.

When the bar or needle is ſtruck ſtanding perpendicularly in theſe parts of the world, its loweſt end becomes the north pole, even when the bar had ſome magnetiſm before, and receives the ſhock whilſt ſtanding with its ſouth pole downwards. When all the other circumſtances are alike, the bars ſeem to acquire an equal degree of magnetic power, whether they are ſtruck whilſt ſtanding horizontally in the magnetic meridian, or perpendicular to the horizon.

Wh-

When a bar or needle is placed in the magnetic equator, the ſhock ſent through its length very ſeldom, if ever, renders it magnetic; but if the ſhock be paſſed through its width, then the needle becomes magnetic, the extremity of it which laid towards the weſt, generally becoming the north pole.

If a needle or bar ſtrongly magnetic, or a natural magnet, be ſtruck by the electric ſhock, its power is thereby diminiſhed.

When the ſhock is too ſtrong, with reſpect to the ſize of the ſteel needle, ſo as to render it conſiderably hot, then it acquires either none at all, or a very ſmall degree of magnetiſm *.

Hence, a ſtroke of lightning, which is an electrical phenomenon, often renders magnetic pieces of iron, of ſteel, or thoſe

* For thoſe experiments, the bars or needles muſt be proportioned to the degree of electric power; otherwiſe, they will not ſucceed. See Van Marum's account of a very powerful electrical machine, conſtructed for the Muſeum of Teyler at Harlem; and my Treatiſe on Electricity, vol. i. p. 66. and vol. ii. p. 282.

bodies which contain iron, as certain bricks, &c.

If one pole of a magnet, for inſtance the north, be applied to one end C of an oblong piece of iron or ſteel, like C D, fig. 3d of plate I. that end C will become a ſouth pole; and if the bar C D be very long, there will be found a part of it, not far diſtant from C, which is poſſeſſed of the north polarity; and this is followed by another part, poſſeſſed of the ſouth polarity; and ſo on alternately, till the power becomes imperceptible; the number of thoſe ſucceſſive poles depending upon the ſtrength, and principally upon the length of the bar; but if the bar be of a proper length and thickneſs, which muſt be likewiſe proportioned to the ſtrength of the magnet employed, then the bar will have only two poles, its other extremity D acquiring the north polarity.

In the latter caſe, if that pole of the magnet be gradually moved along the ſurface of the bar from C as far as D, it will

afterwards

afterwards be found, that the polarity of the bar is entirely changed, the extremity C being now poſſeſſed of the north, and the extremity D of the ſouth polarity.

It is evident, that, whilſt the magnet is advancing along the ſurface of the bar, the ſouth polarity of the end C, before it changes into a north polarity, muſt decreaſe in ſtrength; and that when the magnet is at a certain point M, the end C has no polarity at all; its ſouth polarity being juſt vaniſhing, and the north polarity juſt beginning. With reſpect to the extremity D, it muſt be obſerved, that its north polarity, by the approach of the magnet, is increaſed as far as a certain limit H; after which, as the magnet comes ſtill nearer to D, the north polarity of this extremity decreaſes, till it vaniſhes when the magnet is arrived at a certain point N; after which its north polarity begins to be changed into a ſouth one.

The points M and N have been called *the points of indifference*; becauſe, when the magnet is at M, the extremity C of the bar has neither the ſouth nor the north polarity; and when the magnet is at N, the end D has no polarity. The point H has been called the *culminating point*, because, when the magnet is at that point, the polarity firſt acquired by the end D of the bar is the ſtrongeſt.

As the determination of thoſe points, in bars of different ſorts of iron, of different lengths, &c. not only ſhews more evidently the action of the magnet, and points out the advantages and diſadvantages attending the practical methods of making artificial magnets, but is beſides likely to open the way to farther diſcoveries; there have been no pains ſpared to inveſtigate the particulars on which their ſituation depends, and a vaſt number of accurate experiments have been made for that purpoſe; but, notwithſtanding thoſe endeavours, ſuch is the various nature of magnets, of iron, &c. that the preſent knowledge of the ſubject does not allow thoſe points to be determined, in a given bar, without actual experiments. — The general laws which may be deduced from the various experiments made for this purpoſe, are the following:

1. The

1. The points M, H, and N do not come always in the order ſhewn by the figure; but, though their order is not always the ſame, yet it is evident that the point H can never coincide with, or come after N, *viz.* nearer to the end D, than the point N.

2. When the bars differ in length only, every thing elſe being the ſame, the longer the bar is (as far as a certain limit, which depends on the ſtrength of the magnet employed) the greater is the diſtance C M.

3. The ſtronger the magnet is, which is employed, the greater is the diſtance C M, as far as a certain limit, which depends upon the proportion between the power of the magnet and the length of the bar; and beyond which limit C M will be ſhorter than if a weaker magnet had been uſed.

4. When the bars differ in length only, every thing elſe being the ſame, the diſtance C H is greater in a longer than in a ſhorter bar, as far as a certain limit, which depends as has been mentioned above.

5. The

5. The ſtronger the magnet is which is uſed, the greater is the diſtance C H, as far as a certain limit, which depends as above.

6. In a longer bar, every thing elſe being the ſame, the diſtance C N is greater than in a ſhorter one, as far as a certain limit, &c.

7. The diſtance C N, in bars of equal length, is greater when a ſtronger than when a weaker magnet is uſed, as far as a certain limit, &c.

8. When the bars differ only in thickneſs, every thing elſe being the ſame, the diſtance C M is greater in thicker than in thinner bars; but the diſtance C N is nearly the ſame in them all, as far as a limit, which depends as above-mentioned.

9. Laſtly, when the bars differ only in hardneſs, the diſtances C M, C H, C N, are ſometimes equal, ſometimes greater, and ſometimes ſhorter, in the harder than in the ſofter bars *.

Beſides the points of indifference and culmination, there is another point to be

* See Van Swinden's *Tentamina theoriæ mathematicæ de phænomenis magneticis.*

conſidered,

confidered, namely, the magnetic centre, which is the point or part between the two poles, where the magnet has no attraction nor repulfion. With refpect to this point, I fhall briefly obferve, that it does not always lie midway between the two poles; and that, when one pole of a magnet is drawn over the furface of an oblong piece of iron, as in the above-mentioned experiment, the magnetic centre moves forwards in proportion as the magnet is advanced; but at a certain limit both the magnet and the faid centre are in the fame place, or rather in oppofite fides of the thicknefs of the bar. The motion and place of the magnetic centre are fubject to a great deal of variety, arifing from the nature, length, and thicknefs of the bar, as well as from the ftrength of the magnet, and from the manner of drawing it along the furface of the iron or other ferruginous body.

When any magnet, but efpecially an oblong one, having two poles, is broke in two, the magnetic centre of each part is at firft generally much nearer that end of the piece which is contiguous to the fracture; but in time it advances nearer the centre of the piece.

What has been obſerved concerning oblong pieces of iron or ſteel, may ſerve to explain the phenomena which take place in pieces of an irregular form; the particular enumeration of all which caſes would be endleſs, and of little if at all of any uſe.

Every piece of iron or ferruginous body is capable of retaining only a certain degree of magnetic power; ſo that if a ſtrong magnet be applied to a comparatively ſmall piece of ſteel, that piece, whilſt it remains within the influence of the magnet, will appear to be very powerfully magnetic; but as ſoon as it is removed from the vicinity of the magnet, its power begins to decreaſe, and in a ſhort time comes down to that degree which the piece of ſteel is capable of, and which may be called *its point of ſaturation*. Hence it follows, that if a certain magnet is juſt ſufficient to communicate to a piece of iron or ſteel the full power of magnetiſm, of which that piece is capable, a ſtronger magnet will not increaſe it in the leaſt.

It has been long diſputed, whether a piece of iron or ſteel was rendered heavier or lighter by being made magnetic; but, upon the whole, it ſeems that its weight is not affected by it *.

As a piece of iron or ſteel, &c. often acquires magnetiſm only by ſtanding in a proper ſituation; ſo, on the contrary, magnets may loſe much or the whole of their power by being improperly ſituated; for, the ſame action of the earth which tends to render them magnetic in the former, will endeavour to deſtroy it in the latter. The ſame thing muſt be underſtood of the

* Gaſſendus, Merſennus, and Gilbert, maintain that the weight of needles is not altered by being made magnetic. Mr. Whiſton ſays he found, by accurate experiments, that a piece of ſteel, weighing 4584 $\frac{1}{8}$ grains, loſt 2$\frac{1}{4}$ grains; and another, which weighed 65726 grains, loſt 14 grains, by being made magnetic. With other perſons, magnetiſm ſeems to have increaſed the weight of ſteel.—But it is very probable that the vicinity of iron, or of ſome other ferruginous body, might have had ſome action on the magnetic ſteel when it was weighed.

ſituation

ſituation of magnets with reſpect to each other. Thus, if two magnets be placed ſo that their contrary poles may be contiguous to each other, they will preſerve one another's power; but if the north pole of one be placed near the north pole of the other, and the ſouth near the ſouth, then they will entirely deſtroy or diminiſh each other's magnetiſm; and if their original powers were very unequal, the polarity of the weaker magnet will be changed by the action of the ſtronger one.

In general, the ſame means, which facilitate the communication of magnetiſm, when pieces of iron, &c. are properly ſituated with reſpect to the poles of the earth, or of other magnets, will likewiſe facilitate the loſs of magnetiſm, when the magnets are improperly ſituated; thus, a red heat deſtroys in a great meaſure, or entirely, the power of a magnet. A ſteel bar, ſtrongly magnetic, will have its power much diminiſhed by being repeatedly ſtruck between two ſtones, eſpecially if it be ſtruck ſtanding in a direction perpendicular to the magnetic meridian. A bar of pretty hard iron, which has acquired ſome degree of permanent magnetiſm, by being made red hot, and then cooled in the direction of the magnetical line, will have that power deſtroyed, or much diminiſhed, by a few ſmart blows on its middle.

We ſhall now conclude this chapter with an enumeration of thoſe particulars which are principally neceſſary to be kept in view, in order to aſcertain the beſt method of conſtructing artificial magnets; reſerving the practical inſtructions for the third Part.

1. The nature of the body muſt be adapted to the power which is to render it magnetic; remembering, that the ſoft ferruginous bodies both acquire and loſe magnetiſm eaſier than thoſe which are harder.

2. The ſhape of the bodies is to be conſidered next, experience ſhewing that an oblong one is in general preferable to any other. In caſe of ſteel bars, they ought to be quite hard, in order to acquire the greateſt poſſible power, provided one has mag-

nets ſufficiently ſtrong for the purpoſe; and if cylindrical, their diameters ought to be about $\frac{1}{15}$th of their length; or if not cylindrical, their thickneſſes ought to be ſuch as nearly to equal the weight of the cylindrical bars of the ſame length, and the diameter of which may be about $\frac{1}{15}$th of their lengths.

3. Several magnets are much preferable to a ſingle one, for the purpoſe of communicating magnetiſm; in the application of which, it muſt be remembered, that the ſouth pole of the magnet produces a north pole in the part of the ferruginous body to which it is applied, and that the north pole of the magnet produces a ſouth pole in the part, &c.

4. If it were required to conſtruct a ſtrong magnet, when the operator has either no magnet at all, or a very weak one; he muſt proceed gradually. It being impoſſible for a hard and large ſteel bar to receive any ſenſible degree of magnetiſm from the action of the earth, or of any other weak magnet, the operator muſt begin with

with giving magnetiſm to ſeveral ſmall and ſoft ſteel bars, impregnating one at a time by means of the weak magnet, or, if he have no magnet, by means of one or more iron rods properly ſituated, which in that caſe are real, though weak magnets. Then, by joining in a proper manner the ſmall ſteel bars already made magnetic, he may communicate a ſtronger power to larger and harder ſteel bars; which will be capable of impregnating bars ſtill larger; and ſo on.

CHAPTER VIII.

Promiſcuous obſervations.

THE directive power of a magnet is extended to a greater diſtance than its attractive power; for inſtance, if a magnet be freely ſuſpended, another magnet, properly ſituated within a certain diſtance of the former, will turn it out of its wonted direction; yet the degree of attraction exerted by those magnets against each other, is not sensible at that distance; which may be easily tried, by fixing one of the magnets to the scale of a balance. The reason of this property is, that the directive power depends both upon the attraction of the poles of different names, and on the repulsion of those of the same name; whereas the attraction takes place only between poles of different names.—In order to render this explanation more intelligible, imagine that a magnetic needle is freely suspended, and is placed within the influence or sphere of action of a magnet. In this disposition, suppose that the north pole of the magnet attracts the south pole of the magnetic needle with a force equal to ten grains; and, as the attraction between poles of different names is nearly equal to the repulsion between poles of the same name, it follows, that the same north pole of the magnet repels the north pole of the magnetic needle with a force equal to ten

grains:

grains: but thoſe two forces both concur in altering the direction of the needle; therefore, the endeavour of the magnet, to turn the needle's direction, is equal to 20 grains; whereas the attraction, or the force by which the needle is drawn towards the magnet, is only equal to the difference between the two above-mentioned oppoſite forces, which difference ariſes from the pole of the magnet being nearer to one than to the other of the poles of the needle.—The ſame reaſoning may be applied to the action between the ſouth pole of the magnet and the ſuſpended needle.

It has been aſſerted by various authors, that if a ſhort bar of ſoft ſteel be repeatedly ſtroked from end to end, in any ſituation, by a ſufficiently long iron bar, likewiſe kept in any ſituation, the ſteel bar will thereby acquire a conſiderable degree of magnetiſm: from which it might perhaps be inferred, that there is no neceſſity of deriving the origin of magnetiſm from the earth. But an accurate inveſtigation of this pretended fact has ſhewn, that the ſteel bar will not acquire magnetiſm in every ſituation. Indeed, as the bar of iron is rendered more or leſs magnetic by the earth in every ſituation, except that which is perpendicular to the magnetical line; in a random way of making the experiment, it is almoſt impoſſible to keep the bar ſo near that direction as to acquire no magnetiſm at all from the earth; but if, in rubbing the ſteel bar, the iron one be kept in a ſituation nearly perpendicular to that of the magnetical line, then the ſteel will acquire no magnetiſm at all. Beſides, when the iron bar is kept in any ſituation, the degree of magnetiſm which it communicates to the bar is greater or leſs in proportion as the direction of the bar is nearer to or farther from that of the magnetical line; which proves, beyond a doubt, that the communicated magnetiſm is originally derived from the earth.

Thus far, relating to the laws of magnetiſm, ſeems ſufficient to be inſerted in this Part of the preſent work; and though there are ſeveral other particulars neceſſary to be known, yet, as they either relate to the

the practical part, or cannot be eaſily understood without the deſcription of other experiments, ſo they will be inſerted in other places, which are more adapted to their reception. I ſhall, therefore, conclude this Part with removing ſome wrong notions relating to magnetiſm, which have been introduced by ignorance and impoſition.

The impoſtors, who are always ready to ſeize every opportunity of defrauding the reſt of mankind, and the ignorant, who are always fond of myſteries, have, from time immemorial, attributed ſeveral extraordinary properties to the magnet, which are not only repugnant to reaſon, but are actually contradicted by all the experiments which have been made, and may be repeated by intelligent and impartial perſons.

It was formerly believed, that there exiſted ſeveral ſorts of magnets, ſome of which attracted gold, others attracted fleſh, &c.; but even very lately it was believed, by ignorant people, that there was a white loadſtone, which had the property of attracting fleſh: the origin of which error is, that there are ſeveral minerals of an earthy kind, moſtly argillaceous, which abſorb moiſture very faſt; in conſequence of which, if they be put upon the lips, they will adhere to it with ſome degree of force.

A great deal of confuſion in the ſcience of magnetiſm has been alſo occaſioned by the application of the word *magnetiſm* to other things, which had nothing to do with it. The chymical affinity between metals, has been called the magnetiſm of metals, by ſome old authors. The vibration occaſioned by the ſound of muſical ſtrings or pipes, upon others which were tuned in concord to them, has been alſo called the magnetiſm of muſic. We hear likewiſe of the magnetiſm of aſtronomy, the magnetiſm of water, &c.

But the greateſt abſurdities relating to the magnet are, its pretended medicinal properties. As late as the beginning of the laſt century, it was pretty commonly believed, that a plaiſter made with powdered loadſtone, when applied to wounds, would

extract

extract iron, or even a knife, from the human body *.—It was ſaid, that the chymiſts could extract an oil of wonderful efficacy from the magnet, beſides ſeveral other preparations. Even at preſent it is not unuſual to find people who believe, that the application of the magnet cures the tooth-ach, eaſes the pains of parturient women, diſperſes white ſwellings, &c.; and, on the contrary, that the wounds made with a knife, or other ſteel inſtrument, which has been previouſly rubbed with a magnet, are mortal.

Without detaining the reader any longer with the narration of more abſurdities, I ſhall only obſerve, that authentic facts prove none of thoſe pretended medicinal or poiſonous qualities in the magnet; and, as magnetiſm does not affect the ſmell, the taſte, or any other ſenſe of the body, it is improbable, to the greateſt degree, that it ſhould have any effect upon animal

* Kircher, who was himſelf of the contrary opinion, relates ſeveral ſuch ſtories. See his work *de arte magnetica*, lib. iii. chap. ii.

bodies. For though there are particles of iron in almoſt every part of an animal body, yet thoſe particles are ſo ſubdivided, calcined, and bear ſo ſmall a proportion to the other elements, that, in a natural ſtate, the magnet has no action on them.

PART II.

THEORY OF MAGNETISM.

THE attraction of the magnet, and very likely moſt of its other principal properties, have been noticed and admired from time immemorial; but the cauſe of thoſe ſurpriſing properties has eluded the moſt accurate reſearches of very able philoſophers. Various theories have been framed for their explanation, and many conjectures have been derived from other powers of nature, which were in ſome meaſure analogous to magnetiſm; but there is a wide difference between matter of fact and the offspring of the imagination. The former is inveſtigated and acquired with labour, and rewards the induſtry of the ſearcher; the latter often ſhews the weakneſs

weakneſs of human underſtanding, and miſleads the blind follower.

Neverthelefs, the framing of hypotheſes in explanation of natural phenomena, has been of ſome uſe in philoſophy, ſince they have at leaſt promoted the experimental enquiry, either for their ſupport or for their deſtruction; the diſtinguiſhing characteriſtics between a falſe hypotheſis, and a true, or very probable one, being, that by farther and farther examination, the ſufficiency of the latter, in explaining the natural appearances, becomes conſtantly more evident, whereas the abſurdity of the former is rendered more manifeſt. It is therefore uſeful, after having aſcertained a number of facts or laws of nature, to attempt a theory for their explanation, eſpecially becauſe, when ſuch theory, *viz.* the real cauſe, is once eſtabliſhed, the application of its effects becomes more eaſy and general. But every enquirer into the operations of nature ought to be ſeriouſly warned againſt becoming too fond of any hypotheſis, even when it ſeems to have the greateſt degree of probability.

In

In conformity to thoſe obſervations, the reader muſt not expect to find, in this Part of the preſent work, a particular account of all, or even of the principal hypotheſes that have been publiſhed at different times by diver sauthors. I ſhall only mention, in brief, what ſeems to be more probable, or what may lead to a farther inveſtigation of the ſubject; and muſt then refer thoſe, who are deſirous of examining other hypotheſes, to the various books written on magnetiſm.

CHAPTER I.

Of the magnetiſm of the earth.

THE hypotheſis of the earth's being a great magnet, from which the magnetiſm of the uſual magnets, the direction of the magnetic-needle, &c. muſt be derived, is evinced by ſo many obſervations, that there can hardly be a philoſopher ſceptic enough to doubt of its truth. The principal reaſons which prove it, almoſt to a demonſtration, are, firſt, that almoſt all the phenomena which may be exhibited with a uſual magnet, may be alſo exhibited with the earth, as far as it may be tried; and, ſecondly, that vaſt maſſes of iron, or ferruginous ſubſtance, actually magnetic, are dug out of the earth almoſt in every part of it.

The phenomena of the compaſs, and of the dipping-needle, in different parts of the world, and the magnetiſm naturally acquired by ſoft iron when properly ſituated, are exactly imitated by a common magnet or a terrella; but the only phenomenon, which has not been obſerved with reſpect to the earth, and which is the principal property of the uſual magnets, is the attraction of a piece of iron, or other ferruginous ſubſtance. For inſtance, if a piece of iron be preſented to either of the poles of a common magnet, it will be attracted powerfully by it; but if it be preſented to the middle of the magnet, the attraction will be found to be hardly perceivable, or at

leaſt

leaſt incomparably weaker than at the poles; in conformity to which, it might be expected, that a piece of iron ſhould be attracted more powerfully downwards when near the poles of the earth than when near the equator, which attraction, being combined with the attraction of gravitation, ought to be known by the difference of the weights of the ſame piece of iron, when weighed near the poles, and when weighed near the equator; for, if the magnetic attraction of the earth upon it be at all ſenſible, it ought to weigh more in the former caſe than in the latter. But this difference of weights has not yet been aſcertained; however, if it were to be tried with all the accuracy neceſſary for ſo nice an experiment, I am inclined to think that it would be found to anſwer, *viz.* that the ſame piece of iron would be found to weigh ſomewhat more, in places nearer to the poles, than it does nearer to the equator; but even, in caſe no ſuch difference of weights were obſerved, it would be improper to infer that the earth does not exert any magnetic attraction towards the iron on its

ſurface,

ſurface, and that this attraction is not ſtronger near the poles than near the equator; becauſe, firſt, the magnetiſm of the earth being very weak, the difference of the attraction in different places muſt be likewiſe very ſmall, notwithſtanding the directive power is conſiderably ſtrong; for, as was explained in the preceding Part, the latter of thoſe powers extends to a much greater diſtance than the former. And, ſecondly, it muſt be conſidered, that the equatorial diameter of the earth is longer than its polar diameter, and that the attraction of gravitation, or the weight of bodies, decreaſes in proportion to the ſquares of the diſtances from the centre of the earth; in conſequence of which, if we abſtract the magnetic attraction, and conſider only the attraction of gravitation, it will appear, that the piece of iron muſt weigh more when weighed near the poles than when weighed near the equator; namely, becauſe, when near the poles, it ſtands actually nearer the centre of the earth than when near the equator.

If the magnetic needle pointed always due north

north and ſouth, or always within a certain diſtance of thoſe points, it would ſhow that the earth has two fixed magnetic poles, either coinciding with its aſtronomical poles, or at ſome diſtance from the ſame; but the continual variation of the magnetic needle ſhows, that thoſe magnetic poles of the earth move with reſpect to the ſurface of the earth, and, on this account, many ſuppoſitions have been offered to the public by divers ingenious perſons. It was imagined, that there was a large magnet incloſed within the body of the earth, which being not fixed to the external part, moved with reſpect to it, and, conſequently, occaſioned the variation of the needle; but in this caſe the variation ought to be regular, *viz.* it ought to move in all parts of the world, ſo as to anſwer to the two points of the large internal magnet; which, however, is not the caſe.

In order to ſupply the deficiency of this hypotheſis, it was farther imagined, that there were four magnetic poles within in the earth, which were moveable with refpect to each other, and that, therefore, the variation of the needle ought to be derived from all their actions conjointly; which would render the theory of the variation exceedingly intricate: but, notwithftanding this difficulty, a regularity, within certain laws and limits, ought to be ftill obfervable refpecting the variation; but no fuch regularity has been yet proved. In fhort, without detaining my reader any longer on this point, it will fuffice to fay, that no theory yet offered has been fufficient to foretel, with certainty, the variation of the needle for any future period of time, or for any place diftant from thofe in which obfervations have been frequently made.

It is now proper to give a fhort account of the principal variation charts that have been publifhed, *viz.* that of Dr. Edmund Halley, which was formed upon the obfervations made in the beginning of the prefent century; and the other chart, formed by Meffrs. Mountaine and Dodfon, upon

upon the obſervations made in the courſe of the year 1756 *.

The method uſed in the conſtruction of thoſe charts is, to mark down with dots, on a general map of the world, all the places in which the declination of the magnetic needle has been aſcertained, and then to draw lines through thoſe points, obſerving to let the ſame line, whether crooked or ſtraight, paſs through all thoſe points or places in which the declination of the needle is the ſame; thus, for inſtance, a line is drawn through all thoſe places in which the declination is 10 degrees weſt; another line is drawn through thoſe places where the declination is of another number of degrees, and ſo on; which are called *lines* of *declination* †. It is evident, that

* See the Phil. Tranſ. for the year 1757.

† Thoſe lines which paſs through the points where the north end of the needle declines to the eaſt of the meridian of the place, are called *lines* of *eaſt declination*; thoſe which paſs through the points where the north extremity of the needle declines to the weſt of the meridian, are called lines of *weſt declination*; and laſtly, thoſe lines which paſs through thoſe points where the needle coincides with the meridian, are called lines of *no declination*.

in ſuch charts the variation of the magnetic needle, in many places, muſt be merely a matter of conjecture or gueſs; and, though there is a kind of tendency of the lines of declination towards certain principal points, yet that ſeeming regularity is ſubject to many exceptions, which render thoſe declination charts of no great uſe.

In Dr. Halley's chart, the line of no declination croſſes the meridian of London at about the 55th degree of ſouth latitude, it then proceeds in an arched manner towards the weſt of the ſaid meridian, and increaſing its curvature as it advances up into the northern hemiſphere, terminates at Charles Town on the coaſt of North America.

In the other of the above-mentioned charts, the line of no declination paſſes more weſtward of the meridian of London, advances with a more irregular curvature, and terminates on the coaſt of Florida, at about the 30th degree of north latitude.

The lines of eaſt variation are on the concave ſide of the above-mentioned line, and

and the lines of weſt declination are on its convex ſide, advancing for a conſiderable extent with nearly the ſame curvature as the line of no declination : but, as you come on this ſide of the tropic of Cancer, the lines of weſt declination, in both charts, are almoſt perpendicular to the meridians.

In the Indian ſea, and in the ſea between the iſland of Madagaſcar and the ſouth pole, the declination lines are conſiderably more irregular, ſo as to render it impoſſible to convey any diſtinct idea of the ſame by writing: the reader, therefore, who is willing to examine this ſubject much farther, may conſult the ſaid charts themſelves.

There is one thing remarkable to be obſerved in thoſe charts, which is, that the declination lines do never croſs each other.

In my opinion, it ſeems that the magnetiſm of the earth ariſes from the magnetiſm of all the magnetic ſubſtances therein contained, and intermixed with other bodies; that the magnetic poles of the earth may be conſidered as the centres of the polarities of all the particular aggregates of the magnetic ſubſtances; and that thoſe principal poles muſt change place, relatively to the ſurface of the earth, according as the particular aggregates of magnetic ſubſtances within the earth are in ſome manner or other altered, ſo as to have their power diminiſhed, increaſed, approached, or removed from the principal poles. But, as thoſe thoughts are moſtly depending on ſome experiments of mine, I ſhall defer ſaying any thing farther about them till after the account of thoſe experiments; which will be found in the fourth Part.

Though no regularity has been eſtabliſhed with reſpect to the variation of the needle, yet, as the various ſituation of the magnetic poles within the earth occaſions a great variety of appearances, and as the right underſtanding of thoſe varieties may be of great uſe to thoſe who wiſh to inveſtigate this intricate ſubject, the developement of which would be of vaſt uſe to mankind; I ſhall now ſubjoin the principal caſes, which ſeem poſſible,

ſible, relating to the poſition of the magnetic poles; imagining, as is moſt natural to ſuppoſe, that they are two, and that they lie on the ſurface of the earth. Theſe caſes are no more than four, *viz**.

CASE I. If the magnetic poles of the earth had coincided with the true poles thereof, there could have been no declination or variation of the mariner's compaſs in any part of the world (that is, if the earth be uniformly magnetical); for in that caſe the needle, in pointing to the magnetic poles, would always have pointed to the true poles alſo; this needle would therefore be neceſſarily directed along the courſe of the meridian, or, in other words, it would have no declination or variation either to the eaſt or weſt thereof.

CASE II. If the magnetic poles were ſituated in the ſame meridian, and in oppoſite parallels; upon that meridian

* Theſe four caſes were drawn up by Dr. Lorimer, a gentleman of great knowledge in magnetics.

which paſſes through the magnetic and true poles, from the one of the magnetic poles to the other, and upon the oppoſite meridian all along, there could be no declination, for the reaſon mentioned in the former Caſe. Likewiſe, upon the equator there would be no declination; for though if one of the magnetic poles were only to act upon the needle, in paſſing along the equator to the diſtance of 90 degrees in longitude eaſt or weſt, the declination would increaſe, ſo that at 90° diſtance from the line of no declination it would be equal to the angle contained between the magnetic and true poles; yet, as the other magnetic pole, in this caſe, is always within the ſame diſtance of the needle, it will act upon the oppoſite end of it with equal force, and conſequently will keep it parallel to itſelf all round the equator. But in going from the equator north or ſouth, the declination would increaſe ſo as to be 180° on the little arches or ſpaces of the meridian contained between the true and the magnetic poles, which is the greateſt poſſible

ſible declination in all caſes whatſoever. It muſt be farther obſerved on this caſe, that the lines of no declination, including thoſe arches of 180°, form two great circles of the globe along the meridian and the equator, croſſing one another at right angles, and dividing the ſurface of this globe into four quarters, two in each hemiſphere, the one hemiſphere having weſt declination in the north and eaſt declination in the ſouth half thereof, and in the oppoſite hemiſphere it would be juſt the reverſe; ſo that each of the arches or ſemi-circles of no declination would have eaſt declination on the one ſide of them, and weſt declination on the other. The ſmall arches of 180° declination, which are between the true and magnetic poles, may be reckoned in all caſes as a part of the lines of no declination; for there indeed the needle conforms itſelf to the meridian as well as in the other parts of the circle, though its ends are reverſed. In ſhort, as all the lines of declination do coincide and terminate in the magnetic and true poles, ſo theſe arches of 180° are a kind of limit, making with each of thoſe lines, as in the preſent caſe, a curve line or figure returning into itſelf; which figures, from 180° between the poles, to 0° declination upon the equator, do each of them include a ſpace larger than the other, till at laſt they fill up the whole quarter of the ſurface of the globe, and conform themſelves, as nearly as poſſible, to the ſhape and figure thereof.

As a variety of this caſe, it may be added, that the magnetic poles may be ſituated in the ſame meridian, but in parallels which are not oppoſite. In that caſe the only alteration which could happen is, that in the hemiſphere in which the magnetic and true poles are neareſt to each other, the figures formed by the lines of declination become ſmaller, and the correſponding figures in the oppoſite hemiſphere, larger. The line of no declination, which, in this caſe, repreſents the equator, would alſo be proportionably nearer to thoſe poles which are neareſt to one another.

CASE III. If the magnetic poles were ſituated in oppoſite meridians, and in oppoſite parallels; upon thoſe meridians which paſs through the magnetic and true poles there could be no declination, for the reaſons mentioned in the former Caſes. But upon the equator, eaſtward or weſtward, to the diſtance of 90° in longitude, the declination would actually increaſe, ſo as there to be equal to the angle which meaſures the diſtance between the true and the magnetic poles; and from thence it would, in the ſame manner, decreaſe for the other 90° to the oppoſite meridian. The declination lines of 10°, 20°, &c. as far as the greateſt declination upon the equator, in this caſe become arches or curves, which conform themſelves, as nearly as may be, to the courſe and direction of the lines of no declination, and are called lines of the firſt order. But the lines of the greateſt equatorial declination croſs one another at the diſtance of 90° in longitude from the meridian or circle of no declination, ſomething in form like the letter X, or like two gothic arches joined at the vertex.

vertex. They are called lines of the ſecond order, and may very properly be conſidered as the boundary between the lines of the firſt and third order, as the lines of no declination are always boundaries between the lines of eaſt and weſt declination. In this caſe, thoſe lines of no declination, including the arches of 180°, form only one great circle along the meridian, dividing the ſurface of this globe into two hemiſpheres, in the one of which there is eaſt declination, and in the other weſt declination.

From the greateſt equatorial declination to the arches of 180°, the declination lines of the third order are curves returning into themſelves, and in ſhape nearly reſembling parabolas erected upon thoſe arches of 180°.

As a variety of this caſe, it may be added, that if the magnetic poles were ſituated in oppoſite meridians, but in parallels which are not oppoſite, then, in that hemiſphere in which the true and the magnetic poles approached neareſt to one another, the figure formed by the lines of declination would

would be ſmaller, and in the oppoſite hemiſphere the correſponding figures would be larger in proportion.

CASE IV. This caſe is a very extenſive one, *viz.* when the magnetic poles are ſituated neither in the ſame nor in oppoſite meridians; and this ſeems to have been the real poſition of thoſe poles ever ſince any obſervations of the declination of the magnetic-needle have been made.

In this Caſe, then, the lines of no declination cannot be either in the direction of a meridian or along the equator, as in the former Caſe, but in a kind of curves, which are variouſly inclined to both; and they divide the ſurface of the globe into two parts, but theſe parts are not hemiſpheres, as in the laſt Caſe, for they may be of a very different extent. If the magnetic poles be ſituated in meridians nearly oppoſite, the curvature of thoſe lines will not be ſo great, that is, they become more like to Caſe III. But as the magnetic poles approach nearer to the ſame meridian, the curvature of the lines of no declination becomes greater, till they almoſt touch one another, ſomething

thing in form like the figure of the number 8, and at laſt they complete the two great circles, as in Caſe II. The lines of the ſecond order, which correſpond to the greateſt equatorial declination, if the magnetic poles be ſituated in meridians nearly oppoſite, have a declination nearly equal to the angle formed between the magnetic and true poles, as in Caſe III; but as the magnetic poles approach towards the ſame meridian, this declination decreaſes, till at laſt it entirely vaniſhes, as in Caſe II. The other declination lines in this Caſe are ſo ſimilar to the former, that they require only to be referred to it. Laſtly, it muſt be obſerved, that, whether the magnetic poles be ſituated in oppoſite parallels or not, makes as little difference in this as in the former Caſe.

Hitherto the magnetic poles have been conſidered to lie on the ſurface of the globe; but if we attentively conſider the ſituation which they may more likely have, it will appear, that in all probability they are not ſituated near the ſurface of this globe, but at ſome depth below it; at leaſt

this

this muſt be the caſe with the ſouth pole; for, ſince the water of the ſea is incapable of magnetiſm, and the ſouthern hemiſphere, eſpecially about the ſouth pole, contains a vaſt deal more ſea than land; it is plain that the ſouth magnetic pole muſt be ſituated at leaſt near the bottom of the ſea; in conſequence of which, the variation of the needle in that hemiſphere muſt be different from what it would be if the magnetic pole were ſituated on the ſurface of the terraqueous globe. The ſame may be obſerved with reſpect to the ſituation of the north magnetic pole. Beſides this, we muſt alſo conſider the irregularities ariſing from the unequal and irregular ſituation of land and ſea; it being natural to conceive, that large tracts of land on one ſide of the magnetic needle, will draw it away from the real meridian, whereas a large ocean can produce no ſuch effect.—This, however, is ſubject to a great deal of variety, ariſing from the nature of the land, the depth of the ſea, the nature of the ground at the bottom of the ſea, &c. It appears, therefore, that a great many cauſes combine to act upon the magnetic needle, occaſioning it to decline from the true meridian, and that it is almoſt impoſſible to form a uſeful theory upon it. However, as this is a ſubject of vaſt importance to mankind, principally for the improvement of navigation, I am far from meaning to diſcourage its being properly examined; but only think it neceſſary to put all the apparent difficulties before the eye of the reſolute adventurer in this field of intricate and difficult inveſtigation.

CHAPTER II.

Analogy between magnetiſm and electricity.

WHEN the knowledge of mankind, relative to electricity, comprehended only the property of amber, and of a few other bodies, which, after being rubbed, attract ſmall bodies, this attraction was hardly diſtinguiſhed from that of magnetiſm;

netiſm; and in fact old books often deſcribe the above-mentioned property of amber, under the appellation of the magnetiſm of amber. The modern ſcientific improvements, eſpecially thoſe made within this century, have ſhewn, that electricity and magnetiſm are two different powers of nature, which are quite diſtinct from each other; but, at the ſame time, it muſt be confeſſed, that there is a ſurpriſing analogy between them; and, as it is by following the ſimilarity between two ſubjects, that diſcoveries are often made in philoſophy, it ſeems neceſſary in this place to point out the particulars in which magnetiſm and electricity reſemble each other, and likewiſe thoſe in which they more eſſentially differ.

That power which philoſophers call electricity, is of two ſorts, namely, the *poſitive* and the *negative electricity*. It is an invariable law in electricity, that bodies poſſeſſed of the ſame ſort of electricity repel each other, whereas thoſe which are poſſeſſed of different electricities attract each other.

Thus

Thus, in magnetics, there is a north and a ſouth pole; thoſe parts of magnetic bodies which are poſſeſſed of the ſame polarity repel each other; but thoſe which are poſſeſſed of different polarities attract each other.

In electricity, whenever a body in a natural ſtate is brought within the ſphere of action of an electrified body, it becomes itſelf electrified, and poſſeſſed of the contrary electricity, after which an attraction takes place; ſo that in truth there is no electric attraction but between bodies poſſeſſed of different electricities: for inſtance, if a piece of paper be brought ſufficiently near a glaſs tube, electrified poſitively, the paper will acquire the negative electricity, and will then be attracted by the tube; but if the paper be ſo circumſtanced as not to have it in its power to acquire that negative electricity, then no attraction will take place.

Thus a ferruginous ſubſtance, which is brought within the ſphere of action of a magnet, cannot be attracted by either pole of the magnet, unleſs it acquires firſt a contrary polarity.

One ſort of electricity cannot be produced by itſelf, but is always accompanied by the other; thus, if a glaſs tube be electrified poſitively on its external ſurface, a negative electricity muſt exiſt, either on its internal ſurface, or on the air contiguous to the tube.

In the ſame manner, the two magnetic poles are always together; nor was there a piece of ferruginous ſubſtance ever produced, which had one polarity and not the other.

The electric virtue can be retained and confined by certain bodies, like glaſs, amber, reſins, and others, called *electrics*; but it eaſily pervades other ſubſtances, called *conductors, or non-electrics.*

The magnetic virtue is retained by ferruginous ſubſtances, eſpecially thoſe of a hard nature, like hard ſteel, and the magnet: but it pervades eaſily, and without the leaſt perceivable impediment, all other ſorts of ſubſtances.

On the other hand, the magnetic power differs from the electric, firſt, in its not affecting our ſenſes with any light, ſmell, taſte, or noiſe; whereas the electricſpark, ſhock, ſmell, and taſte, are known to every perſon converſant in electric experiments. Secondly; magnetiſm attracts only iron, or thoſe bodies which contain that metal in ſome ſtate or other, whereas, the electric power attracts bodies of every ſort. Thirdly; the electric virtue reſides on the ſurface of electrified bodies; whereas the magnetic is quite internal. Laſtly; a magnet loſes nothing of its power by magnetizing other ſubſtances; but an electrified body loſes part of its electricity by electrifying other ſubſtances. Here, however, muſt be remarked, that an electrified body loſes part of its power, when in electrifying another body touches it, and that body acquires then the ſame ſort of electricity; but when that other body is electrified by being only brought within the ſphere of action of the former, in which caſe, it acquires the contrary electricity, then the former body loſes nothing of its power; for inſtance, ſuppoſe that a body A poſſeſſes a certain quantity of poſitive electricity, and that another body B, in a natural ſtate, be gradually brought near A; then the body B, when it comes within a certain diſtance of the

electrified

electrified body A, acquires a negative electricity, which negative electricity takes away nothing of the power of the body A; but if the two bodies come very near, so as to touch, or as that the electricity of the body A may leap from it to the other, then the body B will become electrified positively, and A loses thereby part of its power.—Indeed, if it be duly considered, this last case does not seem ever to take place with magnetism; for bodies appear to be rendered magnetic merely by the action of their spheres of activity, or by that power which enables magnets to act at some distance from their own bodies; and therefore we may justly say, that electrified and magnetic bodies agree in this, *viz.* that they lose nothing of their power, when other bodies are electrified or rendered magnetic in virtue of their spheres of activity.

Several other points of analogy, or of difference, between magnetism and electricity, will, perhaps, occur to those persons who examine both subjects; but if they be attentively considered, I think they will be found to be comprehended in thoſe which have been enumerated above.

CHAPTER III.

Of the hypotheſis of the magnetic fluid.

THE great deſideratum in magnetics is, to know the cauſe which, in a magnet, of whatever ſort it may be, produces the attraction, repulſion, and other magnetic phenomena. It is really ſurpriſing to obſerve, that, by the mere contact, or even by the vicinity of a magnet, a piece of ſteel, &c. acquires ſeveral extraordinary properties, which it afterwards retains obſtinately, and that without having its weight, ſhape, colour, or hardneſs altered in any ſenſible degree, and without the appearance of any ſubſtance being communicated to it by the magnet, which ſubſtance is either perceived by our ſenſes, or at all hindered by the interpoſition of any known body.

Human imagination, ever ready to ſupply the deficiency of real knowledge, has

has offered abundance of hypotheſes; but their inſufficiency to explain the various phenomena of magnetiſm, renders them moſtly improbable, and often evidently abſurd. Some have imagined, that the pores of ferruginous bodies are full of valves, which permit the paſſage of the magnetic fluid in one direction, but prevent its return backwards. Others have imagined, that there is a perpetual circulation of a certain fluid from one pole to the other of every magnet; and of courſe, that on the earth, which is a great magnet, there is likewiſe a perpetual circulation of this magnetic fluid from the regions adjacent to one pole to thoſe adjacent to the other.

Without detaining my reader with the particular account, and confutation of thoſe and other hypotheſes, I ſhall only take notice of the hypotheſis propoſed by the ingenious Aepinus, which, though labouring under ſeveral objections, ſeems however to be the moſt plauſible*.

* Tentamen theoriæ electricitatis et magnetiſmi, auctore F. V. T. Aepino, chap. i. § iii.

From the analogy of the eſtabliſhed or more common hypotheſis of electricity, which goes under the name of Dr. Franklin's, Mr. Aepinus is led to imagine, that there exiſts a fluid productive of all the magnetic phenomena, and conſequently to be called *the magnetic fluid*; that this fluid is ſo very ſubtile as to penetrate the pores of all bodies; and that it is of an elaſtic nature, *viz.* that its particles are repulſive of each other.

He farther ſuppoſes, that there is a mutual attraction between the magnetic fluid and iron, or other ferruginous bodies; but that all other ſubſtances have no action with this fluid; they neither attracting nor repelling each other.

He then obſerves, that there is a great deal of reſemblance between ferruginous bodies and electrics, or non-conductors of electricity; for the magnetic fluid paſſes with difficulty through the pores of the former, as well as the electric fluid paſſes with difficulty through the pores of the latter. However, there is not a body that has any action on the magnetic fluid, and is, at the ſame time, analogous to non-electrics; for inſtance, there is no body, the particles of which attract the magnetic fluid: and yet this fluid can pervade its pores without any obſtruction. In iron, indeed, a kind of gradation of this ſort ſeems to take place; for the ſofter the iron is, the more freely does the magnetic fluid pervade its pores, and, on the contrary, the harder it is, the greater oppoſition it offers to the free paſſage of that fluid; ſo that the iron, when ſoft, ſeems to be more analogous to non-electrics than when hard.

According to this hypotheſis, iron, and all ferruginous ſubſtances, contain a quantity of magnetic fluid, which is equably diſperſed through their ſubſtance, when thoſe bodies are not magnetic; in which ſtate they ſhew no attraction nor repulſion againſt each other, becauſe the repulſion between the particles of the magnetic fluid is balanced by the attraction between the matter of thoſe bodies and the ſaid fluid, in which caſe thoſe bodies are ſaid to be in a natural ſtate: but when, in a ferruginous body, the quantity of magnetic fluid belonging to it is driven to one end, then the body becomes magnetic, one extremity of it being now overcharged with magnetic fluid, and the other extremity, undercharged. Bodies thus conſtituted, *viz.* rendered magnetic, exert a repulſion between their overcharged extremities, in virtue of the repulſion between the particles of that exceſs of magnetic fluid; which is more than overbalanced by the attraction of their matter. There is an attraction exerted between the overcharged extremity of one magnetic body, and the undercharged extremity of the other, on account of the attraction between that fluid and the matter of the body; but to explain the repulſion, which takes place between their undercharged extremities, we muſt either imagine that the matter of ferruginous bodies, when deprived of its magnetic fluid, muſt be repulſive of its own particles, or that the undercharged extremities appear to repel each other only becauſe either of them attracts the oppoſite overcharged extremities;

mities; both which ſuppoſitions are embarraſſed with difficulties.

A ferruginous body, therefore, is rendered magnetic by having the equable diffuſion of magnetic fluid throughout its ſubſtance diſturbed, ſo as to have an overplus of it in one or more parts, and a deficiency of it in one or more other parts; and it remains magnetic as long as its impermeability prevents the reſtoration of the balance between the overcharged and undercharged parts. Moreover, the piece of iron is rendered magnetic by the vicinity of a magnet, becauſe, when the overcharged part or pole of the magnet is preſented to it, the overplus of magnetic fluid in that pole, repels the magnetic fluid away from the neareſt extremity of the iron, which therefore becomes undercharged, or poſſeſſed of the contrary polarity, to the moſt remote part of the iron; which conſequently becomes overcharged, or poſſeſſed of the ſame polarity as the preſented pole of the magnet. When the piece of iron is rendered magnetic by preſent-

ing

ing to it the undercharged extremity or pole of the magnet, then the part of the iron which is nearest to it, becomes overcharged, &c. because that part of the magnet, being deprived of its magnetic fluid, attracts the magnetic fluid of the iron to that extremity of the iron which lies nearest to itself.

In consequence of which it appears, that, in order to give magnetism to a body, as a piece of steel, the strength of the magnet employed must be such as to overcome the resistance, which the substance of the steel makes against the free passage of the magnetic fluid; hence, a piece of soft steel is rendered magnetic more easily than a hard one; hence, a stronger magnet will render magnetic such ferruginous bodies as other smaller magnets have no power upon.

The action of two magnets upon each other is likewise easily explained by this hypothesis. When two equal magnets oppose their contrary poles to each other, they thereby preserve and strengthen their power; but when the homologous poles of two magnets are placed near, then, if the ſtrength and quality of thoſe magnets be equal, they will only diminiſh each other's magnetic power; but if they be unequal in power or other quality, as the hardneſs, ſhape, &c. then the weakeſt will have its power diminiſhed, deſtroyed, or changed, in proportion to its ſoftneſs, weakneſs of magnetiſm, and other circumſtances, which will eaſily occur to the intelligent reader.

PART

PART III.

PRACTICAL MAGNETISM.

THE object of this Part of the present work is, to deſcribe thoſe experiments which are neceſſary to prove the laws of magnetiſm mentioned in the firſt Part; and alſo, to deſcribe thoſe inſtruments which are neceſſary for the uſes to which magnetiſm is ſubſervient. In this deſcription, both of experiments and of inſtruments, I ſhall principally inſiſt upon thoſe particulars, which, being of a general nature, may ſerve as fixt points to guide the ingenious experimenter in the contrivance of more perfect inſtruments, and in the performance of the neceſſary experiments by the moſt eaſy means, it being

being very well known, that, to be obliged to procure a particular inſtrument for almoſt every experiment, which is moſtly the caſe with beginners, when complicated and formal apparatuſſes are deſcribed, conſiderably retards the propagation of uſeful knowledge.

CHAPTER I.

Deſcription of the magnetical inſtruments.

IF we collect under one point of view the magnetic properties, it will be found that they may be comprehended under two general claſſes, namely, the action of the magnet upon unmagnetic ferruginous bodies, and the action of one magnet upon another. The firſt conſiſts only in communicating the magnetic power; the ſecond comprehends the attraction and repulſion, a conſequence of which is the directive property, *viz.* the compaſs and dipping needle. Therefore, the principal inſtruments

inſtruments in magnetics are, a few magnets or magnetic bars, a magnetic needle for the magnet's horizontal direction, and the dipping needle, to ſhew the inclination.

If one do not want to be very nice and particular, a common horſe-ſhoe artificial magnet, which coſts very little, and a few ſewing-needles, will ſhew ſeveral experiments; but perſons who wiſh to be more exact, and to make improvements in the ſubject, ought to be provided with a good ſet of artificial magnets, which uſually conſiſts of ſix bars, a few ſmall magnetic needles, a pretty large needle in a proper box with a graduated circle, and a dipping needle; to which may be added, ſome pieces of ſteel wire, two or three bars of ſoft iron, and a few other things of no great expence, but very uſeful for various experiments.

In this chapter I ſhall deſcribe only the three principal inſtruments, *viz.* the bars, the needles, and dipping needle, the reſt being mentioned occaſionally in the deſcription of the experiments.

The

The magnetic bars are generally ſix in number, and they ought to be made of the beſt ſteel, and left quite hard; but, however, there is not a characteriſtic yet known, by which the ſteel, capable of acquiring the greateſt magnetic power, may be diſtinguiſhed. It will be proper, therefore, to try the ſteel previouſly to uſing it for the conſtruction of the bars. For which purpoſe, take a piece of it, about three inches long, and about a quarter of an inch in thickneſs (no matter whether round or ſquare), make it red hot, and in that ſtate plunge it in cold water, which hardens it ſo that a file will not touch it. This done, apply two powerful magnetic bars to its extremities; keep them in that ſituation for about a minute, taking care to let the north pole of one of the magnetic bars touch one extremity of the piece of ſteel, and the ſouth pole of the other bar touch the oppoſite extremity of the ſteel: then try whether the piece of ſteel will hold ſuſpended a key or other piece of iron that may be at hand. Thus, by trying ſeveral pieces of ſteel of different ſorts, and by treating them all alike, you will eaſily perceive which is capable of lifting the greateſt weight of iron, and, conſequently, that ſort of ſteel is the fitteſt for the conſtruction of the bars.

The dimenſions of thoſe bars ought to have a certain proportion, otherwiſe they will not be capable of a very great power. The moſt advantageous ſhape is when the length is about ten times the breadth, and about twenty times the thickneſs; ſo that if they be five inches long, which is the moſt uſual length, they ought to be about half an inch broad, and about a quarter of an inch in diameter.—The cylindrical bars are not very conveniently managed.

Some perſons have deſcribed particular methods of hardening ſuch bars, *viz.* by plunging them, when red hot, in different liquors. It has been confidently aſſerted, that to put them, when red-hot, in a mixture of ſcraped horn and common ſalt is very advantageous; but, upon the whole, ſimple cold water ſeems to be equal to any other ſubſtance.

It

It is immaterial whether thoſe bars be poliſhed or not; but it will be better to poliſh them; in that ſtate being leſs apt to contract ruſt. One extremity of each bar is generally marked with a line all round, in order to diſtinguiſh one pole from the other, and the marked end is uſually made the north pole.

To each ſet of bars there always belong two pieces of ſoft iron, called *ſupports*, each of which is equal to the ſize of half one of the bars, ſo that, when placed contiguous to one another in one direction, they may be equal to one of the bars. Theſe pieces of iron are uſeful when ſome other ferruginous bodies are to be rendered magnetic, or when the ſame ſet of bars is to be ſtrengthened in power.

When the magnetic bars are kept together, they muſt be placed alternately with the marked end of one contiguous to the unmarked end of the next; as ſhewn in fig. 4.—The method of rendering thoſe bars magnetic will be found in a ſubſequent chapter.

The conſtruction of the compaſs or magnetic needle has undergone a great variety, and almoſt every conſtruction has ſome peculiar advantages. The ſimpleſt magnetic needle is a common ſewing-needle made magnetic, and either ſuſpended by means of a thread tied to its middle, or by laying it gently on the ſurface of water kept in a veſſel; for if the needle be ſmall, it will ſwim upon the ſurface of the water, notwithſtanding its ſpecific gravity is greater than that of water; there being a kind of repulſion between water and ſteel when clean; or perhaps the air may contribute to it. If any part of the needle happens to get a little below the ſurface of the water, then the needle goes immediately to the bottom. The inconvenience attending the firſt of the above-mentioned ſuſpenſions, is the ſtiffneſs of the thread, even of the fineſt ſort, which prevents the free motion of the needle. The principal inconveniences attending the ſecond are, the needle's generally going towards the ſides of the veſſel, and its going to the bottom on the leaſt agitation; which however may be prevented by a piece of cork.

The

The more general, and by far the beſt ſort of ſuſpenſion for magnetic needles, is to let them reſt horizontally with their middles upon ſharp-pointed wires ſet up perpendicularly in a box or other ſupport. The needle for this purpoſe muſt have a conical cavity in its middle, the apex of which may be above the centre of the needle; ſo that when the needle is laid upon the wire, the point of which muſt be in the apex of the conical cavity, its centre of gravity may be below that point of ſuſpenſion; otherwiſe the needle would fall off very eaſily.

In order to anſwer this purpoſe, the needles are generally pierced quite through with a largiſh hole, a piece of hammered braſs is then rivetted into this hole, and the conical cavity is made into the braſs, ſo that the apex of it may ſtand very little above the upper ſurface of the needle, as at A, fig. 5 of plate I. In this conſtruction, the point of the wire B, the very top of which is often made of hard ſteel, whilſt the lower part is of braſs, bears againſt the braſs, and, notwithſtanding that the braſs be hardened, yet by continual rubbing a ſmall indenture, or irregular hole, &c. is often made therein, which occaſions a conſiderable obſtruction to the free motion of the needle; to obviate which, in the beſt needles a piece of agate is ſet in the upper part of the braſs, and the apex of the conical cavity is made in that hard ſtone, which renders the motion of the needle very free and eaſy. The needles thus conſtructed, are ſaid to be furniſhed with an agate cap, and the beſt compaſſes made for the ſea have this ſort of cap *. Fig. 6. of plate I. ſhews a ſection of this agate cap in the braſs, &c.

As a very little irregularity in the ſhape of a piece of ſteel is often productive of

* The compaſſes for the ſea-ſervice formerly, and ſome even at preſent, are made in the following improper manner:—the braſs cap is faſtened to the middle of a circular card, upon which the various points of the horizon, as the eaſt, weſt, &c. are marked; and on the under part two pieces of magnetic ſteel are ſtuck faſt to it, ſo as to lie parallel, and to ſtand about half an inch diſtant from one another, the pin upon which the whole is ſuſpended paſſing between them.

more

more than two magnetic poles, or an improper ſituation of the two poles, which muſt be always avoided; ſome perſons, having objection to the perforation made through the needles, have thought of other ſuſpenſions, in which the perforation might be avoided; the beſt of which propoſals is ſhewn in fig. 7. of plate I. where the magnetic needle A B is faſtened to a piece of braſs C E D, properly bent: in the middle of it, *viz.* at *g*, there is a ſmall conical cavity, where an agate cap may likewiſe be applied. In order to ſuſpend this needle, a bar F H, fig. 8. is made faſt to the box K L, in the middle of which bar is a pointed pin I, upon which the cavity of the piece of braſs that is faſtened to the needle, reſts; the needle A B moving below the croſs-bar F H, and this croſs-bar paſſing between the needle and the piece of braſs that is faſtened to it, *viz.* through *g* of fig. 7.—It is evident, that the needle, in this conſtruction, cannot turn quite round; conſequently, this ſort of ſuſpenſion is not fit for the uſe of veſſels at ſea.

The Chineſe method of ſuſpending the magnetic needle is exceedingly ingenious. The figures 9 and 10 of plate I. repreſent this needle very nearly of its real ſize, and in two points of view, *viz.* in the former the eye of the obſerver is in the direction of the needle; but in the latter, the eye views the needle ſideway *. I is a braſs cap, very thin and light, and towards the edge of it there are two holes, oppoſite to each other. B B is a very ſlender ſlip of braſs, the upper part of which at A is ſhaped like a ring, through which the needle C D paſſes. The extremities of this ſlip of braſs paſs through the holes in the edge of the cap I, and are faſtened to it by being turned over its edge. The magnetic needle C D, conſiſts of a cylindrical ſteel wire, about an inch long, and not above a fortieth of an inch in diameter; and, in order to diſtinguiſh its north extremity, half of it is painted red, and the other

* Theſe drawings were made from ſome Chineſe compaſſes, brought from China by Dr. James Lind, a phyſician at Windſor. The needles in them are very nearly all of a ſize, *viz.* about an inch long.

half

half is black. All this is ſupported by the pin E, which is faſtened to the bottom of the box, and upon which it moves very nimbly. In this conſtruction, notwithſtanding the needle is above the centre of ſuſpenſion, yet the centre of gravity of all the three pieces that are connected together, is below the point of ſuſpenſion, otherwiſe it could not be ſupported. To prevent the needle falling off, when the compaſs, by being carried about, is turned top-ſide down, there is faſtened to the box a plate of very thin braſs, a ſection of which is ſhewn by F G; it has a hole through the middle, which, being ſmaller than the diameter of the aperture of the braſs cap, prevents its receding too much from the point of the wire E, and alſo prevents its falling ſideway.

From repeated experiments, it appears, that the perforation through the magnetic needle is of no detriment, or at leaſt not ſufficient to occaſion any multiplicity of poles, or to prevent the needle's due direction. Its external ſhape is to be more minded, the irregularities of it being by far more detrimental. The little ſwelling generally made about its middle, in order to give it ſtrength juſt where the perforation otherwiſe weakens it, does no damage, provided it be as repreſented in fig. 11. of plate I. and not made with points, edges, or other irregularities, for the ſake of ornament. The magnetic needles, made for the beſt compaſſes uſed at ſea, are conſiderably broad, and a ſlender braſs ring is faſtened to their extremities, upon which the card or paper, with the points of the horizon marked upon it, is ſtretched. But the great objection againſt broad needles is, that the two poles are frequently not in its axis. It would be therefore more proper to make them rather thick than broad; becauſe, if in this caſe their poles happen to be not in its axis, but one be at D, fig. 12. plate I. whilſt the other is at A, they cannot affect the direction of the needle, being, if not in its axis, at leaſt in the ſame plane with it. The moſt eligible ſhape, therefore, ſeems to be that ſhewn by the figures 11 and 12, which exhibit two views of the ſame magnetic needle.

The length of the needles commonly uſed for the ſea, is between four and ſix inches;

inches; but thoſe which are to be uſed for obſerving the daily variation, called *variation needles*, are made longer, ſome of them having been made of more than two feet in length, in order to render their deviation from the meridian more ſenſible. However, in the preſent improved ſtate of conſtructing philoſophical inſtruments, if the work be properly done, a needle of about eight inches length will ſhew the variation within much leſs than half a minute.

Having thus far deſcribed the different ſorts of ſuſpenſions, I ſhall now enumerate the particulars which muſt be had in view in the conſtruction of magnetic needles; and ſhall then proceed to deſcribe the principal ſorts of magnetic compaſſes.

The magnetic needles ought to be made of that ſort of ſteel which is the moſt ſuſceptible of magnetiſm; and they ought to be quite hard, to retain the magnetic power longer *.

* The more common needles are improperly brought down to a blue temper; for though in that ſtate they acquire the magnetiſm much eaſier, yet they, for the ſame reaſon, loſe it much eaſier.

The

The ſhape ought to be as ſimple as poſſible, or free from projections and other irregularities, made by way of ornaments. In ſhort, they ought to be conſtructed ſo as to have only two magnetic poles, and thoſe in that ſame plane which paſſes through the centre of ſuſpenſion *.

They ſhould alſo be made as light as poſſible, in order to diminiſh the friction on the point of ſuſpenſion; which, even when the needles are furniſhed with agate caps, occaſions ſome obſtruction againſt their motion.

The agate caps muſt alſo be made properly, *viz.* their cavity ought to be perfectly conical; which, after having examined ſeveral of them, I can aſſert to be ſeldom the caſe; and indeed it is very difficult to

* The hardening of a piece of ſteel in general, by the uſual method of plunging it, when red-hot, in cold water, frequently alters the ſhape of it by bending it, eſpecially when the piece of ſteel is of an oblong form; for which reaſon, in forming the magnetic needles, they ought to be left by the file ſomewhat larger than neceſſary; becauſe, after the hardening, they may be brought to the proper ſize and ſhape by grinding on a Turkey-ſtone.

ſhape them properly, on account of the hardneſs of the ſtone.

The magnetic needles, though perfectly balanced before the magnetiſm is communicated to them, will afterwards incline one of their extremities, on account of the dipping property of every magnet; and, in order to make them ſtand horizontally, the other extremity is loaded with a little weight, or the preponderating extremity muſt be made lighter by grinding; the latter of which is a very improper way, becauſe, by altering the inclination, which happens eſpecially when the needle is removed from place to place, its horizontal poſition is ſoon deſtroyed, in which caſe it will be neceſſary to grind one end off again.

For this reaſon it is alſo improper to apply a fixed weight to one end of the needle, which is ſometimes done by piercing a hole through the ſteel, and putting a piece of braſs wire in it, ſo as to project a little on either ſide of the needle. The beſt way, therefore, of adding this weight, is to put a ſliding piece of braſs on the preponderating

derating extremity of the needle; for, by ſliding this piece of braſs nearer to or farther from the centre of the needle, the weight of that extremity is eaſily altered when required.

The principal ſorts of magnetic compaſſes are four, *viz.* the magnetic needle, ſimply ſuſpended in a box; the mariner's compaſs, or that uſed at ſea; the azimuth compaſs, or that which is uſed principally at ſea in order to find the declination of the needle at any place *; and the variation compaſs, which, being fixed in a convenient place on land, ſerves to ſhew the daily variation.

The firſt of thoſe ſpecies requires no farther deſcription, than what may be derived from the preceding pages.

The ſecond, or mariner's compaſs, conſiſts of three parts, *viz.* the box, the card or fly, and the needle; ſee fig. 13. of plate I.

* This is called the *azimuth compaſs*, becauſe it ſerves to find the variation by obſerving the azimuth of a celeſtial object; the azimuth being an arch of the horizon, contained between the north or ſouth and the point where a plane, which paſſes through the zenith and the celeſtial object, cuts the horizon.

The box, which contains the card and needle, is made of a circular form, and either of wood or braſs. It is ſuſpended within a ſquare wooden box, by means of two concentric circles, called *jimbols*, ſo fixed by croſs centres to the two boxes, that the inner one, or compaſs box, ſhall retain an horizontal poſition in all motions of the ſhip, whilſt the outer or ſquare box is faſt with reſpect to the veſſel *. The compaſs box is covered with a pane of glaſs, in order that the motion of the card may not be diſturbed by the wind. Reſpecting the conſtruction of the needle, enough has been ſaid in the preceding pages; there remains only to deſcribe the card or fly. The outer edge of this card is divided into 360 degrees; within the circle of which diviſions it is divided again into 32 equal parts or arches, called the *points of the compaſs*, or *rhumbs*; which rhumbs are ſubdivided into quarters.

* Sometimes the jimbols conſiſt of one circle, the axes of which are ſupported by the ſquare box, whilſt the axes of the compaſs box are juſt acroſs the former.

The

The names of thoſe rhumbs, beginning from the north point, and going all round, are the following: the letters ſtanding N. for north; E. for eaſt; S. for ſouth; and W. for weſt.

N.	S.
N. by E.	S. by W.
N. N. E.	S. S. W.
N. E. by N.	S. W. by S.
N. E.	S. W.
N. E. by E.	S. W. by W.
E. N. E.	W. S. W.
E. by N.	W. by S.
E.	W.
E by S.	W. by N.
E. S. E.	W. N. W.
S. E. by E.	N. W. by W.
S. E.	N. W.
S. E. by S.	N. W. by N.
S. S. E.	N. N. W.
S. by E.	N. by W.

TABLE,

TABLE,

Shewing the angles which every rhumb, and every quarter of a rhumb, makes with the meridian.

North.	North.	South.	South.	Rhumbs.		Deg.	Min.
				0	$\frac{1}{4}$	2.	49.
				0	$\frac{1}{2}$	5.	37$\frac{1}{2}$
				0	$\frac{3}{4}$	8.	26.
N. by E.	N. by W.	S. by E.	S. by W.	1	0	11.	15.
				1	$\frac{1}{4}$	14.	04.
				1	$\frac{1}{2}$	16.	52$\frac{1}{2}$
				1	$\frac{3}{4}$	19.	41.
N. N. E.	N. N. W.	S. S. E.	S. S. W.	2	0	22.	30.
				2	$\frac{1}{4}$	25.	19.
				2	$\frac{1}{2}$	28.	07$\frac{1}{2}$
				2	$\frac{3}{4}$	30.	56.
N.E.byN.	N.W. by N.	SE. by S.	S. W. by S.	3	0	33.	45.
				3	$\frac{1}{4}$	36.	34.
				3	$\frac{1}{2}$	39.	22$\frac{1}{2}$
				3	$\frac{3}{4}$	42.	11.
N. E.	N. W.	S. E.	S. W.	4	0	45.	00.
				4	$\frac{1}{4}$	47.	49.
				4	$\frac{1}{2}$	50.	37$\frac{1}{2}$
				4	$\frac{3}{4}$	53.	26.
N.E.byE.	N.W. by W.	S.E. by E.	S. W. by W,	5	0	56.	15.
				5	$\frac{1}{4}$	59.	04.
				5	$\frac{1}{2}$	61.	52$\frac{1}{2}$
				5	$\frac{3}{4}$	64.	41.
E. N. E.	W. N. W.	E. S. E.	W. S. W.	6	0	67.	30.
				6	$\frac{1}{4}$	70.	19.
				6	$\frac{1}{2}$	73.	07$\frac{1}{2}$
				6	$\frac{3}{4}$	75.	56.
E. by N.	W. by N.	E. by S.	W. by S.	7	0	78.	45.
				7	$\frac{1}{4}$	81.	34.
				7	$\frac{1}{2}$	84.	22$\frac{1}{2}$
				7	$\frac{3}{4}$	87.	11.
Eaſt.	Weſt.	Eaſt.	Weſt.	8	0	90.	00.

Notwithſtanding

Notwithſtanding the contrivance of the jimbols, the irregular motion of the compaſs in a rough ſea is, as yet, a conſiderable imperfection attending the uſe of it in veſſels. This inconvenience has been attempted to be remedied by various means, ſome of which are abſolutely wrong, whilſt others have very little effect. The leaſt ſkilled ſort of ſeamen don't like to have the needle of their compaſs too powerfully magnetic, becauſe, they ſay, then the needle is not ſteady. The fact is, that when the needle is not very ſtrongly magnetic, it follows the irregularity of the ſhip's motion more eaſily, which renders it apparently more ſteady; but it muſt be conſidered, that the very ſame cauſe which makes it follow the irregular motion of the ſhip more eaſily, prevents, in an equal proportion, its placing itſelf in the magnetic meridian; conſequently, this ſort of remedy is a very improper one. With the ſame degree of impropriety, the correction of this obſtruction has been often attempted, by increaſing the friction between the cap of the

the needle and the pointed wire upon which it ſtands ſuſpended.

Sometimes they have ſtuck a few pieces of paper, like wings, on the under ſide of the card, which, by making a reſiſtance againſt the air in the box, prevented the vibrations of the needle. For this purpoſe, it has alſo been propoſed to let the needle move in oil or ſome other liquor, keeping it ſtill ſuſpended upon the pin as uſual, in order to let it move concentric with the box; the oil ſerving only to check its vibrations.

Laſtly; it has been practiſed to ſuſpend the box, which contains the needle, upon a pointed wire inſtead of the jimbols. For which purpoſe, the bottom of the box has been made conical, like the bottoms of common wine bottles; the apex of which cone reſted upon the pointed wire, and the convex ſide of the ſaid apex, or that part of it which came within the box, ſupported the needle: but, upon enquiry, I am told, that at ſea none of thoſe contrivances anſwer better than the compaſs ſupported in jimbols, and conſtructed with the precautions mentioned above.

The azimuth compaſs is nothing more than the forementioned compaſs; to which two ſights are adapted, through which the ſun is to be ſeen, in order to find its azimuth, and from thence aſcertain the declination of the magnetic needle, in the manner hereafter to be ſhewn. This ſort of compaſs is repreſented by fig. 14. The particulars in which it differs from the uſual compaſs are the following: *viz.* the ſights F, G, in one of which G there is an oblong aperture with a perpendicular thread or wire through it; and in the other ſight F there is a narrow ſlit, likewiſe perpendicular; the thread or wire H I, ſtretched from one edge of the box to the other; and laſtly, the ring A B of the jimbols reſts with its pivots on the ſemicircle C D, the foot E of which turns in a ſocket, ſo that, whilſt the box K L M is kept ſteady, the compaſs may be turned round, in order to place the ſights F G in the direction of the ſun. There are on the inſide

inside of the box two lines, which fall perpendicularly along the sides of the box, just from the points where the thread H I touches the edge of the box. These lines serve to shew how many degrees the north or south pole of the needle is distant from the azimuth of the sun; for which reason, the middle of the aperture of the sights F and G, the thread H I, and the said lines, must be exactly in the same vertical plane. The use of the thread, which is often omitted in instruments of this sort, is likewise to shew the degrees between the magnetic meridian and the azimuth, when the eye of the observer stands perpendicularly over it. On the side of the box of this sort of compasses, there is generally a nut or stop, which, when pushed, bears against the card and stops it; which is done in order to read more conveniently the degree of the card which coincides with one of the perpendicular lines on the inside of the box.

The variation compass, being intended to shew the daily variation of the magnetic needle on land, is generally made longer than thoſe uſed at ſea; and, as it is not neceſſary to turn it round, the box, inſtead of being circular, is oblong, ſo that, when the box is kept ſteady, the needle can move itſelf for the ſpace of about 40 or 50 degrees. The divided arches are either within the box, or upon an horizontal frame out of the box; and then the compaſs is faſtened on the index, which moves round the centre of the divided arch or arches, and on the edge of which there is a nonius, neceſſary to ſhew the parts of the degrees. In this laſt conſtruction, the index, which, as has been juſt mentioned, carries the compaſs, muſt be moved ſo as to let its fiducial line coincide with the line which paſſes through the poles and centre of ſuſpenſion of the needle: then the extremity of the index will point out the variation, on the divided arch, in degrees and minutes. But when the divided arches are within the box, then the variation is known by only obſerving the diviſions, which coincide with the axis of the needle.

In

In both conſtructions, it is evident, that the beginning of the diviſions of the divided arch or arches muſt be placed exactly in the meridian of the place, or its deviation from the meridian muſt be accurately known, in order that, in reading the degrees of magnetic variation, a proper allowance may be made.

Thoſe compaſſes are fixed in the plane of the meridian, by looking at a meridian mark made at ſome diſtance, through a teleſcope which is generally affixed to them; or by ſituating them on a meridian line drawn in the place where they are to be fixed. But for the method of finding the true meridian of any place, the reader muſt be referred to aſtronomical books, it being an object foreign from the ſubject of this work.

After what has been ſaid in the preceding pages, it is almoſt ſuperfluous to obſerve, that in the conſtruction as well as in the ſituation of the compaſſes, iron muſt be kept at a diſtance as much as poſſible; making the parts of thoſe inſtruments moſtly of wood, or, where wood cannot be properly employed, on account of the diviſions, ſtrength of the parts, &c. to make uſe of ſuch braſs, as, upon examination, is found not to affect the magnetic needle.

The dipping needle, though of late vaſtly improved, is ſtill far from having attained to any perfection. The general way of conſtructing it is, to paſs an axis quite through the needle; to let the extremities of this axis, like the beam of a pair of ſcales, reſt upon two ſupports, ſo that the needle may move itſelf vertically round that axis; hence, when ſituated in the magnetic meridian, it will place itſelf in the magnetic line, and the degrees of its inclination are ſhewn upon a divided circle, in the centre of which the needle is ſuſpended.—Fig. 15. is a repreſentation of this inſtrument; A B being the needle, the axis of which F E reſts upon the middle of the two lateral bars C D, C D, which are made faſt to the divided circle ~~E F~~ IK. This machine is generally placed upon a ſtand G; but when it is to be uſed at ſea, is ſuſpended by

a ring

a ring H to a proper frame, ſo as to hang perpendicularly. When the inſtrument is furniſhed with a ſtand, a ſpirit level is generally annexed to it, and the ſtand has three ſcrews, by which the inſtrument is properly ſituated, *viz.* ſo as to let the centre of motion of the needle, and the mark of 90° on the lower part of the divided circle, be exactly in the ſame line, perpendicular to the horizon.

The greateſt imperfections of this inſtrument are, the balancing of the needle, and the difficulty of knowing whether the needle, after being made magnetic, is balanced or not; for, though it may have been perfectly balanced before, (which is aſcertained by its remaining in whatever ſituation it may be left) yet afterwards, by the adheſion of moiſture or other extraneous matter, it may eaſily loſe its balance, which cannot be known with certainty after being made magnetic.

The method which ſeems the fitteſt to avoid the error ariſing from the want of balance, is, firſt to obſerve the dip of the needle, then to reverſe its magnetiſm, by the application of magnets, ſo that the end of it which before was elevated above the horizon may now be below it; and laſtly, to obſerve its dip again; for a mean of the two obſervations will be pretty near the truth, though the needle may not be perfectly balanced. But of this more in a ſubſequent chapter.

I ſhall now add the deſcription of an univerſal magnetic needle; *viz.* a magnetic needle which ſhews at the ſame time the horizontal and vertical direction of the magnet, or, more properly ſpeaking, places itſelf in the magnetical line; whereas the dipping needle, deſcribed before, muſt be placed in the magnetic meridian. This univerſal needle was contrived by Dr. Lorimer, and a deſcription thereof publiſhed in the firſt part of the 65th vol. of the Phil. Tranſ.; from whence it is tranſcribed.

"*Deſcription of a new dipping needle, by Dr.* J. Lorimer, *in a letter to Sir* John Pringle, *Bart. P. R. S.*

"Whenever any one meets with a *terrella*, or ſpherical loadſtone, the firſt thing he does is to find out its poles; and, having once discovered them, he knows immediately how any small bit of needle will be affected, if it is placed upon any part of the surface of that *terrella*. The poles are most readily discovered by trying where the filings of iron, or a small bit of needle, will stand erect upon the *terrella*; and this is generally found to be upon two points which are diametrically opposite to one another. But the magnetic poles of the earth seem to be placed obliquely to one another (see the Berlin Memoirs, 1757); though where they are actually situated is hitherto unknown; whether they are upon land or water; or, in either case, whether we can come nigh to them. Yet be these things as they may, it appears evident to me, that accurate observations, made as near to those magnetic poles as possible, with a good dipping needle, is the surest way to complete the magnetic theory of this globe, analogous to the method we pursue in examining the *terrella*. But, as all the dipping needles which I have seen, appeared to me to be

very

very ill calculated, for the ſea ſervice at leaſt, I contrived one upon a different plan, in 1764, and had it executed before I left England, by Mr. Siſſon. I have called it an *univerſal magnetic needle*, or *obſervation compaſs*; becauſe I can by it take the dip and amplitude, and even the azimuth, with only one aſſiſtant to take the altitude for me. The needle is of the ſame ſhape and ſize nearly as thoſe uſed now for the compaſſes of the royal navy, and plays vertically upon its own axis, which has two conical points, ſlightly ſupported in two correſponding ſockets, which are inſerted into the oppoſite ſides of a ſmall upright braſs parallelogram, about one inch and a half broad, and ſix inches high. Into this parallelogram is fixed, at right angles, a ſlender braſs circle, about ſix inches diameter, ſilvered and graduated to every half degree, upon which the needle ſhews the dip, by a *vernier* if you chooſe; and this, for the ſake of diſtinction, I ſhall call the circle of magnetic inclination. This braſs parallelogram, and conſequently the circle of inclination,

inclination, alſo turns horizontally upon two other pivots, the one above, and the other below, with correſponding ſockets in the parallelogram. Theſe pivots are fixed in a vertical braſs circle, of the breadth and thickneſs of two tenths of an inch, and of ſuch a diameter, as to allow the circle of inclination and the parallelogram to move freely round within it. This ſecond circle I ſhall call the *general meridian.* It is not graduated, but has a ſmall braſs weight fixed to the lower part of it, to keep it upright; and the circle itſelf is ſcrewed, at right angles, into another circle, of equal internal diameter, of the ſame thickneſs, and twice the breadth, which is ſilvered, and graduated on the upper ſide to every half degree. It repreſents the horizon as it ſwings freely upon jimbols, and is always nearly parallel to it. The whole is contained in a neat mahogany box, of an octagon figure, with a glaſs plate at top, and one on each ſide, for about two thirds down. That part of the frame which contains the glaſs lifts off occaſionally. The whole box

turns

turns round upon a ſtrong braſs centre, fixed in a double plate of mahogany, glewed together croſs ways, to prevent its warping or ſplitting; and this again is ſupported by three braſs feet, ſuch as are uſed for caſes of table knives; froſted that they may not eaſily ſlip, if the veſſel ſhould have any conſiderable motion. It has another ſquare deal box to lock it up in, to preſerve the glaſs, &c. when it is not wanted for uſe.

"The uſe of this inſtrument is very plain, as the inclination or dip is at any time apparent from inſpection only; and alſo the variation, if the frame is turned round till the great vertical circle lies exactly in the plane of the true meridian: for, the circle of inclination being always in the needle's vertical plane, the edge of it will evidently point out upon the horizon the variation eaſt or weſt. But at ſea, when there is not too much motion, you turn the frame round till the vertical circle is in the plane of the ſun's rays; that is, till the ſhadow of the one ſide of it juſt covers the other, and the edge of the

circle

circle of inclination will then give the magnetic amplitude, if the ſun is riſing or ſetting; but the azimuth at all other times of the day; and, the true amplitude or azimuth being found in the uſual way, the difference is the variation. If the motion is conſiderable, obſerve the extremes of the vibration, and take the mean for your magnetic amplitude or azimuth. When the ſun does not ſhine ſo bright as to give a ſhadow, you can ſet the braſs circle in a line with his body, if he is at all viſible, by your eye. The principal advantage at firſt aimed at in this compaſs was, to contrive a dipping needle, which ſhould be ſufficient for making obſervations at ſea; as thoſe needles, to be of uſe, muſt be placed, by ſome means or other, in ſuch a manner, as that all their vibrations ſhall be made in the true magnetic meridian, north and ſouth, otherwiſe they are good for nothing. For if one of them is placed at right angles, acroſs the magnetic line, it will ſtand perpendicularly up and down, in any part of the world; the leaſt dip, therefore, is always in this magnetic line. But the only method of ſetting a dipping needle at ſea has hitherto been to place it in a line with the common compaſs needle; and this muſt be very inaccurate, if they are at any conſiderable diſtance one from the other; or if they were near, the two needles would influence one another, and neither of them could be true: nay, ſuppoſing them for once to be properly placed in this line, the leaſt motion of the ſhip throws them out again. But this inſtrument has a conſtant power in itſelf, not only of ſetting itſelf in the proper poſition, but alſo of keeping itſelf ſo; or of reſtoring itſelf to the ſame ſituation, if at any time it has loſt it; and it is curious to ſee how, by its double motion, it counteracts, as it were, the rolling motion of the veſſel. I have only one thing farther to obſerve, that, as it is impoſſible for human hands to make any inſtrument mathematically true, ſo, when we have two graduations to look to, as in the preſent caſe, one on the north, and the other on the ſouth end of the needle, we ought to

attend

attend to both, and take the medium for the true dip or variation, pretty nearly. But in this compaſs there is another method of examining the obſervations. Take a good artificial magnet, and on the outſide of the compaſs box point one end of it towards the needle, and by moving your magnet, you may thus guide the north-end of the needle round the ſouth, or *vice verſa*, without opening your compaſs box. The magnet being then laid aſide, the needle will come to its true poſition, after a few vibrations: but, as both the needle and the circle of inclination are now reverſed *, it will not point exactly to the ſame diviſion as before; yet a mean of the two will be the truth, as nearly, I believe, as it is poſſible for any inſtrument to give it.

" Query 1ſt. May not a part of this ſmall difference be attributed to the direc-

* Dr. Lorimer means, that the magnet ſhould be applied in ſuch manner as to turn the parallelogram and circle of inclination half way round horizontally, ſo that that end of the axis of the needle, which before pointed to the weſt, ſhall now point to the eaſt.

tion of the magnetic influence (whatever that be) in the ſteel bar? and, if ſuch an experiment could be tried upon the preſent azimuth compaſſes, is it not probable, that the variation in them would be at leaſt as ſenſible?—Query 2d. May not this be the cauſe that two of the beſt of them will differ a ſmall matter from one another?—Query 3d. Would the ends of the needle being made angular, inſtead of the ſquare form, be, in ſome meaſure, a remedy for this ſmall variation?

"I am, &c."

The great objection, which ſeems to offer itſelf againſt the above-deſcribed inſtrument, is the friction, which, eſpecially at the pivots of the circle of inclination, may obſtruct the free motion of the needle.—It certainly requires a moſt exquiſite workmanſhip; and the ſockets wherein the pivots move ought to be made of agate.

CHAP-

CHAPTER II.

Experiments neceſſary to aſcertain the preſence and quality of magnetiſm.

THE object of the experiments of this Chapter is to ſhew the methods of finding out whether or no a body is attractible by the magnet, whether it poſſeſſes any magnetiſm or not, and, in caſe it does, to find out its poles.

EXPERIMENT I.

To aſcertain whether a body has any attraction towards the magnet or not.

The various degrees of attraction between a magnet and ferruginous bodies, require different methods, in order to be rendered manifeſt.

If the given body contain an evident quantity of iron, the operator needs only bring an artificial or real magnet in contact with it, and he will ſoon perceive that there requires a certain force to ſeparate them again; the quantity of which force ſhews the degree of attraction between the given body and the magnet: thus, when two ounces weight are required to ſeparate them, the attraction is as ſtrong again as when one ounce only is ſufficient. In this examination, care muſt be had to let the magnet and body examined always preſent ſimilar ſurfaces to each other, and to come quite into contact; otherwiſe, in examining different bodies, it will be impoſſible to compare their various degrees of attraction towards the ſame magnet.

If the given body be not ſenſibly attracted by the magnet, when tried in the above-mentioned way; then it muſt be put to ſwim upon ſome water kept in an earthen or wooden veſſel, by means of a piece of cork or wood; for if in that ſituation the magnet be brought ſideway of it, the attraction will be ſoon manifeſted by the body coming towards the magnet. It will be neceſſary ſometimes to bring the magnet within about one tenth of an inch diſtance of the ſwimming body, in order to perceive the attraction; in which caſe, as the body advances towards the magnet, this muſt be gradually withdrawn, taking care not to let them ſtrike againſt each other; otherwiſe, after the impulſe, the body, if hard, will generally recede. It muſt be alſo obſerved, to preſent the magnet to the body, when the latter is at reſt.

A ſtill ſmaller degree of attraction, than what may be obſerved by the uſe of water, may be diſcovered, by placing the given body to ſwim upon quickſilver, and by preſenting the magnet to it, in which caſe it will move ſurpriſingly nimble.

In this method, the following particulars muſt be minded, *viz.* the aperture of the veſſel, in which the quickſilver is kept, muſt be at leaſt ſix inches in diameter; otherwiſe, as the ſurface of the quickſilver deſcends near the ſides of the veſſel, and that curvature is proportionably greater in narrow veſſels than in larger ones, the floating body, when the quickſilver is kept in a veſſel of three or four inches, will be perpetually running towards the ſides *. The quickſilver muſt be very pure; but, as it is very difficult to find it, or to preſerve it pure, it muſt be frequently paſſed through a funnel of paper, *viz.* a piece of writing paper rolled up conically, and having a ſmall aperture of about a fortieth of an inch in diameter; for, if the quickſilver be impure, the floating body will move with leſs facility upon it than upon water. The air about it muſt not be diſturbed much, in order to keep the body without motion, in which ſtate one of the poles of a ſtrong magnet is to be preſented on one ſide of it, in the ſame manner as when the experiment is tried on water; following the ſame precautions.

EXPERIMENT II.

To aſcertain whether a given body has any magnetiſm or not.

This experiment requires exactly the ſame operations as the firſt, with only this difference, *viz.* that in this the given body,

* A common ſoup plate is very fit for this purpoſe.

in

in caſe it has not magnetiſm ſufficient to ſhew itſelf by a ſenſible degree of attraction when a piece of iron is preſented to it, muſt be placed to ſwim upon water or quickſilver; and, inſtead of the magnet, as uſed in the firſt experiment, a piece of ſoft and clean iron muſt be approached to it, with the ſame precautions; for, if the body have any magnetiſm, it will be ſoon attracted by the piece of iron, which, for this experiment, muſt not be very long nor very heavy; a piece of about half an ounce weight, and nearly an inch long, is very proper for the purpoſe.

EXPERIMENT III.

A magnetic body being given, to find out its poles.

Preſent the various parts of the ſurface of the magnetic body ſucceſſively to one of the poles of a magnetic needle, and you will ſoon diſcover which parts of the given body are poſſeſſed of a contrary polarity, by the needle's ſtanding perpendicularly towards them. Then preſent the various parts of the ſurface of the ſame body to the other pole of the needle, &c.

In this operation, care muſt be taken not to bring the magnetic body too near the needle, for fear of changing its polarity. The diſtance at which ſuch an effect will take place is various, according to the ſtrength of the magnetic body; ſo that it is impoſſible to preſcribe it; but the operator will never miſtake, if he keeps the magnetic body ſo far from the needle as juſt to affect it ſenſibly.

EXPERIMENT IV.

To obtain the ſame object as in the preceding experiment, by other methods.

If the given body have only two poles, they may be aſcertained without the magnetic needle, *viz.* by ſprinkling ſome iron filings upon it, and obſerving where the particles of the filings ſtand erect and perpendicular to the ſurface of the body; for thoſe places

places are the poles; and, in order to diſtinguiſh the north pole from the ſouth, place the ſaid body on a piece of wood, and let it ſwim upon water, or tie it to a thread, and let it hang freely from it; in which caſe, the body will ſoon ſhew its north pole, by turning it towards the north, and, of courſe, the oppoſite pole will be turned towards the ſouth. In both thoſe caſes, *viz.* when the magnetic body is made to ſwim upon water, or ſuſpended by a thread, it muſt be ſo placed as that its poles may lie horizontally.

This method, however, is not ſo preciſe as when a magnetic needle is uſed; firſt, becauſe it will not do when the given body has more than two poles, and, ſecondly, becauſe, even when it has two poles only, they do not lie always in the ſame ſtraight line, which paſſes through the centre of the body.

CHAPTER III.

Containing experiments concerning the action of a magnet on ferruginous bodies that are not magnetic.

PROPERLY ſpeaking, the magnet has no action upon unmagnetic bodies; for, when a bit of iron, or other ferruginous body, is preſented to it, the body becomes magnetic firſt, and then is attracted; ſo that in this chapter it is only meant to treat of the action of the magnet on thoſe bodies, which were not magnetic before they were preſented to it.

EXPERIMENT I.

To obſerve the effects produced by a magnet on ſoft iron.

Place a magnetic needle upon a pin ſtuck on a table, and, when the needle ſtands ſteady, place an iron bar of about eight inches long, and between a quarter of an inch and one inch thick, upon the table,

table, ſo that one end of it may be on one ſide of the north pole of the needle, and ſo near it as to draw it a little way out of its natural direction. In this ſituation, approach gradually the north pole of a magnet to the other extremity of the bar, and you will ſee that the needle's north end will recede from the bar more and more, in proportion as the magnet is brought nearer to the bar. If the experiment be repeated, with only this difference, *viz.* that the ſouth pole of the magnet be directed towards the iron bar, then the north end of the needle will advance nearer and nearer to the bar, in proportion as the ſouth extremity of the magnet is brought nearer to the iron.

The reaſon of this phenomenon is, that, by the approach of the north pole of the magnet, in the firſt caſe, the extremity of the iron bar, which lies next to it, acquires a ſouth polarity, and, of courſe, the oppoſite extremity acquires the north polarity; in conſequence of which, the needle is repelled, becauſe magnetic poles of the ſame name repel each other; but in the ſecond

caſe,

caſe, when the ſouth pole of the magnet is brought near the bar, the end of the bar, which is next to it, acquires the north polarity, and the oppoſite end, acquiring the ſouth polarity, attracts the north end of the needle.

If, whilſt the pole of the magnet ſtands contiguous to one end of the bar, a ſmall magnetic needle be preſented within a certain diſtance to various parts of the ſurface of the latter, it will be obſerved, by the attraction and repulſion of the needle, that that half of the bar, which is next to the magnet, poſſeſſes the contrary polarity, and the other half the ſame polarity with the pole of the magnet that is applied to the iron.

The magnetic centre, however, or the limit between the polarities, is not always in the middle of the bar; it is generally nearer that end which is preſented to the magnet. This difference is greater as the magnet is weaker, and the length of the bar increaſes; but when the bar exceeds a certain length, which depends on the ſtrength of the magnet, then the bar acquires ſeveral ſucceſſive poles, *viz.* when the north pole of the magnet is contiguous to one of its extremities, that extremity becomes a ſouth pole; a few inches farther on you will have a north polarity, then another ſouth polarity, and ſo on. In this caſe, the firſt magnetic centre comes very near that end of the bar which ſtands next to the magnet, and other magnetic centres are formed between every pair of ſucceſſive poles.

Thoſe ſucceſſive poles become weaker and weaker in power, according as they recede from that end of the bar which is contiguous to the magnet, ſo that, in a pretty extended bar, they quite vaniſh long before they come to the farther end of it; hence, if one pole of a magnet be applied to the end of a long bar, the other end of the bar will not thereby acquire any magnetiſm. This will happen, when a magnet, capable of lifting about two pounds weight of iron, is applied to one extremity of an iron bar, about one inch ſquare, and above five feet long.

On

On removing the magnet, the bar, if of ſoft iron, will immediately loſe all its magnetiſm, otherwiſe will retain it a longer or ſhorter time, in proportion to its hardneſs.

If the above-mentioned experiment be tried with bars of the ſame dimenſions, but of different degrees of hardneſs, it will appear, from the attraction or repulſion of the magnetic needle, that ſoft iron acquires a ſtronger magnetic power than hard iron, or ſteel, &c.

EXPERIMENT II.

To ſhew the action of the magnet on ferruginous bodies, by the repulſion and attraction of two pieces of wire.

Tie two pieces of ſoft iron wire, A B, A B, fig. 1. of plate II. each to a ſeparate thread, A C, A C, which join at top, and, forming them in a loop, ſuſpend them, by putting the loop on a pin, ſo that the wires A B, A B, may hang at ſome diſtance from the wall. Then bring the marked end, D, of a magnetic bar, which is uſually the north pole, juſt

under

under them, and it will be found, that the wires will immediately repel each other, as ſhewn in fig. 2. and this divergency will be greater when the magnet is brought nearer within a certain limit, and will decreaſe, according as the magnet is removed. The reaſon of this phenomenon is very eaſily deduced from the general laws of magnetiſm, *viz.* by the vicinity of the north pole D of the magnet, the extremities B, B, of the wires acquire the ſouth polarity, conſequently they repel each other; and the extremities A, A, both acquire the ſame polarity, namely the north, hence they likewiſe repel each other.

If, inſtead of the north pole of the magnet, the ſouth pole be preſented, the wires will repel each other in the ſame manner as before; but now their extremities B, B, will become north poles, and the extremities A, A, will become ſouth poles.

On removing the magnet, the wires, if of ſoft iron, will ſoon collapſe, having loſt all the magnetic power; but if ſteel wires or common ſewing needles be uſed, they

will

will continue to repel each other after the removal of the magnet, the magnetic power being retained by ſteel.

It has been ſaid above, that, when the magnet is brought nearer and nearer to the wires, the divergency of the latter will increaſe, as far as *a certain limit*. The reaſon of this limit is the attraction between the magnet and the extremities of the wires, which, when the magnet comes too near, counteracts the repulſion between the extremities, B, B; ſo that the wires in that caſe ſtand as ſhewn in fig. 3. In fact, when the experiment is tried with ſteel wires, or needles, which retain the communicated magnetiſm after the removal of the magnet, their lower extremities will diverge more after having removed the magnet than when they ſtand very near it.

EXPERIMENT III.

To ſhew the action of the magnet upon ferruginous bodies, by means of four pieces of ſteel wire or ſewing needles.

Take four pieces of ſteel wire, or four common ſewing needles, tie threads to them,

them, and join them two by two, in the manner deſcribed in the preceding experiment; then bring the ſame pole of the magnet under both pairs, *viz.* one after the other, by which means they will acquire a permanent magnetiſm, and the wires of each pair will repel each other. After putting the magnet aſide, if you bring one pair of wires near the other pair, ſo that their lower extremities may be all in one level, the four wires will repel each other, forming a ſquare, becauſe their loweſt extremities are all poſſeſſed of the ſame polarity.

If inſtead of giving the ſame polarity to all the lower extremities, and the contrary polarity to all the upper extremities, you give one polarity to the lower extremities of one pair, and the contrary polarity to the lower extremities of the other pair; then, whilſt thoſe pairs are kept far from each other, the wires of each will fly away from one another; but if the two pairs be brought near, all the four wires will ſtick together in one bundle; the reaſon of which is, becauſe the contrary polarities of both

pairs,

pairs, being put near, will attract each other, and destroy the repulsion between the wires of the single pairs.

Instead of two, you may make several pairs of wires or needles, and, by giving one sort of polarity to the lower extremities of some, and the contrary polarity to the lower extremities of others, you may produce effects analogous to those described above.

EXPERIMENT IV.

Of the action of the magnet on iron filings.

Strew some iron filings upon a sheet of paper laid upon a table, and place a small artificial magnet among them; then give a few gentle knocks to the table with your hand, so as to shake a little the filings, and you will find that they dispose themselves round the magnetic bar, in the manner represented by fig. 4. plate II. many particles clinging to one another, and forming themselves into lines, which, at the very poles, are in the same direction

with

with the axis of the magnet, a little ſide-way of the poles they begin to bend, and then they form complete arches, reaching from a point in the north half of the magnet to a point in the other half, which is poſſeſſed of the ſouth polarity.

This phenomenon, obſerved from time immemorial, has given occaſion to various perſons to believe, that there was a circulation of a fluid from one of the poles of every magnet to the other pole, in conſequence of which the iron or ſteel filings were thus diſpoſed round the magnet. At firſt ſight, a perſon little ſkilled in magnetics would eaſily be induced to believe the ſaid circulation of a fluid; but a little conſideration will eaſily ſhew the abſurdity of the ſuppoſition, becauſe, if the fluid, of whatever nature it may be, did really circulate from one pole to the other, and had any action on th filings, theſe would be all driven toward that pole to which the moving fluid directed its courſe.

The true cauſe of the diſpoſition of the filings is, their becoming actually magnetic, and their two extremities being poſſeſſed of different polarities. Suppoſe firſt, that only one oblong particle of iron be affixed to the various parts of the ſurface of the magnet; it is evident, from what has been ſaid above, that on the poles this particle of iron A B, fig. 5, plate II. would ſtand perpendicular to the ſurface, becauſe its farther extremity B, having the ſame polarity as the extremity C of the magnet, is equally repelled by it on every ſide, and is far from the influence of the other extremity D; on the ſides near to the poles the ſaid particle will ſtand inclined, becauſe the fartheſt pole of the magnet begins now to act upon it; and on the middle of the magnet the wire will lie quite cloſe to it, or, if it be kept at ſome diſtance, will lie parallel to the magnet, becauſe the two poles of the magnet, being equidiſtant from the extremities of the iron particle, have an equal action upon it. Now, when there are many particles of iron, *viz.* the filings, near the magnet, thoſe particles which touch its ſurface are rendered magnetic,

conſequently

consequently they attract other particles, and these being made also magnetic, attract others, and so on, forming strings of small magnets, which gradually decrease in power as they recede from the magnet. As each of those particles has two magnetic poles, by a little consideration it will appear, that the farthest ends of those strings or lines which proceed from the parts adjacent to one of the poles of the magnet, for instance, the north, are likewise possessed of the north polarity, and the farthest extremities of those strings which proceed from the parts adjacent to the south pole of the magnet, are possessed of the south polarity; hence, when they come sufficiently near, they attract the extremities of the former strings, and consequently form the curves delineated on the figure.

The shaking of the table in this experiment serves to stir the filings, by making them jump up a little way, and thus place themselves in the proper situation; otherwise, the action of the magnet, will not have power sufficient to dispose properly thoſe particles which ſtand at a conſiderable diſtance.

EXPERIMENT V.

To ſhew the action of the magnet on iron by means of a ſuſpended body.

Tie a thread to one end of a bit of ſoft iron wire A B, fig. 6. plate II. about four inches long, and ſuſpend it freely; place a ſtand of any ſort in ſuch a manner as to ſupport a bar of ſoft iron C D, ſo as to let one of its extremities C be about three quarters of an inch diſtant from the lower extremity B of the wire. This done, if you bring either pole of a ſtrong magnet E F under it, you will find that the end B of the wire A B will recede from the end C of the iron bar, becauſe they are both poſſeſſed of the ſame polarity; but if the magnet be applied to the upper part of the wire, in the ſituation G H, then the end B of the wire will be attracted by the extremity C of the iron bar; becauſe, ſuppoſing G to be the north pole of the magnet, C being the extremity of the bar C D, that ſtands neareſt to the north pole G, acquires a ſouth polarity, and attracts the end B of the wire; becauſe B being the part of the wire which ſtands remoteſt from the north pole G, acquires the ſame, namely, the north polarity.

EXPERIMENT VI.

To ſhew the effect of magnets on a crooked wire.

Let an iron wire of about a quarter of an inch in diameter, and four or five inches long, be bent ſomewhat like a gothic arch, *viz.* with a ſharp corner in the middle, A B C, fig. 7, of plate II. and tie it faſt to a croſs bar, or let an aſſiſtant hold it with the corner downwards: then apply either pole of the magnet D E to one of its extremities A, and whilſt the magnet remains in that ſituation, apply a piece of iron H, of no great ſize, to the corner C, and you will find that the iron remains ſuſpended. Now, if another magnet be applied to the other extremity B of the crooked wire, ſo that the pole G may be contrary to the pole E, the iron H will immediately fall off; but if the pole G be analogous to the pole E, *viz.* be both ſouth, or both north, then the iron H not only will remain adhering to C, but the ſaid corner will be capable of ſupporting a weight ſtill greater than H. The reaſon of which is, becauſe, in the former caſe, the extremities A B of the bent wire being poſſeſſed of different polarities, the corner C was the magnetic centre, where there is no attraction nor repulſion; whereas, in the ſecond caſe, both extremities of the bent wire being poſſeſſed of the ſame polarity, the corner C was neceſſitated to acquire the contrary polarity; and in this caſe, the bent wire muſt have two magnetic centres, *viz.* one on each ſide.

EXPERIMENT VII.

Shewing in what circumſtances a magnet can lift the greateſt weight.

Take a magnetic bar, and find by trial an oblong piece of iron, about 4 inches long, and of a weight little greater than the magnet will ſupport. It is plain that if you affix this iron to one pole of the magnet, the moment you remove your hand the iron will drop; but if, before you remove the hand, you preſent another larger piece of iron juſt under the lower extremity of the former, and within half or three quarters of an inch from it, you will find that the magnet will then ſupport that piece of iron which it could not ſupport before, when a ſecondary piece of iron was not under it. In ſhort, a magnet can lift a greater weight of iron from over another piece of iron, as an anvil, or the like, than from over a table.

The reaſon of which property is, that in the former caſe, the iron baſis, or inferior piece of iron, becoming itſelf in ſome meaſure magnetic, helps to increaſe the magnetiſm of the firſt piece of iron, and conſequently tends to increaſe the attraction between it and the magnet; which does not take place when the iron is lifted from over a table, or ſomething elſe which is incapable of acquiring any magnetiſm.

In order to render this property more intelligible, ſuppoſe that a piece of iron be affixed to the north pole of a magnet; it is plain, that by the action of the magnet, the part of it that ſtands next to the magnet has acquired a ſouth polarity, and its other, or inferior extremity, has acquired a north polarity, the attraction being a conſequence of this acquired magnetiſm, and being greater or ſmaller in proportion as that acquired magnetiſm is more or leſs powerful; conſequently, whatever tends to increaſe that magnetiſm in the piece of iron, muſt likewiſe increaſe the attraction. Now, when another piece of iron is under the former, that other piece of iron, being within the ſphere of action of the magnetic bar, becomes magnetic, and

the

the part of it which is contiguous to the north pole of the magnet acquires the ſouth polarity; but this is contiguous to the lower end, which is the north pole, of the firſt piece of iron, therefore it muſt increaſe that north polarity, and, of courſe, the ſouth polarity of the upper end of the firſt piece of iron, which ſtands next to the magnet.

In fact, if, inſtead of the ſecondary piece of iron, you put the ſouth pole of another magnet at a little diſtance below the lower extremity of the ſuſpended iron, you will produce the ſame effect, *viz.* will increaſe the attraction between it and the north pole of the firſt magnet; but if you preſent the north pole of the ſecond magnet under it, then you will produce the contrary effect, *viz.* will weaken its magnetic power, and, of courſe, diminiſh the attraction.

EXPERIMENT VIII.

To ſhew the variable power of a magnet by ſuſpending iron to it.

Suſpend a magnet, in a place that is not much ſhook, and apply to it as much weight of iron as it will juſt ſupport *. Let a hook or a ſcale, like thoſe uſed for a balance, be faſtened to this iron. On the day following, you may put a little more weight into the ſcale, which the magnet will ſupport. One or two days after, a little more weight may be added; and ſo on; the power of the magnet increaſing daily: and, though this increaſe of power is neither unlimited nor very regular; being affected in ſome meaſure by the viciſſitudes of heat and cold, &c.; yet, upon the whole, the power of a magnet will be conſiderably increaſed by this artifice.

It is very remarkable, that if, in the courſe of the operation, the iron were to drop from the magnet, on replacing it, you will find that the magnet will no longer ſupport as much weight as it did a moment before, ſo that now you muſt diminiſh the weight, though in the courſe of the following days you may increaſe it

* For this purpoſe, the magnet, either natural or artificial, ought to be armed, or made in the ſhape of a horſe-ſhoe; *viz.* ſo as to have the poles in one plane; in this form the effect being more conſpicuous.

gradually

gradually again; hence, in placing the weights into the ſcale, or upon the hook, care muſt be taken not to give it any jerk, ſo as to cauſe the iron to fall off; otherwiſe a great deal of the work will be loſt.

The reaſon of this experiment is, that the iron being rendered magnetic, tends to ſtrengthen the magnetiſm of the magnet, in the ſame manner as any other magnet endeavours to render magnetic any ferruginous ſubſtance that is placed within its ſphere of action. When the iron falls off, the magnet loſes part of the acquired power, eſpecially if the magnet had acquired more than its point of ſaturation, there having been removed the cauſe which kept it up; and when the iron is replaced, the magnet will not recover the loſt power very readily, becauſe there is required a conſiderable time to communicate a certain degree of magnetic power to a hard ferruginous ſubſtance, as the magnet is, eſpecially when that magnetiſm muſt be communicated by the action of a proportionably weak magnet, like the iron weight.

According to Aepinus's hypotheſis of the

the magnetic fluid, this experiment is explained thus :—The magnetic fluid in a magnet is not equally difperfed through its fubftance; but one pole, or half of it, is overcharged and the other undercharged. There is a ftrong attraction between the undercharged part and the fuperfluous quantity of magnetic fluid in the overcharged part, and the reftoration of the balance is in great meafure prevented by the hardnefs or fome other quality of the magnet. Now, when the iron is affixed to the magnet, it becomes magnetic, *viz.* that part of it which is contiguous to the overcharged pole of the magnet, becomes undercharged, and the oppofite one becomes overcharged. In this fituation, the undercharged part of the iron, endeavouring to draw the magnetic fluid of the magnet towards itfelf, accumulates or draws it ftill nearer to that overcharged pole of the magnet, and, on the other fide, the overcharged part of the iron being contiguous to the undercharged pole of the magnet, tends continually to drive the magnetic fluid away from that undercharged pole of the

the magnet; but the power of the magnet, according to the hypothesis, depends on the unequal distribution of the magnetic fluid, therefore the action of the iron, by endeavouring continually to increase that unequal distribution, must increase the power of the magnet.

It follows from this experiment, that a magnet is apt to lose much of its power when kept without any iron affixed to it.

EXPERIMENT IX.

To shew the various effects produced by a magnet on different sorts of ferruginous substances.

Let several bars be made, of different sorts of iron and steel, but all of the same dimensions, *viz.* about five inches long, and half an inch thick; then examine them, one by one, in the following manner:— Place a magnetic needle so that one pole of it may be about an inch distant from one end of the bar of iron or steel, but the needle

needle and bar muſt not be in one direction; then apply one pole of a magnet to the other extremity of the bar; by the application of which, the needle will be moved from the ſituation in which it ſtood before. Thus repeating the operation with all the different bars, it will be found, that the needle is affected moſt when the bar is of ſoft iron, and leaſt when it is of hard ſteel, or of the brittle ſort of caſt iron; the other ferruginous ſubſtances affecting the needle in ſome intermediate degree between thoſe two extremes.

This experiment plainly ſhews, that the magnet has more action upon ſoft iron than on any other ſtate of that metal; ſoft iron acquiring the greateſt degree of magnetic power, and conſequently diſturbing the needle moſt. Hence it appears why a magnet attracts ſoft iron more powerfully than any other ferruginous ſubſtance, *viz.* becauſe ſoft iron becomes more powerfully magnetic when acted on by the magnet.

In this experiment it will alſo be found, that thoſe bars which become leaſt mag-

netic,

netic, and of courſe affect the needle leaſt, after the removal of the magnet will retain ſome magnetiſm; whereas the ſoft iron will loſe it immediately; which evidently ſhews, that the difficulty of acquiring magnetiſm, and of retaining it when once acquired, is owing to the ſame cauſe, namely, the obſtruction offered by the ferruginous ſubſtance to the free paſſage of the magnetic fluid, or of that power which produces the magnetic phenomena.

CHAPTER IV.

Of the action of magnets on each other.

EXPERIMENT I.

To ſhew the action of a magnet on a magnetic ſteel wire.

TAKE a ſoft ſteel wire, like A B, fig. 8, of plate II. about five inches long, and a quarter of an inch thick, and give it ſome magnetiſm, by placing it between two magnetic bars for a minute or two. This done, dcne, find its magnetic centre C, according to the experiment deſcribed in the ſecond chapter; then lay it upon a table, and put a magnetic bar, D E, near it, ſo that their north poles may be towards each other. In this ſituation, if you examine the wire A B, by means of the magnetic needle, you will find that the action of the magnet D C has removed the magnetic centre C farther from the end B; and the nearer the magnet is approached to B, the nearer will the magnetic centre C come to the extremity A. At laſt the end B of the ſteel wire will become a ſouth pole, the north pole will be removed towards C, and another magnetic centre will ariſe between thoſe two poles. In this experiment, a great deal of variety is occaſioned by the various ſtrength of the magnet, the length and ſoftneſs of the ſteel bar, and the diſtance between the one and the other.

1. If the ſteel bar be very long, it will acquire ſeveral ſucceſſive poles, and the original magnetic centre C, will not come proportionably ſo near the extremity A as when the wire is ſhorter.

2. If

2. If the wire A B be very ſhort, by the approximation of the magnet, its poles will be reverſed, ſo that B, which was the north pole, will now become ſouth, and the extremity A will become the north pole.

3. If the power of the magnet D E, be ſo weak, as to come nearly to an equality with the magnetic power of the wire A B, then they will have an equal power upon each other; and the conſequence will be, that the north poles of both will be a little removed from the extremities B and D; provided the ſubſtance of the magnets is equally ſoft.

4. By a gradual approximation of the ſtrong magnet D E, to the ſteel wire A B, the extremity B of the latter muſt have its polarity firſt diminiſhed, then annihilated, and laſtly reverſed.

From an attentive conſideration of the above-mentioned particulars, it will appear, that, before the pole B is changed, the two magnets muſt exert a repulſion againſt each other; that when the polarity of B is annihilated, the two magnets can neither attract nor repel each other; and, laſtly, that when the extremity B has acquired a ſouth polarity, the two magnets muſt attract each other.

In Caſe 3, the two magnets can have little or no power on each other; ſo that no attraction nor repulſion will take place between them.

EXPERIMENT II.

To ſhew the action of both magnetic poles, of two magnets, on each other.

What has been ſaid in the preceding experiment, with reſpect to one magnetic pole, will now be eaſily applied to explain the action of both poles of one magnet, on the analogous poles of another magnet.

Let C E D, A F B, fig. 9. of plate II. be two ſemicircular magnets, and let their poles of the ſame name be approached towards each other; A, C being north poles, and B, D ſouth poles. The conſequence of this approximation will be various, according to the various ſtrengths of the

the magnets, and the diſtance between them. Thus, if they be unequal in power, on their being gradually brought near to each other, the poles of the weak one muſt be gradually weakened, in which caſe, a repulſion is exerted between the magnets; then they are annihilated; in which caſe, no attraction nor repulſion will take place; and, laſtly, they will be changed, and then the two magnets will attract each other.

If the magnets be equal in power, and of a very hard nature, they will always repel each other, becauſe the poles of neither of them are deſtroyed or reverſed; but, if equal in power, and of a ſofter nature, then, when brought ſufficiently near, will deſtroy each other's polarity, and, of courſe, no attraction nor repulſion will take place.

In this experiment, the magnetic centres, E and F, will not be removed from their places, the action of the two poles being equal on both ſides; ſo that the only thing that can happen, is the generation of more magnetic centres, and, of

 courſe,

courſe, of more magnetic poles, the number of which depends on the length, hardneſs, and power of the magnets,

EXPERIMENT III.

To ſhew the action between the contrary poles of two magnets.

In the two preceding experiments, the homologous poles of the magnets were oppoſed to each other; but, if they be repeated, by preſenting the ſouth poles to the north poles, the phenomena will be as follows, *viz.*

The magnetic poles of each magnet will be ſtrengthened, the nearer they are approached to each other; the attraction will increaſe in the ſame proportion, and it can never be changed into repulſion. But, as the degree of attraction depends on the ſtrength of the contrary poles, every thing elſe remaining the ſame, and as the increaſe of the polarity of one magnet from the action of another magnet, principally depends

pends upon the ſoftneſs of one of the magnets, it follows, that, in certain circumſtances, a weaker magnet may be attracted more powerfully than a ſtronger one.

In order to render this kind of paradox very evident, let two ſmall magnetic bars be made, exactly of the ſame dimenſions, but let one be made of the hardeſt, and the other of the ſofteſt ſteel. Let the latter have a very weak magnetic power, but the former a greater power. This done, if you apply thoſe magnets ſingly, and alternately, to a third magnet, conſiderably more powerful than either of them, you will find, that the weak magnet, *viz.* that of ſoft ſteel, will be attracted more powerfully than the other; the reaſon of which is, that the ſoft ſteel magnet will have its poles rendered conſiderably ſtronger by the vicinity of the third magnet, and that on account of its ſoftneſs, though, for the very ſame reaſon, its power will be ſoon diminiſhed when removed from that ſphere of action; whereas the magnet of hard ſteel, though its poles be increaſed a little by the action of the third magnet, yet, on account of its hardneſs, they will not be increaſed to ſuch a degree as thoſe of the ſoft ſteel one.

It appears therefore, from this and the two preceding experiments, that when two magnets are approached near each other, they may repel, attract, or not act at all on one another, according to the various enumerated circumſtances; that the repulſion at a diſtance may be changed into attraction, by bringing the magnets nearer; that the attraction taking place when the magnets are within a certain diſtance of each other, may be changed into repulſion by increaſing that diſtance *; and that a

* Thus when two magnetic bars, pretty long, but not very hard, and of different powers, are placed in the ſame direction, with the north pole of one contiguous to the north pole of the other, the weak magnet will have its north pole changed into a ſouth pole for a ſhort way, in conſequence of which, an attraction will take place; but when the magnets are removed farther off, then the original ſouth extremity of the weak bar will reſtore the north polarity of the oppoſite extremity, and, conſequently, a repulſion will enſue.

weaker

weaker magnet, in certain cafes, may be attracted with greater force than a ftronger one; this law remaining certain and unaltered in any cafe, *viz.* that the poles of the fame name repel, and thofe of a different name attract, each other; fo that, when an attraction takes place between thofe parts of ferruginous fubftances, which were before poffeffed of the fame polarity, it may be concluded, that the polarity of one of them has been actually changed.

EXPERIMENT IV.

To increafe or diminifh the attraction between a magnet and a piece of iron, by the action of another magnet, equal in power to the former.

Place a magnetic bar, A B, fig. 10. of plate II. fo that one of its poles may project a fhort way beyond the table, and apply an iron weight, C, to it; then take another magnetic bar, D E, like the former, and bring it parallel to, and juft over the other, with the contrary poles towards each other; in consequence of which, the attraction of B will be diminished, so that the iron C, if very heavy, will drop off, and the magnet can only support a smaller piece of iron. In short, this attraction will be diminished, and, when the magnets come quite into contact, provided they be of an equal power, the attraction will entirely vanish; but if the experiment be repeated, and the homologous poles of the magnets be approached to each other, then the attraction, instead of being diminished, will be increased.

As the attraction between the iron and the magnet is owing to the iron acquiring a different polarity, it follows, that whatever contributes to increase that different polarity, increases likewise the attraction, and, on the contrary, whatever diminishes or destroys that different polarity in the iron, must likewise diminish or destroy the attraction. Therefore, when the extremities E and B of the magnets are both north poles, or both south poles, that part of the iron which is next to B becomes more and more strongly possessed of the contrary polarity,

larity, the more the magnets are approached; but when B and E are poles of different name, they will prevent the iron acquiring any polarity, becauſe, if the action of one tends to communicate to it a north polarity, the action of the other will endeavour to communicate a ſouth polarity to the ſame extremity of the iron.

EXPERIMENT V.

To increaſe or diminiſh the attraction between a magnet and a piece of iron, by the action of another more or leſs powerful magnet.

If the preceding experiment be repeated with magnets of unequal power, for inſtance, the magnet D E be much more powerful; on approaching the two magnets to each other, it will be found, that the greateſt degree of attraction, when the contrary poles are towards each other, and the entire deſtruction of the attraction, when the homologous poles are towards each other, will take place before the magnets come into contact; the reaſon of which the ingenious reader may eaſily underſtand, after what has been ſaid before.

EXPERIMENT VI.

To ſhew the generation of the poles, and of the magnetic centres, in the parts of a broken magnet.

Take a magnetic bar A B, fig. 11. of plate II. of very hard ſteel, and having only two poles, A and B.—A magnetic bar about 6 or 8 inches long, and about a quarter of an inch in diameter, anſwers very well for this experiment. The magnetic centre of this bar will be in its middle, C, or very little diſtant from that point. Now if, by a ſmart ſtroke of a hammer, you break off F B, about one third part of the magnet, it might be expected the part F B, which before the fracture was all poſſeſſed of one polarity, for inſtance, the north, would now continue ſo; but upon examination it will be found, that that part of the fragment, which was contiguous to the fracture, has acquired the contrary polarity, namely the ſouth, and a magnetic centre E will be generated.

It has been obſerved, that the magnetic centre of this fragment, at firſt, is always nearer to the fracture F, but in time it advances nearer to the middle of the fragment. The original centre C of the other piece, A F, after the fracture, will likewiſe advance nearer to the middle of it.

This experiment may be diverſified in the following manner :—A ſteel bar, of about ſix inches long, and a quarter of an inch thick, being made quite hard, may be broke in two unequal parts; theſe parts may be joined together, and preſſed againſt each other, ſo as to make them look as if the bar had not been broke ; in this ſituation, it may be rendered magnetic by the application of very powerful magnets to its extremities ; after which, on examination, the whole bar will be found to have two poles on its extremities, and one magnetic centre in its middle ; but if the parts be ſeparated, each will be found to have two poles and a magnetic centre, &c.

What has been here ſaid of artificial magnets, has been found true with natural magnets alſo, and with magnets having

more

more than two poles; in ſhort, if a magnet be broke in ſeveral pieces, every fragment is a complete magnet, having at leaſt two poles and one magnetic centre; nor was a piece of a magnet ever produced which had only one polarity.

EXPERIMENT VII.

Of removing the magnetic centre in a magnet.

The ſame means, which facilitate the tranſition of the magnetic power from one part to the other of a ferruginous body, have likewiſe the power of removing the magnetic centre, in magnets which have it not in their middle, and to make it approach nearer to that point; hence this may be effected various ways, *viz.* by ſtriking a magnetic bar repeatedly, by heating it, by hard rubbing, &c.; but it muſt be conſidered, that thoſe very means generally tend to weaken the magnetiſm of the magnet; therefore they ought not to be applied beyond what may be neceſſary to produce a ſenſible removal of the magnetic centre from its original place.

CHAPTER V.

Of communicated magnetiſm, or of the various methods of making artificial magnets.

EXPERIMENT I.

To make a piece of iron acquire the magnetiſm from the earth.

TAKE a bar of ſoft iron, about two or three feet long, and between half and two inches thick (ſome kitchen pokers are very fit for this experiment) and place it ſtraight up *. Then place a

* In a proper manner of making the experiment, the iron bar ought to be placed in the magnetical line, *viz.* in the direction of the dipping needle; but, as few perſons are furniſhed with a dipping needle, and many may be deſirous of performing this curious experiment, it will be ſufficient for thoſe perſons to place the bar ſtraight up, when they are in higher latitude than 40° north or ſouth, but to place it horizontally when they are nearer to the equator than the above-mentioned degree of latitude.

magnetic

magnetic needle on a pin, and, holding the pin in your hand, preſent the needle to the various parts of the bar from top to bottom, and you will find, that in this iſland the lower half of the bar is poſſeſſed of the north polarity, capable of repelling the north and of attracting the ſouth pole of the needle, and the upper half is poſſeſſed of the ſouth polarity, capable of repelling the ſouth and of attracting the north pole of the needle. The attraction is ſtrongeſt at the very extremities of the bar, it diminiſhes as it recedes from them, and vaniſhes about its middle, where no one pole of the needle is attracted in preference to the other. In ſhort, in that ſituation, the iron bar is as much a magnet as any piece of iron that ſtands within the influence of a magnet *.

If you turn the bar top-ſide down, the extremity of it, which was ſouth pole when

* Beſides its power on the needle, if the iron bar be not very ſhort, it will even attract ſmall pieces of iron, as filings, &c. that are placed near its extremity.

it ſtood uppermoſt, will now become north pole, and the other extremity will become ſouth pole.

In the ſouthern parts of the world, the lower part of the bar is a ſouth pole; or, to be more explicit, when, in any part of the world, the bar is ſituated in the magnetic line, the extremities of the bar will acquire the polarities correſponding to the neareſt poles of the earth.

EXPERIMENT II.

To fix in an iron bar the magnetiſm which is communicated to it by the earth.

The very ſoft iron acquires the greateſt degree of magnetic power in the ſhorteſt time, but loſes it with the ſame quickneſs; ſo that, if the preceding experiment be performed with a bar of that ſort of iron, the magnetiſm communicated to it by the earth will not be permanent; but if it be made red-hot, and be left to cool in the magnetic line, or if it be repeatedly ſtruck with a hammer, whilſt ſtanding in the

the magnetic line, it will thereby acquire a ſmall degree of permanent magnetiſm; which power, however, either by leaving the bar for ſome time in an improper ſituation, or by inverting and ſtriking it again, will be ſoon deſtroyed.

When the iron is ſomewhat harder, the acquired magnetiſm laſts much longer; though a longer time, or longer operation, be required in order to render it magnetic.

As the conſtant action of a weak magnet on a ferruginous body continually tends to increaſe the magnetiſm of that body; ſo the iron bars, which are left in the direction of the magnetic line for a conſiderable time, become continually more ſtrongly magnetic, and the acquired power becomes more permanent.

The reaſon why iron, by long ſtanding, by hammering, &c. acquires a permanent magnetiſm from the earth, whereas by the mere poſition, in a ſhort time, the power is not at all permanent, ſeems to be the unequal texture of the iron: ſuppoſe, for inſtance, that a piece of iron is compoſed of hard and ſoft particles, or of ſome, through which the magnetic power moves very eaſily, and others, through which it moves very ſlowly. The former then, of thoſe particles, acquire the magnetiſm at firſt from the earth, and loſe it very eaſily; but by continuing in the ſame poſition, or by being ſoftened, &c. the hard particles gradually acquire magnetiſm from the former, and, having once acquired it, retain that power for a long time. It is, beſides, very probable, and, in certain circumſtances, actually proved, that ſome ſort of iron becomes harder by being kept long expoſed to the atmoſphere.

EXPERIMENT III.

To communicate a permanent magnetiſm to a ferruginous body, by means of an iron bar, whilſt this is rendered magnetic by the earth.

The ſimpleſt method of producing this effect, is deſcribed in the Philoſophical

Tranſactions, by Mr. Arnold Marcel *; part of whoſe paper I think it not improper to tranſcribe in this place, it being the firſt method of the kind that I find publiſhed.

"In the year," ſays he, "1726, making "ſeveral further obſervations about the "magnetical force, which I found in "great pieces of iron, I made uſe of a "large iron vice, about 90 lb weight, in "which I fixed a ſmall anvil of about "12 lb. Upon the bright ſurface of this "anvil I laid the ſteel, to which I would "give the virtue, in a poſition of north "and ſouth, which happened to be in a "diagonal of the ſquare ſurface of the an-"vil; then I took a piece of iron, one "inch ſquare, and 33 inches long, of "about eight lb. weight, having at one "end the figure here repreſented (fig. 12. "plate II.) brightly poliſhed at A, and "taper at the other end: Then I held "faſt down the piece of ſteel upon the "anvil with one hand, and with the other

* Martyn's Abridgment, Vol. VI. Part II. p. 278.

"I held

" I held the iron bar aforefaid perpendi-
" cular, with its point A upon the fteel,
" and, preffing hard, I rubbed the fteel
" with the iron bar towards me, from
" north to fouth, feveral ftrokes, always
" carrying the bar far enough round
" about, to begin again at the north, to
" prevent the drawing back of the mag-
" netical force. Having thus given 10 or
" 12 ftrokes, I turned the fteel upfide
" down, leaving it in the fame pofition
" as to north and fouth, and, after rubbing
" it and turning it, till I rubbed it about
" 400 times, it received, by degrees, more
" and more ftrength, and at laft had as
" much as if it had been touched by a
" ftrong load-ftone. The place where I
" began to rub, was always that which
" pointed to the north when the needle
" was hung, the end where I had ended
" the ftroke turning to the fouth. Some-
" times it has happened, that in a few
" ftrokes I gave the fteel its virtue; nay,
" even in the very firft ftroke, one may
" give a great deal to a fmall needle. This
" way I have given the magnetical virtue

" to needles of ſea-compaſſes, made of " one piece of ſteel, ſo ſtrongly, that " one of the poles would take up $\frac{3}{4}$, and the " other a whole ounce of iron: although " theſe needles were anointed with linſeed " oil, which made a hard coat, to keep " them from ruſting, yet they kept the " virtue; but in ſtrengthening theſe ſort " of needles, I rubbed by turns firſt to the " right and then to the left ſide.

" The ſame way I brought the virtue " into the point of a knife, ſo that it " would ſuſtain 1$\frac{3}{4}$ ounce.

" I brought the ſaid virtue into four " ſmall pieces of ſteel, each one inch long, " and $\frac{1}{12}$ inch broad, as thin as the ſpring of " a watch. Theſe four pieces I joined " together, as into an artificial loadſtone, " weighing 18 grains *Troy*, and then it did " draw up and ſuſtain an iron nail, which " weighed 144 grains *Troy*. This artificial " loadſtone has now theſe ſix years been " tumbled about, and been lying among " iron and ſteel, and in any poſition, and " yet it has rather got more than loſt " any of its virtue.

The

" The magnetical virtue being thus
" brought into iron or ſteel, I have far-
" ther obſerved, that that end where the
" ſtroke was begun, would draw to the
" north, and where the ſtroke ended, to
" the ſouth, in whatever ſituation the ſteel
" had been laid upon the anvil to give
" it the virtue. I took a piece of ſteel, and
" rubbed it from one end to the middle,
" and then from the other end to the
" middle, and found it had two north
" poles, one at each end, and the middle
" a ſouth pole.

" Further, beginning to rub from the
" middle towards each end of another
" piece of ſteel, I found it to have at each
" end a ſouth pole, and in the middle a
" north pole."

A very eaſy way of giving magnetiſm to a ſmall piece of ſoft ſteel, is the following:—Take two pokers of ſoft iron, or two iron bars, of about an inch ſquare, and more than 3 feet in length, keep them in the magnetical line, or (if in this iſland) perpendicularly, as ſhewn in fig. 13. of plate II. Then let the piece of ſteel C B be either faſtened to the edge of a table, or be held by an aſſiſtant; and, placing the lower extremity of the bar A B, and the upper extremity of the bar C D, both on the ſame ſide, and in the middle of the ſteel, ſtroke the ſteel from the middle towards its extremities, moving the end of the bar C D from the middle of the piece of ſteel towards its end C, at the ſame time that the end of the bar A B is moving from the middle of the piece of ſteel to its other extremity B, and when the bars are arrived to the ſaid extremities, remove them from the ſteel, and apply them again to the middle, and ſo on; thus ſtroking the piece of ſteel about 40 or 50 times on every ſide, will give it a conſiderable degree of magnetiſm.

It is evident, that if in this experiment, when the iron bars are arrived to the extremities of the ſteel, you bring them back to the middle of it, by drawing them along the ſurface of the ſteel, the experiment will not ſucceed, becauſe the magnetic power communicated by their rubbing the ſteel in one direction, will be deſtroyed by their contrary motion.

EXPERIMENT

EXPERIMENT IV.

*To conſtruct artificial magnets, after the manner of Mr. Canton *.*

Let ſix bars be made of ſoft ſteel, about 3 inches long, $\frac{1}{4}$ inch broad, and $\frac{1}{20}$ inch thick. Let alſo ſix other ſteel bars be made quite hard, and about ſix inches long, half an inch broad, and one eighth thick. Each of thoſe ſets of bars muſt have two pieces of ſoft iron, called ſupports or conductors, both equal to one bar of the reſpective ſet. One end of each of theſe 12 bars muſt be marked with a line, which end is to become the north pole. Have ready alſo an iron poker and tongs, that have been long in uſe.

Place the poker nearly upright, or rather in the magnetical line, with its point downwards; and let one of the ſoft ſteel bars be tied, by means of a thread, to the middle of it, and with the marked end downwards; then with the lower end of the tongs, held alſo in an upright poſition, or in the mag-

* Phil. Tranſ. for the year 1751 and 1752.

netical line, ſtroke the ſteel bar from the marked end upwards, about 10 times, on both ſides, which will give it power enough to keep ſuſpended a ſmall key. Thus communicate the magnetiſm to four of the ſmall bars.

This done, lay the two other ſmall bars on a table, parallel to each other, about a quarter of an inch aſunder, and between their iron conductors, A B, C D. fig. 14. of plate II.; taking care to place the marked end of one of the bars on one ſide, and the marked end of the other bar on the oppoſite ſide. Now place the four bars, already made magnetic, in the form ſhewn in fig. 15. *viz.* two with their north poles downwards, and the other two with their ſouth poles downwards. The two of each pair muſt be placed breadth to breadth, and the two pairs being put contiguous to each other at top, muſt be kept open to a ſmall angle by the interpoſition of ſome hard ſubſtance I. This ſort of compound magnet, formed of the four bars, muſt be placed with its aperture on the middle of one of the ſoft bars A C, taking care to

let

let the ſouth poles H be towards the marked end of the bar A C, and the north poles F towards the other extremity. In this poſition, the compound magnet muſt be ſlid from end to end of the ſaid bar, *viz.* when the poles H are arrived at C, move the compound magnet backwards the other way, till the poles F come to A, &c. Thus ſtroke the lying bar four times, ending at the middle; from whence take up the compound magnet, and remove it to the middle of the other lying bar B D, taking care, as above, to let the ſouth poles be towards the marked end of the bar; rub this in the like manner; then turn the bars A C, B D, with the ſides that ſtood towards the table upwards, and repeat the operation on thoſe other ſides. This being done, take up the two bars A C, B D, and let them form the inner two of the compound magnet; and place thoſe which were before the two outſide ones, between the pieces of iron, or conductors, and rub them with the compound magnet formed out of the other four bars, in the ſame manner as before. This operation

ration muſt be repeated till each of the ſix bars has been rubbed four or five times, by which means they will acquire a conſiderable degree of magnetic power.

When the ſmall bars have been thus rendered magnetic, in order to communicate the magnetiſm to the large bars, lay two of them upon the table, between their two conductors, or pieces of iron, in the ſame manner, and with the ſame precautions, as were uſed for the ſmall bars; then form a compound magnet with the ſix ſmall bars, placing three of them with the north poles downwards, and the three others with their ſouth poles downwards. Place thoſe two parcels at an angle, as was done with four of them, the north extremity of one parcel being put contiguous to the ſouth extremity of the other, and with this compound magnet ſtroke four of the large bars, one after the other, about twenty times on each ſide, by which means they will acquire ſome magnetic power.

When the four large bars have been ſo far rendered magnetic, the ſmall bars are laid

laid aſide, and the large ones are ſtrengthened by themſelves, in the ſame manner as was done with the ſmall bars.

With ſome ſort of ſteel a few ſtrokes are ſufficient to impart to them all the power they are capable of retaining; other ſorts require a longer operation; and ſometimes it is impoſſible to give them more than a juſt ſenſible degree of magnetiſm.

In order to expedite the operation, the bars ought to be fixed in a groove, or between braſs pins; otherwiſe the attraction and friction between the bars will be continually deranging them, when placed between the conductors.

After what has been ſaid in the preceding pages, the reader may eaſily comprehend the reaſons of the operations here deſcribed, for conſtructing artificial magnets.

EXPERIMENT V.

To communicate magnetiſm by means of two magnetic bars.

It may be readily underſtood, that in order to communicate magnetiſm by means of two magnetic bars, the operation goes on much in the ſame manner as in the preceding experiment; but as it is more convenient to uſe two bars, and as the obſervations which may be made on the uſe of them are alſo applicable to the other methods of communicating magnetiſm, I thought proper to treat of it apart.

In order to communicate magnetiſm to a ſteel bar, to the needle of a compaſs, &c. place the bar or needle A B, fig. 16. plate II. upon a table; then place the two magnetic bars C D, E F, ſtraight up upon A B, at a little and equal diſtance from the middle of the bar A B, and in ſuch manner as the ſouth pole D of one of the bars may be neareſt to that end of the bar A B, which is required to become the north pole, &c. then theſe two bars muſt be ſlid gradually towards one extremity of the bar, keeping them conſtantly at the ſame diſtance from each other; and when one of the magnetic bars, for inſtance C D, is arrived at A, then they muſt be ſlid the contrary way, till E F arrives at B; and thus the bar A B muſt be rubbed a greater or ſmaller number of times till it will be found, by trial, to have acquired a conſiderable power. When the magnetic bars are powerful, and the bar A B is of very good ſteel, and not very large, a dozen of ſtrokes are fully ſufficient.—When the magnetic bars are to be removed from the bar A B, care muſt be had to bring them to the ſame ſituation where they were firſt placed, *viz.* at a little and equal diſtance from the middle of the bar A B, and then they may be lifted up.

In this operation the effect of the bars may be improved ſeveral ways, which will be found neceſſary when the bar A B is proportionably large, and it is required to give it the greateſt poſſible power. This may be effected, firſt, by joining the magnetic

netic bars at top, interpofing a piece of wood or other fubftance, except iron, to keep them apart, as fhewn in fig. 17; for in this manner, the upper poles of the bars being contiguous, will tend to ftrengthen each other, and, of courfe, their lower poles will alfo be ftrengthened. Secondly, by placing the bar, to be rendered magnetic, between two bars of foft iron, or two other magnets, as fhewn in fig. 17. or in the manner directed in the preceding experiment. Thirdly, the magnetic bars may be inclined the contrary way, after the manner ufed by Mr. Aepinus, fig. 18. plate II. fo that the magnets C D, E F, may make an angle of about 15 degrees with the bar A B.

The bar A B may, in the fame manner, be rendered magnetic by means of an armed magnet, as fhewn in fig. 19. or by a horfe-fhoe magnet, as fhewn in fig. 20. placing both the poles of the magnet in contact with the bar, &c.

In all thofe methods the bar to be rendered magnetic muft be ftroked on every fide; and in order to let the magnetic centre fall juft in its middle, care muft be had

to

to ſtroke one half of the bar juſt as often as the other half.

Whenever a ſteel bar, or in general a piece of ferruginous ſubſtance, is rendered magnetic by applying two bars, or whenever two magnetic poles are applied to it at the ſame time, as uſed in this and the preceding experiment, the operation is uſually called the *double touch*, in diſtinction from the *ſingle touch*, which is when only one magnetic pole is applied to it.

EXPERIMENT VI.

To communicate the magnetic power to crooked ſteel bars.

Artificial magnets are frequently made in the ſhape of a ſemicircle, or like a horſe-ſhoe, for the ſake of bringing both poles in the ſame plain. Theſe are rendered magnetic in the ſame manner as the ſtraight bars, excepting only, that the magnetic bars which are uſed for it, muſt follow the curvature of the ſteel bar; thus, if it be required to render magnetic the piece of ſteel A B C, fig. ~~20~~ 21. plate II.

place

place it flat upon a table, and to its extremities apply the magnets D F, E G; joining their extremities F G with the conductor or piece of ſoft iron F G. Then apply the magnetic bars H, I, to the middle of the piece A B C, and ſtroke it with them, from end to end, following the direction of the bent ſteel; ſo that on one ſide of it the magnetic bars may ſtand in the direction indicated by the dotted repreſentation L K.—In this manner, when the piece of ſteel has been rubbed a ſufficient number of times on one ſide, turn the other ſide upwards, and repeat the operation till it has acquired a ſufficient degree of magnetiſm.

In this operation the ſame precautions muſt be followed as were recommended for the method of communicating the magnetiſm to ſtraight bars, *viz.* the magnets D F, E G, as well as the magnets H, I, muſt be placed ſo that their ſouth poles muſt be towards that extremity of the bent ſteel which is required to be made the north pole, and their north poles towards the other extremity. The mag-

nets

nets I, H muſt be firſt placed on the middle of the bent ſteel; and after having drawn them over one leg of it as often as over the other, in order to let the magnetic centre fall juſt in the middle of the bent ſteel, they are removed, &c.

EXPERIMENT VII.

To communicate magnetiſm by the application of only one magnetic pole.

If a perſon have only one magnetic bar, or a terrella, with which he wiſhed to give magnetiſm to a needle or other bar, the only way of effecting it is, to apply one pole of the terrella, or magnetic bar A B, fig. 22. plate II. to one extremity C of the needle, and to draw it all along the ſurface of it till it reaches to the other extremity D; then the magnet being removed muſt be applied again to the extremity C, and muſt be drawn over the needle as before. Thus the needle muſt be rubbed ſeveral times, by which means it it will acquire a confiderable degree of magnetifm.

It muft be obferved, that the extremity of the needle which the pole of the magnet touched laft, acquires the contrary polarity. Thus, in the prefent inftance, if B be the north pole of the magnet, then the extremity D of the needle will afterwards be found to have acquired the fouth polarity, and the other extremity C, the north.

In this operation it is evident, that after the firft ftroke, when the magnet is applied again to C, this extremity, having acquired the north polarity, will have that power deftroyed by the vicinity of the north pole B of the magnet; fo that it feems that every ftroke undoes what was done in the preceding; however the fact is, that by repeating the ftrokes the power is increafed; but, in general, this method will never be fo advantageous as when more than one magnetic pole is ufed; hence it ought not to be ufed excepting in cafe of neceffity, *viz.* when one has only one magnetic bar or terrella.

EXPERIMENT VIII.

To ſhew the diſadvantages ariſing from the improper uſe of magnets of different power, and of ſteel not properly hardened.

After having communicated the magnetic power to a ſteel bar, by means of a given magnet, examine its power; then take a weaker magnet, and with it rub the ſteel bar again in the ſame direction as was done before; uſing the ſame pole, and, in ſhort, following exactly the ſame operation; after which it might be expected, that the magnetic power of the ſteel bar was increaſed; but, on the contrary, it will be found that its power is diminiſhed, being now not ſtronger than if the ſteel bar had been rendered magnetic by the ſecond weak magnet alone.

In this experiment it is required that the ſecond magnet, though weaker than the firſt, yet be not ſo ſtrong as to render the ſteel magnetic to its point of ſaturation, *viz.* as much as it can hold; for in that caſe the difference between the effects of the two magnets could not be obſerved.

It appears, therefore, that if in communicating magnetiſm, it be advantageous to uſe weak magnets firſt, and then ſtronger ones, yet the contrary is detrimental.

In reſpect to the ſoft nature of the ſteel that is uſed for artificial magnets, it muſt be obſerved, that ſoft ſteel, or iron, beſides its loſing the magnetic power very eaſily, is ſubject to acquire more than two poles. This may be obſerved in the following manner:—Take two wires, about fourteen inches long, and an eighth of an inch in diameter; and let one be of ſteel, quite hard, and the other of very ſoft ſteel, or of iron, but not of the ſofteſt ſort; then, by means of magnetic bars, render theſe two wires magnetic, one after the other, treating them both alike, and it will be generally found, that the wire of hard ſteel will have acquired only two magnetic poles, one at each extremity; whereas the other wire will have more than two poles.

EXPERIMENT IX.

To improve natural magnets.

The ſame means by which ſteel bars are rendered magnetic, or are ſtrengthened in power, may be applied to increaſe the power of a weak natural magnet, or to render magnetic certain iron ores; but as the natural magnets are in general very ſhort, one can ſeldom do more than place them between ſtrong magnetic bars; however, when they are ſufficiently long, beſides putting them between magnets, they muſt be rubbed with other magnetic bars, in the ſame manner, and uſing the ſame precautions as were recommended in the methods of making artificial magnets.

For this operation it is always proper to remove the armature from the natural magnets if they have any, as is generally the caſe.

CHAPTER VI.

Of the uſe of the Magnetical Inſtruments.

THE magnetical inſtruments may be reduced to three, *viz.* the magnetic bars, the compaſs, and the dipping needle. There needs nothing more be ſaid, in particular, relating to the magnetic bars; their uſe in communicating magnetiſm to other bodies, and in diſcovering the preſence of iron in various ſubſtances, having been already ſufficiently examined.

As to the uſe of the ſimple compaſs, the reader can hardly expect any farther explanation; for as its office is to place itſelf always in the ſame poſition, it ſerves to ſhew the bearing of different places, eſpecially where there is no other fixed object to guide the obſerver. It may be only proper to remark, that at ſea, when the veſſel is very much agitated, and of courſe the card of the compaſs is not ſteady, the beſt way of determining the true direction of the veſſel, is to take a mean between the

extremes

extremes of the vibrations of the needle. Thus, ſuppoſe the card was to vibrate, ſo that its north and eaſt points were the extremes of the vibrations, *viz.* thoſe points did alternately coincide with the fixed line in the box, then the true direction of the veſſel would be *N. E.* or nearly ſo.

But as the magnetic needle ſeldom points due north and ſouth, the bearings of places cannot be accurately known by the compaſs, unleſs its declination be aſcertained; which is eaſily known on land, by means of a variation compaſs placed in the true meridian of the place; but in order to aſcertain it at ſea, by means of the azimuth compaſs, there requires an obſervation of a celeſtial object, and ſome calculation. I ſhall now add the rules neceſſary to perform this operation, but without going any farther than the mere operation; it being incompatible with the nature of this work to explain the aſtronomical and mathematical principles upon which thoſe rules depend.

DEFINITIONS.

The *true amplitude* of a celeſtial object, is an arch of the horizon contained between the eaſt or weſt points of the horizon, and that point of the ſaid horizon which the centre of that celeſtial object cuts in its riſing or ſetting.

The ſun's amplitude is reckoned eaſtward in the morning, and weſtward in the afternoon; and its quantity is accounted from the eaſt or weſt points, towards the north or ſouth. Thus, if the ſun, in ſetting, were to paſs two degrees northward of the weſt point of the horizon, then it is ſaid that the ſun's weſtern amplitude is two degrees north.

The *true azimuth* of a celeſtial object is an arch of the horizon intercepted between the north or ſouth point, and that point where a plain, paſſing through the zenith and the celeſtial object, cuts the horizon.

The ſun's azimuth is reckoned eaſtward

in

in the morning, and weſtward in the afternoon.

It is uſually eſtimated from the ſouth, or from the north, according as it is nearer to the one or to the other of thoſe points. Thus, if it be found, by obſervation, that the plain, which paſſes through the zenith and a ſtar, cuts the horizon juſt midway between the eaſt and the ſouth, then it is ſaid that the ſtar's azimuth is 45° eaſtward of ſouth.

The *magnetic amplitude* of a celeſtial object is its bearing by the compaſs when in the horizon.

The *magnetic azimuth* of a celeſtial object is its bearing by the compaſs when above the horizon.

The variation is found by comparing together the true and magnetic amplitudes or azimuths of celeſtial objects.

PROBLEM

PROBLEM I.

To obſerve at ſea the magnetic amplitude of a celeſtial object with the azimuth compaſs.

Place the compaſs on a ſteady place, from whence the horizon may be clearly ſeen; and, looking through the ſight vanes of the compaſs, turn the inſtrument round till the centre of the ſun, or other celeſtial object, may be ſeen through the narrow ſlit which is in one of the ſight vanes, exactly on the thread which biſects the aperture in the other ſight vane; and when the centre of the celeſtial object, whether riſing or ſetting, is juſt in the horizon, puſh the ſtop, in the ſide of the box, ſo as to ſtop the card, and then read the degree of the card which ſtands juſt againſt the fiducial line in the box, which is the amplitude ſought.

In this operation ſome allowance muſt be made for the height of the obſerver's eye above the level of the ſea.

PROBLEM

PROBLEM II.

To obſerve at ſea the magnetic azimuth of a celeſtial object with the azimuth compaſs.

Situate the inſtrument in a proper place, as before, and looking through the narrow ſlit in one of the ſight vanes, turn the box round, till the centre of the celeſtial object, when above the horizon, may be ſeen to coincide with the thread in the ſlit of the other ſight vane, or till the ſhadow of that thread, when the ſun is obſerved, falls exactly along the line of the index, and in the ſame inſtant ſtop the card; then read the degree, as before, which is the azimuth ſought.

When the veſſel is very much agitated, this, or the preceding obſervation, is beſt performed by two perſons, in the following manner; *viz.* let one look through the ſights, and turn the box till the centre of the ſun coincides with the thread, taking care to keep a conſtant ſight of the coincidence, notwithſtanding the motion of the

the veſſel. He muſt then ſignify that coincidence by word or ſign to the other perſon, who muſt, at the ſame time, obſerve what degree of the card is againſt the fiducial line in the box. When the card vibrates very much, the obſerver muſt take the middle degree between the extremes of the vibrations, as mentioned in the beginning of this Chapter.

N. B. At the ſame inſtant in which the magnetic azimuth of a celeſtial object is obſerved, the altitude of the ſame object muſt be taken with a ſextant.

PROBLEM III.

The latitude of the place of obſervation, and the declination of a celeſtial object, being given, to find the true amplitude of that object.

The analogy is the following, *viz.* the coſine of the latitude is to the radius, as the ſine of the declination is to the coſine of the amplitude. The firſt, ſecond, and third members of this analogy being known,

known, the fourth, *viz.* the amplitude, is found by the common rule of proportion, which, by the help of a logarithmical table, is performed thus:

Add the logarithm of the ſine of declination to the logarithm of the radius, and from the ſum ſubtract the logarithm of the coſine of the latitude. The remainder is the logarithm of the coſine of the amplitude.—For inſtance, in latitude 38° 25′ north, the ſun's declination being 18° 59′; required its amplitude?

Log. ſine of 18° 59′	=	9,51227
Log. of radius -	=	10,00000
Sum - - -	=	19,51227
Log. coſ. of 38° 25′	=	9,89405
Remainder - -	=	9,61822

which is the logarithm of 24° 32′, the amplitude required; which is of the ſame name with the given declination, *viz.* north when the declination is north, as in the preſent inſtance, and ſouth when the declination is ſouth.

PROBLEM

PROBLEM IV.

The latitude of the place of obſervation, the declination of a celeſtial object, and its altitude, being given; required the true azimuth of that object.

If the declination and latitude be both north, or both ſouth, call the codeclination A; but if they be one ſouth, and the other north, add 90° to the declination, and call the ſum A.

Call the difference between the colatitude and coaltitude, B.

Let the half of the ſum of A and B be called D, and the half of their difference be called C.

Then add together the four following logarithms, *viz.* the arithmetic complement of the logarithmic ſine of the colatitude, the arithmetic complement of the logarithmical ſine of the coaltitude, the logarithmic ſine of D, and the logarithmic ſine of C.

Now take half the ſum of thoſe four

logarithms, and that is the logarithmic ſine of half the azimuth required.

For inſtance, in latitude 40° 38′ north, the ſun's altitude in the afternoon was 20° 46′, and its declination 17° 10′ ſouth; required the ſun's azimuth for that time.

The declination + 90°	=	107° 10′	=	A
The coaltitude -	=	69° 14′		
The colatitude -	=	49° 22′		
The difference -	=	19° 52′	=	B
The half ſum of A and B	=	63° 31′	=	D
The half difference of A and B	=	43° 39′	=	C
The arith. compl. of log. ſine of colat.			=	0,11982
The arith. compl. of log. ſine of coalt.			=	0,02917
The log. ſine of D - -			=	9,95185
The log. ſine of C - -			=	9,83901
Sum of thoſe four logarithms -			=	19,93985

the half of which is 9,96992, and this is the logarithmic ſine of 38° 55′; the double of which, *viz.* 77° 50′, is the required ſun's azimuth from the north point of the horizon.

PROBLEM

PROBLEM V.

The true and magnetic amplitudes, or azimuths, of a celeſtial object, being given, to aſcertain the variation of the compaſs for that time and place.

Let the amplitudes, as well as the azimuths, be all reckoned from the north point, which is done by ſubtracting it from 90° when the amplitude is northward of the eaſt or weſt points, or by adding it to 90° when it is ſouthward of the ſaid points; then either the magnetic amplitude is leſs or greater than the true amplitude.

When the magnetic amplitude is leſs than the true, and they are both on the ſame ſide of the north point, their difference is the variation towards the contrary ſide of the north; but if they be on different ſides of the north point, then their ſum is the variation towards the ſame ſide with the true amplitude.

When the magnetic amplitude is greater than

than the true, and they are on the ſame ſide of the north point of the horizon, their difference ſhews the variation towards the ſame ſide; but if they be on different ſides, then their ſum is the variation towards the ſame ſide with the true amplitude. Thus, if the magnetic amplitude is 80° eaſtward of north, and the true amplitude is 82° towards the ſame ſide, then the variation is 2° weſt; and if the magnetic amplitude be 76° eaſtward of north, whilſt the true is 5° weſtward of north, then the variation is 81° weſt.

What has been here ſaid of the amplitudes, muſt be likewiſe underſtood of the azimuths, when the variation is to be eſtimated from them.

PROBLEM VI.

To obſerve the dipping of the magnetic needle.

For this operation nothing more is required than to place the dipping needle in the magnetic meridian, which muſt be aſcertained by means of a good compaſs; but then the two inſtruments muſt be placed ſufficiently far from each other. Sometimes the frame which holds the dipping needle is furniſhed with two ſight vanes on an index, which moves horizontally, and through which a diſtant object, the bearing of which is accurately known, may be kept in view, in order to fix the dipping needle in the magnetic meridian; taking care to let the plain of the needle form the neceſſary angle with the index, or bearing of the diſtant object; which is ſhewn by the divided circle juſt under the index.

To compenſate in ſome manner for the poſſible want of balance, the poles of the dipping needle are uſually reverſed, by means of magnetic bars; ſo that its two ends may be made to dip alternately, and a mean is taken of the two or more obſervations.

The greateſt imperfection of the dipping needle is, that the magnetiſm of the earth acts upon it differently according to its different degrees of inclination, and alſo according to its greater or leſs magnetic power. This property, which at firſt ſight ſeems to be rather paradoxical, wil be rendered evident by the following explanation.

Let A B, fig. 23. of plate II. be the dipping needle; the circle, E F, repreſenting one end of its axis; the lower part F, of which reſts upon the ſupport C D; and E F is the line which paſſes through the centre of the needle, and divides it into two equal parts. It is evident, that before the needle has acquired any magnetiſm, if it be of a uniform figure, and the axis be truly cylindrical, and placed in its middle, the needle muſt remain in any ſituation it is placed, becauſe the perpendicular raiſed from the point where the axis E F touches the ſupport C D, paſſes always through the centre of the needle, dividing it into two equal and like parts; ſo that the needle is perfectly balanced in any degree of inclination. But it muſt be remarked, that though the needle be perfectly balanced, yet when it ſtands in an inclined ſituation, as ſhewn in fig. 24. the part of it G A, which ſtands above the ſupporting point G, is longer than the part B G, which ſtands below it; and this difference increaſes as the inclination increaſes, becauſe the axis of the needle is not a mathematical line, but a body of a certain diameter; ſo that when the needle ſtands perpendicular, the part of it which lies above the ſupporting plain exceeds the other part juſt by the diameter of the axis. Now, when the needle is inclined, as in fig. 24. ſuppoſe that two equal and like forces be applied to its extremities A and B, it is evident, that the force applied to the extremity A muſt have more power to move the needle than that applied to B, becauſe G A is the longeſt lever of the two. This inequality of effect muſt increaſe with the inclination, and is greateſt when the needle ſtands perpendicular.

The application of thoſe forces takes place when the needle is made magnetic; for as the greateſt attractive and repulſive powers between the magnetic poles of the earth, and the poles of the needle, act

upon

upon the extremities A and B, the irregularity above mentioned muſt increaſe with the inclination, and with the degree of the needle's magnetic power.

Various methods have been propoſed, in order to compenſate for this irregularity; but none has yet been found to obviate it perfectly; and they generally introduce new imperfections.

CHAPTER VII.

Promiſcuous Experiments.

EXPERIMENT I.

The magnetic paradox.

UPON the table A B, fig. 25, of plate II. place a piece of iron wire, not above a tenth of an inch long. Let the magnetic bar E F be held at about 4 or 5 inches above the table, with either pole downwards, and in ſuch a place as that the perpendicular let fall from it to the table may touch the table at G, *viz.* two or three inches diſtance from the iron wire; thoſe diſtances, however, are ſubject to a good deal of variety, ariſing from the power of the magnet.

By the action of the magnet the iron wire will elevate one of its ends, as repreſented by C D, forming with the table an angle, which is larger the nearer the wire comes to the point G, where it ſtands quite erect.

In this ſituation, if you give gentle knocks to the table, the wire C D will gradually proceed towards G, every knock making it jump up and advance a little way. The reaſon of which a ſuperficial obſerver would immediately attribute to the attraction between the magnet and the iron wire, which being not ſufficiently ſtrong to raiſe the wire from the table, has juſt power enough to draw it a little nearer to the point G, when the motion of the table lifts it up.

Thus far the experiment ſhews nothing extraordinary;

extraordinary; but if it be repeated with only this variation, *viz.* that the magnet, inſtead of being held above the table, be placed below it, *viz.* at H I; the event will be, that the wire, which will now make an obtuſe angle towards G, as repreſented by K L, on knocking the table will gradually recede from the point G, ſhewing as if the magnet repelled it; which has given to this experiment the name of *magnetical paradox*; for, in fact, the magnet attracts the wire.

This phenomenon reſults from the directive property of the magnet acting at a greater diſtance than the attractive, as has been explained in Chapter VIII. of the firſt Part of this work.

In order to explain the immediate cauſe of this phenomenon, it muſt be conſidered, that the wire K L, fig. 26, plate II. being rendered magnetic by the action of the magnet H, is inclined to it according to the abovementioned laws of the dipping needle; but, on account of its weight, and becauſe it is ſupported not in its centre, but by one end, namely K, which ſtands upon the table, it does not incline ſo much as it ought to do if it were freely ſuſpended by its centre, the end K now being a little higher than its proper ſituation. Let M N be the perpendicular, which paſſes through the centre of the wire. Now when, by the motion given to the table, the wire is made to jump; this, whilſt remaining in the air, will take its proper inclination, as ſhewn by *r* Q, its centre remaining in the ſame perpendicular M N; for the directive power of the magnet H acts at a greater diſtance than its attraction. In this ſituation it is evident, that a perpendicular P O, let fall from the lower extremity *r* of the wire, touches the table in a point farther from G than the point K; and as the wire after the jump comes down to the table again with the proper inclination, *viz.* parallel to *r* Q, it follows, that now its lower end muſt touch the table at O: and thus every knock will force it to recede a little more from the point G, which lies juſt over the magnet H.

The ſame explanation applied to the firſt

part

part of the experiment, will ſhew that the wire muſt in that caſe, *viz.* when the magnet is held above the table, approach continually the point G.

This experiment may be diverſified by uſing iron filings inſtead of the iron wire; for, in the firſt caſe, the filings diſperſed over the table will be gradually collected about the point G; and in the latter caſe, the filings placed about the point G will be gradually forced to recede from that point.

EXPERIMENT II.

To arm natural and artificial magnets.

When a piece of natural magnet is required to be armed, the firſt operation is to find out its poles; then let the magnet be properly ſhaped, *viz.* either in the form of a terrella, or in the more uſual one of a parallelopipedon, in which latter caſe care muſt be had to let the poles fall about the middle of two oppoſite ſurfaces, in which

which direction the magnet ought to have the greateſt length poſſible; it having been often obſerved, that a natural magnet is weakened in power much more by cutting off a part of its length, in the direction of the poles, *viz.* ſo as to make the magnetic axis ſhorter, than in any other direction.

After having ſhaped the magnet properly, let two plates of ſoft iron be made, equal in breadth to thoſe ſurfaces where the poles ſtand, and to project a little way on one ſide of the ſtone, as ſhewn by fig. 1. plate I. Thoſe projections D, D, muſt be much narrower than the breadth of the plates. For magnets ſmaller than one ounce, the lower ſurfaces of the projections to which the iron F is to be applied, need not be larger than about one tenth of an inch; and from a quarter to half an inch is ſufficient for larger magnets.

The thickneſs of the plates C D, C D, muſt be proportioned to the power of the magnet; there being a certain ſize, which is the propereſt for any magnet, a larger or ſmaller thickneſs than which being not ſo advantageous. This thickneſs cannot

be

be eaſily determined without actual trial; hence the beſt way is to make them very thick at firſt; then filing a little off, and examining the power of the magnet alternately; for the power increaſes gradually till a certain degree, at which limit the filing ought to be diſcontinued.

It is indifferent whether the armature be kept on by tying, or by a box, whether of metal or of wood; but as the box is the moſt permanent, this ought to be preferred; and it may be made of any metal excepting iron or ſteel.

When the magnet is ſpherical, the armature, or pieces of iron, muſt be adapted to that ſurface, and each to cover about a quarter of it.

What has been here ſaid about the natural magnet, is equally applicable to the artificial ones; ſo that many magnetic bars may be joined together, and may be armed ſo as to form a very powerful *compound magnet*.

The armature rather ſtrengthens the power of the magnet, for the ſame reaſon for which a piece of iron, affixed to a magnet, tends to render it more powerful.

If

If the artificial magnets be made in the ſhape of a horſe-ſhoe, or of a ſemicircle, then there is no need of the armature, it being ſufficient to join them together, either by rivetting or by a box; and, indeed, even with ſtraight bars the compound magnet may be made without the armature; but then, as the two magnetic poles cannot act in the ſame plain, it is proper to have two of thoſe compound magnets, for the purpoſe of giving, more conveniently, magnetiſm to other bodies*.

* By this means the late Dr. Gowin Knight conſtructed two very powerful artificial magnets, or magazines of magnetic bars, which are now in the repoſitory of the Royal Society. Each of thoſe magazines conſiſts of 240 bars, diſpoſed in four lengths, ſo as to form a parallelopipedon, every length containing 64 bars. All thoſe bars are kept together by means of iron braces, and the whole is ſuſpended upon pivots and a proper wooden pedeſtal or carriage, ſo as to be eaſily placed in any required poſition.—For a farther deſcription of thoſe magnetic magazines, ſee the Phil. Tranſ. vol. LXVI. p. 591.

EXPERIMENT III.

To communicate magnetiſm to a needle by means of electricity.

Place a ſmall ſewing needle, or a piece of ſteel wire, on a table, and connect one extremity of it with the outſide of a charged electric jar or battery *, by means of a wire. Let the other extremity of the needle be connected, by means of another wire, to one branch of the uſual diſcharging rod; then bring the other knob of the diſcharging rod in contact with the knob of the jar or battery, ſo as to make the diſcharge, which paſſing through the needle will render it magnetic, or reverſe its poles, &c. according to the circumſtances enumerated in the firſt Part of this work.

* This jar or battery ought, at leaſt, to have two ſquare feet of coated ſurface, but this depends on the ſize of the needle.——See the writers on electricity for an explanation of the electrical inſtruments.

EXPERIMENT IV.

To ſhew that magnetiſm requires a certain time to penetrate through a piece of iron.

Place a bulky piece of iron, for inſtance, a ſhort piece of about 40 or 50 lb. weight, ſideway of one of the poles of a magnetic needle, ſo as to draw the needle a little out of its natural direction. Then apply one pole of a ſtrong magnet to the fartheſt end of the iron, and you will find that there requires ſome time, *viz.* ſome ſeconds, before the needle be affected by it. This time is different according to the different ſize of the piece of iron, and of the power of the magnet.

EXPERIMENT V.

To imitate the natural magnets.

Take ſome martial æthiops, or, which is more eaſily procured, reduce into very fine

fine powder the ſcales of iron, which fall from red-hot iron when hammered, and which are found abundantly in ſmiths ſhops. Mix this powder with drying linſeed-oil, ſo as to form it into a very ſtiff paſte, and ſhape it in a mould ſo as to give it any form you require, whether of a terrella, a human head, or any other. This done, place it in a warm place for ſome weeks, and it will dry ſo as to become very hard. Then render it magnetic, by the proper application of powerful magnets, and it will acquire a conſiderable power*.

EXPERIMENT

* The late Dr. John Fothergill, giving an account of Dr. Knight's magnetical machine, in the 66th vol. of the Phil. Tranſ. p. 595, mentions the following remarkable circumſtance; which, however, I think muſt have been partly occaſioned by ſome miſtake or miſinformation. "I do not know," *ſays he*, "that the Doctor left behind him any deſcription "of a compoſition he had made to form artificial load-"ſtones. I have ſeen in his poſſeſſion, and many "other of his friends have likewiſe ſeen, ſuch a com-"poſition; which retained the magnetic virtue in a "manner much more fixed, than either any real load-"ſtone, or any magnetic bar, however well tempered.

"In

EXPERIMENT VI.

To weaken, or to deſtroy the magnetiſm of a wire, by bending.

Communicate the magnetic power to an iron wire, or ſoft ſteel wire, of about four or five inches in length, and about $\frac{1}{16}$

" In the natural ones, he could change the poles in an " inſtant, ſo likewiſe in the hardeſt bars ; but in the " compoſition the poles were immoveable. He had " ſeveral ſmall pieces of this compoſition, which had " ſtrong magnetic powers. The largeſt was about half " an inch in breadth, very little longer than broad, " and near a quarter of an inch thick. It was not " armed, but the ends were powerfully magnetic; " nor could the poles be altered, though it was placed " between two of his largeſt bars, and they were very " ſtrongly impregnated. The maſs was not very " heavy, and had much the appearance of a piece of " black lead, though not quite ſo ſhining. I believe " he never divulged the compoſition ; but, I think, " he once told me, the baſis of it was filings of iron, " reduced by long-continued attrition with water to " a perfectly impalpable ſtate, and then incorporated " with ſome pliant matter, to give it due conſiſt- " ence."

of

of an inch in diameter; then roll it round a ſmall ſtick, ſo as to make four or five revolutions round the ſtick; after which, on ſtraightening the wire again, its magnetiſm will be generally found to be quite deſtroyed by the bending, or conſiderably weakened.

The effect is the ſame with ſhorter or longer wires; for if they make one revolution round the ſtick, the effect will take place, which is evidently owing to the ſtreſs or derangement of the particles of the wire, as is rendered more evident by the following obſervation; *viz.* that if the wire be of ſuch ſpringy nature as to recover its ſtraight ſituation if left to itſelf after coiling it round the ſtick, then its magnetiſm is either not at all, or little diminiſhed; ſo that in order to produce the above-mentioned effect, a ſtraining of the parts of the wire is abſolutely neceſſary.

When only the middle of the wire is bent, and its extremities remain ſtraight, then the magnetiſm is ſeldom deſtroyed, or even diminiſhed.

If a piece of magnetic wire be cleft or ſplit lengthways, the parts will have ſometimes contrary, and ſometimes the ſame poles as they had when in one piece. When one part is much thinner than the other, then this ſlender part will generally have its poles reverſed.

PART IV.

NEW MAGNETICAL EXPERIMENTS.

HAVING in the preceding pages taken notice of whatever had been aſcertained with reſpect to magnetiſm, and of the experiments which ſeemed neceſſary to prove thoſe magnetical laws, I ſhall now briefly relate thoſe experiments of mine relative to magnetiſm, which were attended with ſome apparently uſeful event, arranging in each chapter thoſe particulars which are naturally more connected together, without paying any regard to the time in which the experiments were made, and alſo without mentioning a variety of unſucceſsful trials, or of projects not yet verified by actual experience.

CHAPTER I.

Deſcription of a new ſort of ſuſpenſion for a magnetic needle, principally intended for aſcertaining ſmall degrees of magnetic attraction; and ſome remarks on the uſe of quickſilver.

PREVIOUS to the narration of the experiments on the magnetiſm of braſs and of iron in its different ſtates, which are to be related in this Part, I ſhall deſcribe the magnetic needle generally uſed for thoſe experiments, which is ſuſpended in a particular manner; it being a very ſimple, and at the ſame time a very nimble ſort of ſuſpenſion.

Experience having ſhewn, that large magnetic needles are not proper for experiments wherein a very ſmall degree of magnetiſm muſt be aſcertained, and the free motion of the uſual ſmall needles being proportionably more obſtructed by the nature of their ſuſpenſion, even when furniſhed with agate caps, I endeavoured

to

to contrive a ſort of ſuſpenſion which might anſwer the purpoſe better than the needles ſuſpended in the uſual manner; and, after ſeveral attempts, at laſt I conſtructed a chain of horſe-hair, conſiſting of five or ſix links, to which the needle was ſuſpended. Each link is about three quarters of an inch in diameter; and the extremities of each piece of hair, which is formed in a ring, are joined by a knot, and ſecured by a little ſealing-wax. The link on one end of this chain is ſuſpended on a pin in a proper frame, or on any ſupport that may be at hand; and to the link of the other extremity, which lies lowermoſt, a piece of fine ſilver wire is hooked. This wire is about an inch and a half long, and its lower extremity is faſtened round a ſmall and cylindrical piece of cork, through which a common ſewing needle, made magnetic, is thruſt horizontally. Thus the magnetic needle is kept ſuſpended by a hair-chain, the links of which, on account of the ſmoothneſs and lightneſs of the hair, move very freely in each other, and allow the needle more than a whole revolution round its centre, with ſo ſmall a degree of friction as may be conſidered next to nothing. By comparing this needle with others of the beſt ſort now in uſe, I find it much more ſenſible; for when bodies which have an exceedingly ſmall magnetic power are tried, this needle will be frequently attracted by them when the others are not ſenſibly affected.

In order to try farther the delicacy of ſuch ſuſpenſion, I placed a piece of looking-glaſs under the needle, and nearly horizontal; ſo that the image of the needle was ſeen in it. Now, as a fine line had been previouſly marked on the glaſs, things were ſo diſpoſed as that the image of the needle might coincide with the line marked on the glaſs, the eye of the obſerver being placed in a proper point of view; afterwards, by ſhaking the needle either very gently or very quickly, I repeatedly endeavoured to place it out of the magnetic meridian; but every endeavour proved ineffectual, for the needle

dle conſtantly ſettled in the ſame direction, without any ſenſible deviation.

With a needle thus ſuſpended a variation compaſs might be very eaſily conſtructed, and it would, perhaps, be more accurate than thoſe commonly in uſe. For this purpoſe the needle ought to be about three inches long, and the piece of looking-glaſs ought to be fixed upon the index of an Hadley's ſextant, which muſt be placed horizontally under the needle, with its edge or fiducial line in the meridian of the place, in order to obſerve the daily variation of the needle. I have made only a rough model of ſuch a variation compaſs, and it ſeemed to anſwer very well.

This conſtruction appears to have the following advantages over the common ſort: 1ſt. The needle being cylindrical, and without a hole through the middle, would be leſs ſubject to have more than two poles. 2dly. The needle being ſlender, its poles would ſtand more exactly in its axis, which with the common flat needles is ſeldom the caſe. 3dly. It will appear, by a little conſideration, that in this conſtruction there is no need of the needle's centre of motion keeping always in the ſame invariable point, which renders the conſtruction both very eaſy and very accurate. And, laſtly, as the ſextant may be placed at a conſiderable diſtance below the needle, and the reſt of the frame may be made of any ſize, there would be no neceſſity of placing any braſs or other metal ſo near the needle as might affect it in caſe this metal had any magnetiſm, which generally happens with braſs.

In order to examine the magnetiſm of divers ſubſtances, beſides the above deſcribed needle, I uſed to place the ſubſtance to be examined, upon water, ſometimes reſting it upon flat pieces of cork or upon quickſilver, which laſt method, though incomparably nicer than the others, is however very troubleſome on account of the following circumſtances, for which reaſon I generally contented myſelf with uſing only the needle ſuſpended by a hair chain.

In the courſe of the experiments in which

which quickſilver was uſed, I obſerved a remarkable phenomenon, reſpecting the ſurface of that metal; it is, that though ſubſtances will float upon it wonderfully nimble when it is firſt poured out into the open veſſel, yet a ſhort time after, *viz.* after having remained for an hour or two, and often a ſhorter time, in the open veſſel, a piece of braſs or other ſubſtance will by no means float upon it with equal facility; ſo that ſome ſubſtances, which after firſt pouring out the quickſilver into the open veſſel were evidently attracted by the magnet, an hour after were not in the leaſt moved by it.

The only effectual method which would render the quickſilver again fit for the purpoſe, was to paſs it through a funnel of paper, as deſcribed in page 180; which operation I have been obliged ſometimes to repeat four or five times in about two hours time.

There ſeems to be formed a kind of cruſt upon the ſurface of the mercury thus expoſed, which, though inviſible by mere inſpection, may be perceived by mov-

ing

ing the floating ſubſtance upon it; for ſoon after, having paſſed the quickſilver through the paper funnel, the floating ſubſtance, when moved, ſeems to proceed by itſelf; whereas ſome time after the ſame ſubſtance, when moved, ſeems to communicate that motion to the adjacent quickſilver, and to drag it along with itſelf, ſomewhat like what happens when one moves ſomething that floats upon the ſurface of a liquor which begins to coagulate.

The formation of this cruſt I attributed to the imperfect metals, which, though in ſmall quantities, are generally amalgamated with the common ſort of quickſilver; for that amalgamation tending to dephlogiſticate thoſe metals, the half calcined part floats at the top; and it is moſt likely that the ſaid dephlogiſtication goes on very quick in the open air. What ~~invalidates~~ strengthens this ſuppoſition is, that the purer the quickſilver is, the leaſt is the cruſt formed, or oppoſition made to the floating ſubſtances; however, I have obſerved it in ſome meaſure, even in the pureſt quickſilver, and am inclined to think, that it muſt be

partly

partly owing to ſome moiſture or inviſible duſt, which adheres to the ſurface of the quickſilver that is expoſed to the atmoſphere.

CHAPTER II.

Examination of the magnetical properties of braſs.

A FEW years ago, being intent on making ſome magnetic experiments, in which braſs was concerned, I uſed to examine firſt whether the pieces of braſs had any magnetiſm or not, and rejected thoſe pieces which had an evident degree of that power. In the courſe of thoſe experiments I remember to have obſerved, that thoſe pieces of braſs which had been hammered were generally magnetic, and much more ſo than others; in conſequence of which I made no uſe of hammered braſs in thoſe experiments. But about a year and a half ago, having ordered a theodolite at a philoſophical inſtrument ſhop, I particularly enjoined the workmen to try the braſs, both ſoft and hammered, before they worked it, and to make no uſe of that which had an evident degree of magnetic power. They found, that hammered braſs, even ſuch as before the hammering had no magnetiſm, could afterwards diſturb the magnetic needle very ſenſibly. Theſe obſervations induced me to make the following experiments.

Experiment I. An oblong piece of braſs, weighing ſomewhat leſs than half an ounce, being examined, by preſenting every part of its ſurface to the ſuſpended needle, ſhewed no ſign of magnetiſm whatever. It was then hammered for about two minutes; the conſequence of which was, that it became magnetic ſo far as to attract either end of the needle from about a quarter of an inch diſtance. This ſame piece of braſs being now put into the fire ſo as to become red-hot, by which means it was ſoftened, and when cold being preſented to the ſuſpended needle, its magnetiſm was found to be entirely gone. Hammering made it again magnetic; ſoftening by fire took the magnetiſm away a ſecond time: and thus the magnetiſm was repeatedly given it by hammering, and was deſtroyed by ſoftening; ſometimes ſhewing to have acquired a ſenſible degree of that power even after two or three ſtrokes of the hammer.

Experiment II. The reſult of the firſt experiment would naturally induce one to ſuſpect, that the hammer and anvil might have imparted ſome ſmall quantity of ſteel to the braſs, which rendered it magnetic; and that this magnetiſm was deſtroyed in ſoftening the braſs, inſomuch as the fire calcined the ſmall quantity of ſteel that had adhered to it. In conſequence of which conſideration, I took other pieces of braſs beſides that uſed before, and hammered them between card-paper, changing the pieces of paper as often as was neceſſary, ſince they were eaſily broken by the hammer; but the pieces of braſs became conſtantly magnetic by the hammering, and their magnetiſm was deſtroyed by fire.

In this experiment I generally gave to the braſs not above thirty ſtrokes with the hammer.

Experiment III. Still ſuſpecting that the hammer and the anvil might have imparted ſome ſmall quantity of iron to the braſs, becauſe the pieces of card-paper ſometimes were broken by the firſt or ſecond ſtroke, in which caſe either the hammer or the anvil touched the braſs, I hardened a piece of braſs by beating it between two large flints; *viz.* uſing one for the hammer, and the other for the anvil. The piece of braſs became magnetic, though in this caſe it ſeemed to have acquired not ſo much power as when it had been hardened with the hammer; but it muſt be obſerved, that the flints being rough and irregular, the piece of braſs could not be hardened by them ſo eaſily, or ſo equally, as by the other method.

The flints, being examined both before and after the experiment, were found to have not the leaſt degree of magnetiſm.

Experiment IV. A piece of braſs, which by hammering had been rendered ſo ſtrongly

magnetic

magnetic as to attract either pole of the needle from about a quarter of an inch diſtance, was put into a crucible, together with a conſiderable quantity of charcoal duſt, which ſurrounded it every where. The crucible was covered with clay, and being placed into the fire, was kept red-hot for about ten minutes. After cooling, the piece of braſs was taken out of the crucible, and being examined, was found to have entirely loſt its magnetiſm. The object of this experiment was to aſcertain whether the loſs of magnetiſm, in a piece of braſs that was ſoftened, was owing to the calcination of the ferruginous particles, which, notwithſtanding the preceding experiment, might ſtill be ſuſpected to be imparted to it; becauſe in this way of ſoftening the braſs, the ferruginous particles being ſurrounded with charcoal duſt, could not have been calcined; hence the braſs ought not to have loſt its magnetiſm, which however was not the reſult of the experiment.

Experiment V. One of thoſe pieces of braſs, which had been uſed for the foregoing

going experiments, and which had been deprived of magnetiſm by fire, was hammered between two large and pretty thick pieces of copper, which had not the leaſt magnetiſm; and after a few ſtrokes of the hammer, it became ſenſibly magnetic.

Experiment VI. In order to examine the difference of this property in braſs of various kinds, I have tried a great many pieces of Engliſh as well as foreign braſs; ſome of which was very old, and ſo fine and uniform, that an eminent watchmaker of my acquaintance uſed it for the very beſt ſort of watch-work. But I find that they moſtly have the property of becoming magnetic by hammering, and of loſing that power when ſoftened. There are, however, ſome pieces which acquire no magnetiſm by the hammering, though they are rendered equally hard by it as thoſe which acquire the magnetiſm. By attentively examining them, I have not yet been able to diſtinguiſh, without a trial, which pieces are capable of acquiring magnetiſm, and which not; the colour, apparent texture,

and

and degree of ductility, ſeeming to afford no ſure indication.

Experiment VII. The preceding experiments ſeem to render evident the exiſtence of magnetiſm, or of the power of attracting and being attracted by the magnet, independent of iron; yet an objection may be made againſt this conſequence, which is, that the braſs which becomes magnetic by hammering, and loſes that power by ſoftening, might contain a ſmall quantity of iron, to which that magnetiſm was owing; and that this iron, or martial earth, diſperſed through the ſubſtance of the braſs, might become phlogiſticated by the action of the hammering; inſomuch as the braſs being forced into a ſmaller ſpace, might perhaps give ſome of its phlogiſton to the martial earth, and thus render it ſenſibly magnetic; and, on the contrary, the action of the fire in ſoftening, might remove that phlogiſton from the martial earth, and give it again to the braſs; hence the former, remaining quite dephlogiſticated, would no longer ſhew any ſigns of magnetiſm. The conſideration that iron may be dephlogiſticated or calcined more eaſily than braſs, gave an apparent weight to the ſuppoſition; but the following experiments ſeem to expel every doubt.

Having choſen a piece of braſs, which would acquire no magnetiſm by hammering, I placed it upon an anvil, together with a conſiderable quantity of *crocus martis,* which crocus had no action on the magnetic needle; then began hammering the braſs, and turning it frequently, in order to let part of the crocus adhere to it; and, in fact, the crocus had, in ſeveral places, been faſtened ſo well into the braſs, that hard wiping with a woollen cloth would not rub it off. The braſs appeared red in thoſe places; but, after having been hammered for a long time, it acquired no magnetiſm whatever. The hardening, therefore, could not render the iron calx ſo far phlogiſticated as to affect the magnetic needle.

Experiment VIII. In order to diverſify the preceding experiment, I drilled a hole, about one-eighth of an inch long, and little more than one-fiftieth of an inch in diameter,

eter, into a piece of braſs that was not rendered magnetic by hammering, and filled it with *crocus martis*; then I hammered the piece of braſs, thus incloſing the calx of iron, and afterwards preſented it to the ſuſpended magnetic needle; but there was not the leaſt ſign of attraction: the martial earth, therefore, had not acquired any phlogiſton from the braſs by the action of hammering.

Experiment IX. The ſame piece of braſs, containing a ſmall quantity of calx of iron, was put into the fire, and was made quite red-hot, in which ſtate it remained for about three minutes. Then, after cooling, it was preſented to the magnetic needle, and this was attracted by the braſs only in that place wherein the calx of iron was contained. The action, therefore, of the fire had rendered the martial earth ſo far phlogiſticated as to attract the magnetic needle; hence, if the magnetiſm of braſs were owing to any ferruginous matter contained in it, a piece of braſs ought to become magnetic when ſoftened;

which is contrary to the foregoing obſervations.

Experiment X. A hole, ſimilar to that mentioned in the VIIIth Experiment, was drilled into a piece of braſs that would not become magnetic by hammering, and into it was put ſome black calx of iron, which was ſo far phlogiſticated as to be attractable by the magnet, and the hole was cloſed by a few ſtrokes of the hammer. In conſequence of this, the piece of braſs, when preſented to the ſuſpended needle, would attract it only about that place where the magnetic calx was contained. This attraction was very weak. The piece of braſs thus prepared, was then put into the fire, and was kept for about ſix minutes in a heat very little ſhort of that neceſſary to melt braſs, and after cooling I preſented it to the needle, expecting that the fire might have dephlogiſticated the calx of iron ſo far as not to let it act any longer upon the needle; but the attraction appeared to be of the ſame degree it was before the heating.

It

It ſeems, therefore, clear, that the magnetiſm acquired by braſs, when hammered, is not owing to iron contained in it; and conſequently, that *magnetiſm, or the power of being attracted by, and attracting, the magnet, may exiſt independent of iron.*

Experiment XI. A ſmall quantity of iron was mixed, by means of the blow-pipe, with about four times its weight of ſuch braſs as would not become magnetic by hammering. The whole globule weighed about two grains, and it attracted the magnetic needle very powerfully. I then melted this globule of braſs and iron with about fifty grains of the ſame ſort of braſs as had been uſed before. After cooling, the whole lump of braſs appeared to have very little power upon the magnetic needle, every part of its ſurface attracting one end of the ſuſpended needle, ſo as to let it juſt adhere to it when the air was not at all diſturbed. But this weak and hardly perceivable degree of magnetiſm was not increaſed by hammering, nor annihilated by ſoftening.

In this experiment I thought to have

fuſed and incorporated together braſs and iron; but ſome ſubſequent trials gave reaſon to believe, that the iron is concealed in ſome part or other of the melted braſs, rather than equably diffuſed through the ſubſtance of the latter; and the principal reaſon for this ſuppoſition is, that when thoſe pieces of mixed metal are tried upon the quickſilver, ſome points in their ſurfaces are generally attracted by the magnet in preference to others.

It muſt here alſo be obſerved, that having repeated moſt of the preceding experiments, by examining the pieces of braſs upon quickſilver, and preſenting the magnet to them, inſtead of preſenting them to the needle, the reſult was, that very ſeldom a piece of braſs occurred, which was not affected by the magnet; and even when they were not affected by it, their indifference was not very clear and deciſive; and indeed there are very few ſubſtances in nature, which, when examined by this means, are not, in ſome degree, attracted by the magnet; ſo general is the diſperſion of iron, or ſuch is the tendency

tendency which moſt bodies have towards the magnet.

Such braſs which in the former experiments appeared to have no magnetiſm naturally, nor to acquire any by hammering, was now found to be moſtly magnetic, though in ſo ſmall a degree as to be diſcoverable only when floating upon quickſilver; but thoſe pieces of braſs which naturally had not any degree of magnetiſm ſufficient to affect the needle, nor acquired any by hammering, but yet ſhewed ſome tendency towards the magnet when floating upon quickſilver, never, or very ſeldom, had that tendency increaſed by hammering.

It is now proper to collect, under one point of view, all the obſervations which have been deduced from the foregoing and other experiments relating to the magnetic properties of braſs. It appears, therefore,

1ſt. That moſt braſs becomes magnetic by hammering, and loſes the magnetiſm by annealing or ſoftening in the fire, or at leaſt its magnetiſm is ſo far weakened by it as afterwards to be only difcoverable when fet to float on quickfilver.

2dly. That the acquired magnetifm is not owing to particles of iron or fteel imparted to the brafs by the tools employed, or naturally mixed with the brafs.

3dly. Thofe pieces of brafs which have that property, retain it without any diminution after a great number of repeated trials, *viz.* after having been repeatedly hardened and foftened. But I have not found any means of giving that property to fuch brafs as had it not naturally.

4thly. A large piece of brafs has generally a magnetic power fomewhat ftronger than a fmaller piece; and the flat furface of the piece draws the needle more forcibly than the edge or corner of it.

5thly. If only one end of a large piece of brafs be hammered, then that end alone will difturb the magnetic needle, and not the reft.

6thly. The magnetic power which brafs acquires by hammering has a certain limit, beyond which it cannot be increafed by farther

farther hammering. This limit is various in pieces of braſs of different thickneſs and likewiſe of different quality.

7thly. Though there are ſome pieces of braſs which have not the property 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 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.

8thly. 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,

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.

9thly. I have likewiſe often obſerved, that a long continuance in 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 farther 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 calaminaris*) alſo poſſeſſes that property; at at leaſt, all the pieces of it, which I have tried, have that property.

From theſe obſervations it follows, that when braſs is to be uſed for the conſtruction of inſtruments wherein a magnetic needle is concerned, as dipping needles, variation compaſſes, &c. the braſs ſhould be either left quite ſoft, or it ſhould be choſen of ſuch a ſort as will not be made magnetic by hammering; which ſort, however, does not occur very frequently.

CHAPTER III.

Examination of the magnetic properties of ſome other metallic ſubſtances.

THE reſult of the experiments on braſs induced me to examine other metallic ſubſtances, and eſpecially its components, *viz.* copper and zinc: though the reſult of the experiments has not been very remarkable, excepting with platina, which

which metal has properties in great meaſure analogous to thoſe of braſs.

Having examined various pieces of copper, by means of the ſuſpended magnetic needle, and having never found them magnetical, except only ſometimes in ſuch places which had been filed, and where ſome particles of ſteel might have been left by the file, I next proceeded to hammer ſome pieces of it, not only in the uſual way, but likewiſe between flints: the reſult, however, was very dubious; for though, in general, they had no effect whatever on the needle, yet ſometimes I thought the needle was really attracted by ſome pieces of hammered copper; but then this attractive power was ſo exceedingly ſmall as not to be depended upon.

Zinc, either not hammered, or hammered as far as could be done without breaking it, ſhewed no ſigns of attraction whatever, when preſented to the magnetic needle. Neither had a mixture of zinc and tin any action upon the needle.

A piece of broken reflector of a teleſcope, which conſiſted of tin and copper; a mixture a mixture of tin, zinc, and a little copper; a piece of ſilver, both ſoft and hammered; a piece of pure gold, both ſoft and hammered; a mixture of gold and ſilver, both hard and ſoft; and another mixture of a great deal of ſilver, a little copper, and a leſs quantity of gold, either before or after hammering, had not the leaſt action on the magnetic needle.

Nickel is a metallic ſubſtance, which has been ſuſpected to poſſeſs ſome degree of attraction towards the magnet, independent of iron; and this ſuſpicion has been founded upon obſerving, that nickel retained its magnetiſm after having been repeatedly purified*. There are, however, perſons who have denied the magnetiſm of purified nickel; and I have ſeen ſome pieces of it which did not, in the leaſt, affect the magnetic needle. It is probable that thoſe pieces were not pure nickel, and perhaps ſome cobalt was contained in them; but I ſee no reaſon why the nickel, when alloyed with a little co-

* See Kirwan's Mineralogy, p. 342 and 367.

balt,

balt, ſhould ſhew no attraction towards the magnet, if that property did really belong eſſentially to it.

Platina was the metal I laſt examined, and the experiments made with it ſeem to deſerve particular attention.

Experiment I. A large piece of platina, which after having been precipitated from its ſolution in *aqua regia*, had been fuſed, or rather concreted together, being preſented to the ſuſpended magnetic needle, ſhewed not the leaſt ſign of magnetiſm. It was then hammered; but after the third or fourth ſtroke of the hammer it broke into many pieces, ſeveral of which being tried, ſhewed no attraction, nor could any of the fineſt particles be attracted by the magnet preſented very nearly over them. The broken ſurface of this piece of platina was full of cavities, ſome of which were large, and others juſt diſcernible; and altogether the metal ſeemed to have undergone an imperfect fuſion.

Experiment II. The grains of native platina were examined next, by putting a magnet juſt over them; but the magnet attracted

attracted not above ten or twenty particles out of about half an ounce of platina: and those which were attracted had little or no shining metallic appearance, like the rest, and were exceedingly small.

Experiment III. Having picked out several of the largest grains of platina, I presented the magnet to them; but they were not in the least attracted by it. One of those grains was then hammered; by which means, after about eight or ten strokes, it was spread into a plate, about a tenth of an inch in diameter, and nearly circular; afterwards, the magnet being presented to it, the former attracted it from the distance of about one-twentieth of an inch. The other grains being all hammered one after the other, were rendered by it so far magnetic as to be attracted by the magnet, and to disturb the magnetic needle when presented to it. But there were some amongst them which acquired no magnetism at all, though they had been purposely hammered much longer than the others.

As far as I could observe, those pieces

which would not acquire any magnetiſm by hammering, had not a very ſhining appearance before the hammering, though afterwards they could not be diſtinguiſhed from the others by their appearance; and they ſeemed not to ſpread under the hammer ſo eaſily as the others.

In general, three or four ſtrokes are ſufficient to render a grain of platina evidently attractable by the magnet; but about ten ſtrokes give it the full power it is ſuſceptible of.

Experiment IV. Thoſe grains of platina, which in the preceding Experiment the hammering had rendered capable of being attracted by the magnet, being put upon a charcoal, were made red-hot by means of a blow-pipe; and afterwards, being preſented to the magnet, and likewiſe to the ſuſpended needle, they ſhewed not the leaſt ſign of attraction. Heat, therefore, deprives them, as well as braſs, of the property acquired by hammering. A ſecond hammering rendered them again attractable, though not ſo quickly, nor in ſo great a degree as it had done the firſt time. However,

ever, it muſt be obſerved, that the pieces of platina having been rendered flat and thin by the firſt hammering, could not be ſo eaſily ſtruck, nor ſpread much more, by the ſecond.

Experiment V. When the grains of platina were examined by the magnet whilſt floating on the ſurface of quickſilver, almoſt every one of them was attracted in a ſmall degree; and this attraction was generally ſomewhat increaſed by the hammering, even in thoſe which had it never increaſed ſo far as to attract the magnetic needle.

If it be true, as thoſe experiments ſeem to prove beyond a doubt, that the power of being attracted by the magnet may exiſt, or may belong to other ſubſtances, independent of iron, it muſt follow, that the attraction of a few particles of any unknown ſubſtance by the magnet is not a ſure ſign of the preſence of iron. Hence thoſe ſubſtances, which hitherto have been conſidered as containing ferruginous particles, for no other reaſon but becauſe the magnet attracted them in a ſmall degree, muſt be conſidered as dubious; and the concluſion of the exiſtence of iron ought not to be admitted, except when thoſe particles, which have been ſeparated by the magnet, appear to be iron by ſome other trial; for though it be true, that iron is always attracted by the magnet, yet it does not hence follow, that whatever is attracted by the magnet muſt be iron.

CHAPTER IV.

Experiments and obſervations relating to the attraction between ferruginous ſubſtances and the magnet, in their different ſtates of exiſtence.

IT is a propoſition well eſtabliſhed in magnetics, that ſoft iron, or ſoft ſteel, acquires magnetiſm very eaſily, and loſes it with equal facility; but that hard ſteel acquires that power with difficulty, and afterwards

afterwards retains it obſtinately. From the conſideration of thoſe properties, I was led to imagine, that if a piece of ſteel, whilſt red-hot, were placed between magnetic bars, and whilſt ſtanding in that ſituation cold water were to be ſuddenly poured upon it, ſo as to harden it, there might, perhaps, be obtained an artificial magnet, much more powerful than what can be produced by the ordinary way; becauſe the magnetic bars, employed for ſuch purpoſe, would communicate a great degree of magnetic power to the ſteel, when red-hot, and conſequently ſoft, which power would be fixed upon the ſteel by the hardening.

In order to put this project to the trial, ſix magnetic bars were ſo diſpoſed, in an oblong earthen veſſel, as that the north poles of three of them might be oppoſite the ſouth poles of the three others, forming two parcels of bars, lying in the ſame direction, and about three inches aſunder, which was nearly the length of the ſteel bar which was intended to be rendered magnetic. Things being thus diſpoſed, the ſteel bar was made quite red-hot, and in that ſtate was placed between the magnetic bars; after which, cold water was immediately poured upon it, which rendered it ſo hard as not to admit being filed: its magnetiſm was found to be conſiderably ſtrong, but by no means extraordinary. From repeated trials with ſteel bars of different ſizes, and by uſing a greater or leſs number of magnetic bars, I found, that ſhort ſteel bars acquire a proportionably greater degree of magnetiſm, by this method, than thoſe which were longer; that the magnetiſm in the longer bars is not proportionably as ſtrong, principally becauſe the artificial magnets, being placed at their extremities, have very little power on thoſe parts of the pieces of ſteel which are nearer its centre; and, laſtly, that when, in order to remedy the juſt-mentioned inconvenience, more magnets are placed nearer the middle of the ſteel bar, then this piece of ſteel generally acquires many ſucceſſive magnetic poles.

Upon the whole, it ſeems that though this method alone be not ſufficient to communicate to ſteel bars an extraordinary degree of magnetiſm, yet it may be of great uſe in conſtructing large artificial magnets; for if thoſe bars, inſtead of being hardened in the uſual way, by plunging them, when red-hot, in water, be hardened whilſt ſtanding between powerful magnets, they will thereby acquire a conſiderable degree of magnetic power, without any additional trouble to the workman. They may then be poliſhed, after which they may be rendered more ſtrongly magnetic by the uſual method of touching them with other magnetic bars; whereas it is a very laborious operation to render magnetic large bars of hardened ſteel from the very beginning, *viz.* when they have none of that power.

In the courſe of performing thoſe trials, I frequently obſerved, that the pieces of ſteel, whilſt they were red-hot, ſeemed not to be attracted by the magnets; ſo that the leaſt ſhock, and even the pouring of the water, could remove them from the proper ſituation, which rather ſurpriſed me; becauſe it has been aſſerted by ſome

 authors,

authors, that the magnet attracts red-hot iron as well as cold. Kircher especially says, that he tried the experiment*, and found that the piece of iron, heated so as to be hardly discernible from a burning coal, was attracted by the magnet as easily as when cold; and he even assigns a reason why the power of a magnet is destroyed by a great degree of heat; whereas the red heating of the iron will not prevent its being attracted by the magnet. The reason he gives is, that the fire corrupts and calcines the magnet, but purifies the iron. The following experiments were made in order to ascertain this matter:

I kept a piece of steel in the fire till it was quite red-hot, and in that state presented the magnet to it, so as to touch it repeatedly in various places; but no sign of attraction could be perceived before the redness disappeared. I mean, however, such redness as may be evidently seen in the clear day-light; for, as was shewn by other experiments, when the magnet be-

* De Magnete, lib. I. p. II. theorem XXXI.

gins

gins to attract the heated iron, the redneſs of the latter can ſtill be ſeen in the dark.

Having repeated the experiment with different pieces of iron, and of ſteel, the reſult was conſtantly the ſame, *viz.* whilſt the iron or ſteel remained quite red-hot, or white-hot, the magnet did not attract it; but the attraction began when the degree of redneſs, which is clearly perceivable in the day-light, began to diſappear; and it was as ſtrong as ever when the iron was cooled a little more than when the redneſs quite diſappeared in the dark. In regard to this limit, or maximum of attraction, I think I have obſerved, as well as the nature of the experiment would permit, a difference between ſteel and iron; which is, that in the ſteel the maximum of attraction follows the diſappearance of the red heat ſooner than in iron.

This experiment is ſubject to two ſources of miſtake, which perhaps miſled Father Kircher, and which it is neceſſary to mention, for the ſake of others who wiſh to repeat it. The firſt is, that when a piece of iron, of no great extent, is red-hot, or even white-hot, in one place, and below a red heat in other parts, the magnet will frequently attract it, though the red-hot ſide be preſented to it. The ſecond cauſe of miſtake is, that when a ſmall piece of iron or ſteel, as a common ſewing needle, is made red-hot, and is then preſented to the magnet, if the magnet touch it, that contact cools it inſtantly below the neceſſary degree of heat, and of courſe the attraction takes place. It is owing to this laſt cauſe that I have not yet been able to aſcertain, whether the attraction between the magnet and the iron be quite annihilated, or only diminiſhed to a great degree, by rendering the iron red or white hot; ſo that I can only ſay with certainty, that a magnet will not attract a certain piece of iron red-hot or white hot; whereas it will attract another piece of iron, at leaſt fifty times bigger, if it be cold, or below a red heat.

To try this experiment in a different and more convincing manner, I heated a large iron nail till it was white-hot, and

in

in that ſtate placed it upon an earthen ſupport, near one pole of the magnetic needle, ſo as to lie not in the ſame direction, but on one ſide of it. Then, looking attentively on the graduated circle of the compaſs, I obſerved, that the needle was not in the leaſt moved from its natural ſituation, whilſt the nail remained red-hot; but as ſoon as the redneſs began to diſappear, the needle advanced towards the nail, and a few ſeconds after the needle pointed directly towards it.

I tried whether, in this experiment, any difference was occaſioned by the magnet's being natural or artificial; but, as it might be expected, there was none.

In purſuance of thoſe magnetic experiments wherein heat is concerned, I tried the effects which took place when the magnet was heated; but, as the diminution of its power by heating, and an increaſe of it by cooling, were obſerved and deſcribed by the late Mr. Canton*, I ſhall only add a circumſtance, which may perhaps be new. It is, that an artificial magnet, after having had its power diminiſhed

* Phil. Tranſ. Vol. LI.

by

by heating, does not recover it intirely again by cooling; having conſtantly found, that the magnets which had been heated, after cooling would never hold as great a weight of iron as they did before. The heat to which thoſe magnets were expoſed never exceeded that of boiling water. This was rendered more evident by the following experiment.

A magnetic bar was placed, in an earthen veſſel, at ſome diſtance from the ſouth pole of the needle of a very good compaſs; by the action of which magnet that end of the needle was drawn ſeveral degrees from the magnetic meridian, or from the direction in which it ſtood before. In this ſituation of the apparatus, boiling water was poured into the veſſel wherein the magnet ſtood, in conſequence of which the needle went back two degrees and a half. Some time after, when the water was quite cold, the needle was found nearer to the magnet, but not ſo near as it ſtood before the hot water was poured into the veſſel.

Next to the effects of heat, I was de-

ſirous

ſirous of trying what could be effected by decompoſing the iron; and for this purpoſe an earthen veſſel, containing about two ounces of iron filings, was placed near the ſouth end of the needle of the compaſs, by which the needle was drawn a little out of its natural direction. Having marked where the needle now ſtood, ſome water firſt, and then ſome vitriolic acid, were poured upon the filings, which occaſioned a briſk effervеſcence, and a copious production of inflammable air; but ſoon after the beginning of the effervеſcence, I was ſurpriſed to obſerve, that the needle came nearer to the veſſel, ſhewing that the attraction between the needle and the filings had been increaſed by the action of the vitriolic acid upon the latter, which is contrary to what could have been expected; for if we conſider that the power of a magnet is diminiſhed by heat, and that red-hot iron has either no attraction at all, or an exceedingly ſmall degree of it, towards the magnet, we might have concluded, that the action of the vitriolic

vitriolic acid upon iron would immediately diminiſh its attraction, beſides the other ſtrong reaſon, ariſing from the dephlogiſtication of the iron occaſioned by the effervefcence; and, in fact, ſome time after, when the violence of the efferveſcence, and of courſe the production of inflammable air, begins likewiſe to diminiſh; and at laſt, when the efferveſcence is hardly perceptible, the needle is found to ſtand farther from the veſſel containing the filings, &c. than it ſtood before the vitriolic acid was added, which diminution of attraction is certainly owing to the loſs of phlogiſton; it being well known, that iron is leſs and leſs attracted by the magnet in proportion as it approaches nearer to the calcined ſtate.

As a ſingle experiment ought not to be depended upon, when an error may be occaſioned by many concurring circumſtances, I repeated this experiment with great precaution, taking care that nothing might ſhake the needle, or the reſt of the apparatus; but the reſult was nearly the

ſame,

ſame, the attraction between the iron filings and the needle being at firſt increaſed by the action of the vitriolic acid.

In order to aſcertain that this effect was not owing to the heat generated by the efferveſcence, the pot, with ſome iron filings, was placed near the magnetic needle, as before; then ſome boiling water was poured upon the filings, which heated them much more than the diluted vitriolic acid could have done; but the magnetic needle was not moved in the leaſt from its original ſituation.

The ſuſpicion which occurred next was, whether the efferveſcence might not agitate the iron filings, ſo as to bring a greater number of them to that ſide of the veſſel which ſtands contiguous to the magnetic needle. In order to obviate this objection, the experiment was repeated with a ſingle piece of ſteel wire, twiſted in various directions, ſo as to be admitted into the pot; in which caſe the metal preſented a large ſurface to the acid, and it was not ſubject to be moved by the efferveſcence.

The

The reſult was ſimilar to that obſerved with the filings, *viz.* the attraction was increaſed by the action of the acid on the wire: and here follows the particular account of the experiment.

About ſix yards of clean ſteel wire, ſomewhat leſs than one-fiftieth of an inch in diameter, being twiſted in various directions, was put into an earthen veſſel, which was placed near the ſouth end of the magnetic needle, which in conſequence of that was drawn from its natural ſituation, *viz.* from 281° to 280°. After adding the diluted vitriolic acid, a ſtrong efferveſcence commenced, and the needle came to 279° 47′. About five minutes after, it ſtood at 279° 35′; five minutes after this, it ſtood at 279° 30′. And a little after this obſervation, it apeared to be even ſomewhat nearer to the pot than the abovementioned point. The experiment was then diſcontinued; and on removing the pot, the needle went back to its original ſituation, *viz.* 281°, which ſhewed, that its alteration, during the procefs, was occafioned by the action of the acid on the fteel, and not by any extraneous caufe.

On examination, the wire was found only blackened on its furface, but not nearly confumed; I had, therefore, the curiofity of trying the fame wire again, and accordingly it was placed, in the fame veffel, near the magnetic needle, which attracted the latter from its original fituation 281° to 280°. After having added the acid, the needle came nearer, as in the preceding experiment; and a fhort time after it ftood at 279° 30′, at which time the pot was removed, there being no occafion to continue the experiment any longer.

On pouring the liquor out of the pot, the wire did not appear to be much wafted. The pot was then replaced near the needle, fo as to attract it a little, as before; but on pouring boiling water upon the wire, a pretty brifk effervefcence took place, and the needle was, in confequence, attracted ftill nearer. This experiment fhewed, that though the diluted acid had

been

been poured out, yet there remained a quantity of it adhering to the wire, which was ſufficient to renew the effervefcence, when aſſiſted by the heat of boiling water.

Upon the whole, it appears, that the action of vitriolic acid upon iron or ſteel increaſes their attraction towards the magnet; that this increaſe of action has a limit, after which it begins to decreaſe; and that this limit ſeems to come ſooner when iron than when ſteel is uſed; but, however, with regard to this laſt particular I am not yet quite certain, ſince, in the experiments hitherto made, the variety in the ſhape or bulk of the iron or ſteel may have occaſioned a conſiderable difference.

After the reſult of thoſe experiments, it was natural to examine the effect which other acids might have on iron and ſteel; therefore the above-mentioned experiment of the ſteel wire was repeated with nitrous inſtead of vitriolic acid; the reſult of which was, that the attraction between the magnetic needle and the wire was increaſed, but not ſo much as when vitriolic acid had been uſed. The maximum

of

of the attraction ſeemed to come ſooner when nitrous than when vitriolic acid is uſed; after which limit the attraction decreaſes much faſter in the former than in the latter caſe, which is evidently owing to the metal being more eaſily dephlogiſticated and diſſolved by the nitrous than by the vitriolic acid.

The marine acid was tried next; but, notwithſtanding all the precautions I could take, it always occaſioned a very weak efferveſcence, and the needle was not in the leaſt affected by it.—A ſtrong effervefcence ſeems neceſſary to increaſe the attraction between the magnet and iron or ſteel.

CHAPTER V.

Promiſcuous experiments, and ſome thoughts concerning the cauſe of the variation of the needle.

THE following experiment will ſhow, that an exceedingly ſmall quantity of iron will render a body ſenſibly capable of being attracted by the magnet. Having choſen a piece of Turkey-ſtone, which weighed about an ounce, I examined it by a very ſenſibly magnetic needle, and it did not ſhew the leaſt degree of attraction, the needle not being moved from its uſual direction by the vicinity of any part of the ſurface of the ſtone; I then weighed a piece of ſteel, with a pair of ſcales that turned with the twentieth part of a grain, and afterwards drew one end of it over the ſurface of the ſtone in various directions. This done, the piece of ſteel was weighed again, and was found to have loſt ſo ſmall a part of its weight as not to be diſcernible by that pair of ſcales; yet the Turkey-ſtone, which had acquired only that ſmall quantity of ſteel, affected the magnetic needle very ſenſibly.

Chemiſtry ſeems not to afford any means by which ſo ſmall a quantity of iron may be deciſively detected in a body that weighs one ounce. Hence it follows, that though no iron can be diſcovered in a body by chemical methods, yet it ſhould not be concluded, that the ſaid body, if it affect the magnetic needle, does not owe its magnetiſm to ſome ſmall quantity of iron concealed in its ſubſtance.

Having examined the magnetiſm which iron acquires from the earth by mere poſition, in bars of various lengths, I always found them poſſeſſed of only two poles, even when the bars were about twenty feet in length; one half being poſſeſſed of one polarity, and the other half of the contrary polarity. Sometimes, indeed, I found more than two poles, but then the bar was not of a uniform nature, and its poles were not eaſily reverſed by inverting the poſition of the bar.

After having thus related the reſult of experiments, I may be permitted to add a few thoughts concerning the application of thoſe obſervations towards accounting for the variation of the magnetic needle.

This wonderful phenomenon has, ſince it was firſt diſcovered, employed the thoughts of very able philoſophers; many hypotheſes having been offered, not only for its explanation, but even to foretel the future variations in various parts of the world. I need not detain my reader with a particular hiſtory of thoſe hypotheſes; but ſhall only obſerve, in general, that neither have their predictions anſwered, nor were any of them founded upon evident principles. The ſuppoſition of a large magnet being incloſed within the body of the earth, and of its relatively moving with reſpect to the outward ſhell or cruſt; the ſuppoſition of there being four moveable magnetic poles within the earth; the hypotheſis of a magnetic power, partly within and partly without the ſurface of the earth; together with ſeveral other hypotheſes on the ſame ſubject, are not only unwarranted by actual experiments, but do neither ſeem analogous to the other operations of nature. The late ingenious Mr. Canton, F. R. S. was the firſt, who endeavoured to account for the daily variation of the magnetic needle by the heating and cooling of the magnetic bodies in different parts of the earth's ſurface; which was in conſequence of his having firſt obſerved, that the action of the magnet on the needle was diminiſhed by heating, and increaſed by cooling*.

Following Mr. Canton's judicious method of deriving the explanation of natural appearances from properties actually proved by experiments, I think, that the increaſe and diminution of magnetic attraction, by heating and cooling of the magnet, as obſerved by Mr. Canton, together with the reſult of the experiments deſcribed in the preceding Chapter, ſeem fully ſufficient to account for the general variation of the needle.

* Phil. Tranſ. Vol. LI. p. 398.

If we collect under one point of view all the causes hitherto ascertained, which can increase or diminish the attraction between magnetic bodies, we shall find, that the attraction between the magnet and iron, or between magnet and magnet, is increased by cooling, by a regeneration of iron, or phlogistication of its calx, and, within certain limitations, by the action of acids upon the iron; that this attraction is diminished by heating, and by the decomposition of iron; and, lastly, that it is probably annihilated by a very great degree of heat.

These truths being premised, it must be considered, first, that, according to innumerable observations and daily experience, the body of the earth contains almost every where ferruginous bodies in various states and bulks. Secondly, that the magnetic needle must be attracted by all those bodies, and its situation or direction must be determined by all those attractions considered together, *viz.* from their common centre of action. Thirdly, that by removing or altering the degrees of of attraction of ſome of thoſe bodies, which are ſituate on one ſide of the magnetic meridian, more than of thoſe ſituated on the other ſide, the above-mentioned common centre of attractions, and, of courſe, the direction of the magnetic needle, muſt be altered, which, in fact, is the variation of the needle. And, laſtly, that this alteration in the attractions of ſome of the ferruginous bodies in the earth muſt undoubtedly take place, it being occaſioned by the parts of the earth being irregularly heated and cooled, by the action of volcanos, which decompoſe or otherwiſe alter large maſſes of ferruginous ſubſtance; by earthquakes, which remove ferruginous bodies from their original places; and we may add alſo by the *aurora borealis*; for though we are as yet ignorant of the cauſe of that ſurpriſing phenomenon, it is, however, certain, that the magnetic needle has been frequently diſturbed when the *aurora borealis* appeared very ſtrong.

The magnetic needle, therefore, being neceſſarily affected by theſe cauſes, and they appearing ſufficient to acount for its variation, it ſeems unneceſſary to have recourſe to other hypothetical cauſes, which are not eſtabliſhed on actual experience.

In order to exemplify this explanation of the variation in a familiar manner, I made the following experiment:—Four earthen veſſels were diſpoſed round the magnetic needle, two near its ſouth, and the other two near its north pole, but not at equal diſtances. In one of thoſe veſſels there was placed a natural magnet; the ſecond contained ſeveral ſmall bits of magnetic ſteel mixed with earth; and in each of the other two there were put about four ounces of iron filings. Things being thus diſpoſed, and left undiſturbed for about half an hour, the needle remained unaltered. Then the pieces of magnetic ſteel and earth were ſtirred with a ſtick, in conſequence of which the needle was agitated. After this, ſome diluted vitriolic acid was poured upon the filings in one of the veſſels, the action of which attracted the needle that way; but whilſt the needle remained in that ſituation, ſome diluted vitriolic acid was poured upon the

iron

iron filings in the other veſſel, which ſtood on the other ſide; in conſequence of which the needle went back again towards its former direction. Whilſt the efferveſcences were going on in the two veſſels, the magnet in the firſt veſſel was heated by means of boiling water, which occaſioned another alteration in the direction of the magnetic needle; and thus, by altering the ſtate of the ferruginous ſubſtances in the veſſels, the needle's direction was altered, in evident imitation of the natural variation.

APPENDIX.

ADDITIONS.

TO page 10.—In the process for converting cast iron into malleable iron, besides the action of heat and air, the metal is also hammered in various directions by heavy hammers.

To page 131.—Amongst the other points of analogy between magnetism and electricity, the following observation must be enumerated; *viz.* that when the *aurora borealis* (which has been thought to be an electrical phenomenon) forms a luminous arch towards the northern part of the horizon, the most elevated part or middle

middle of that arch is generally in the magnetic meridian.

To page 153.—In the ufual conftruction of magnetic needles, the points or extremities of the needle, which indicate the divifions on the graduated circle, &c. are below the point of the needle's fufpenfion; hence, when the needle vibrates not horizontally but like a pendulum, thofe points cannot be fteadily directed to the fame divifions; to avoid which, in the beft fort of needles, efpecially thofe ufed for variation compaffes, two pieces of other metal are affixed to the extremities of the needle; which pieces are firft bent a litle way upwards, and then they are turned again horizontally, fo as to terminate in the fame line with the needle's point of fufpenfion.

To page 162.—The pivots of the jimbols of this, as well as of the common fort of compaffes, muft lie in the fame plane with the point of fufpenfion of the needle or card; in order to avoid, as much as poffible, the irregularity of the vibrations.

A LETTER

A LETTER *to the* AUTHOR.

Dear Sir,

When you was pleaſed to mention your having inſerted, in your new publication on Magnetiſm, the general caſes I had furniſhed you with, reſpecting the declinations of the magnetic needle which would reſult from every poſſible aſſumed poſition of the magnetic poles, ſuppoſing the earth to be one great homogeneous natural magnet; I wiſhed that you had added, as an example of the laſt and moſt important caſe, the real ſtate of the magnetical declinations about the middle of this century; which, from the beſt obſervations I could then procure, I had alſo committed to paper above twenty years ago. But I find it would now come too late for your Printer; and, upon farther conſideration, I am of opinion, that it would be of much more conſequence, if either yourſelf, or ſome of the other ingenious Members of the Royal Society, would take the trouble of comparing the magnetical obſervations made during the different voyages which, by order of his preſent Majeſty, were all

undertaken

undertaken and performed during the time I was abroad; and from the whole, together with ſuch other helps as they might have acceſs to, if one general chart, ſuch as Dr. Halley's, was now publiſhed, it would not only prove a valuable preſent to our modern navigators, but might alſo furniſh a material ſtep towards the inveſtigation of this curious and intereſting ſubject.

It is very remarkable, that when Captain Cook, in his ſecond voyage, croſſed the line of no declination, which paſſes through the continent of New Holland, the declination of his compaſſes altered about 14° in two days run: again, in his laſt voyage, though not ſo far ſouth, the alteration of the declination, in proportion to the diſtance, was greater than uſual near to that line. The dipping-needle likewiſe ſhows a conſiderable degree of inclination upon this line. In ſhort, from various conſiderations it would appear, that if this Earth has the common properties of a natural magnet with only two poles, one of them muſt be ſituated in this line; and, though not within the 60° of of latitude, as Mr. Euler imagined, yet it may poſſibly be found not far from the 70°. If, therefore, it appears practicable to ſail to the 70° of ſouth latitude, or beyond it, about the meridian of Botany Bay, keping in eaſt declination; and then to run weſtward till the weſt declination becomes evident: if at the ſame time they have a dipping-needle on board, that without much trouble could give the magnetic inclination at ſea with a tolerable degree of accuracy*; and about a hundred weight of ſoft iron, with a good balance, I cannot help thinking that ſome curious diſcovery might be made.

The ingenious M. Maupertuis, in his letter to the late King of Pruſſia on the advancement of the ſciences, among other curious articles, having mentioned a northern voyage, adds, "to obſerve the phe-
" nomena of the loadſtone, on the very
" ſpot from whence it is ſuppoſed to

* See the deſcription of my dipping-needle, page 168, and in the Philoſophical Tranſactions Vol. LXV.

" draw

" draw its original influence." But ſuch voyages were not in the power of Frederic the Great. It is to our preſent gracious Sovereign that the world will ever be indebted for ſuch noble, extenſive, and diſintereſted diſcoveries. All acceſs to the north pole having been proved impracticable, by the voyages of Lord Mulgrave and Capt. Cook, it now only remains to be determined, whether it is poſſible to come at the ſouth magnetic pole; which, for the reaſons already mentioned, ſeems at leaſt more probable, if it be judiciouſly attempted.—Along with this, I have ſent you a few curſory obſervations on the declination, which I have always conſidered as the moſt important, as well as the moſt curious part of the ſubject of magnetiſm. If you chuſe to publiſh them in your Appendix, you are not to conſider them as complete or infallible: I only wiſh to take this opportunity of exciting enquiry into this very intereſting ſubject; and when your Book comes to a ſecond edition, I hope to have it in my power to communicate

communicate ſomething more ſatisfactory on this head; for I ever am,

Dear Sir,

Your moſt obedient

humble ſervant,

J. LORIMER.

Mr. CAVALLO.

1ſt. That line, which I ſhall call the Atlantic line of no declination, ſeems to take its origin from the north magnetic pole, and croſſing the different meridians in a ſouth-eaſterly direction, reſembling in form the long letter S, it traverſes the continent of North America, enters the Atlantic ocean to the northward of Charles-Town, and ſo proceeds towards the ſouth pole. Upon the weſt ſide of this line there is eaſt declination, and upon the eaſt ſide thereof, weſt declination; which laſt gradually increaſes as you go to the eaſtward, till you get beyond the Cape of Good Hope, or about mid-way between the Atlantic and the Eaſt-India line of no declination, where it amounts to 31°, about the latitude of 48° ſouth;

and then it regularly decreaſes to the Eaſt-India line of no declination.

Again, as you go to the eaſtward of that line of no declination, the eaſt declination increaſes rapidly till you get to the eaſtward of New Zealand, where it is upwards of 13° even in that latitude; but from thence as you proceed eaſtward, for about 40° in longitude, this declination appears to decreaſe; and again it increaſes till you are to the eaſtward of Cape Horn; where, in the latitude of 51° ſouth, it amounts to 21° 28′, and then gradually decreaſes to the Atlantic line of no declination aforeſaid. Upon the whole, it would appear, that theſe obſervations agree pretty nearly with the 4th general caſe which I formerly ſent you, except in that decreaſing eaſt declination to the eaſtward of New Zealand. But admitting that the vaſt body of water in the great Pacific ocean, which cannot have any magnetic properties, ſhould have no effect in producing this irregularity, yet we are not to expect even that the ſolid parts of this globe can be ſo uni-

formly

formly magnetical throughout, as to anſwer entirely with calculation in every part thereof.

2d. The magnetic needle not only declines, or varies from the true north, differently in different parts of the earth at any one time; but likewiſe in the ſame place this declination is different at different times: I would therefore call it, by way of diſtinction, the variation of the magnetic needle.

3d. At London and Paris, where the moſt accurate obſervations have been made, towards the latter end of the ſixteenth century (and we cannot pretend to much earlier obſervations) there was between 11° and 12° of eaſt declination, which gradually decreaſed; ſo that in leſs than a hundred years afterwards, there was no declination at all in thoſe places. From 1657 at London, and 1666 at Paris, a weſt declination began, and has ever ſince increaſed, gradually though not uniformly, or in the direct proportion of the times; for ſuch is the nature of the magnetic declination, that, like the apparent motion of the planets, ſometimes it is faſter, ſometimes ſlower, and at other times it is ſtationary; analogous alſo to the elongations of the inferior planets, at one time it is to the eaſt, and at another time to the weſt, alternately.

We may further obſerve, that the declination lines of the ſame name, have always reſpectively paſſed London ſome years before the ſame lines arrived at Paris; and the like obſervations have been made in other parts of the northern hemiſphere: that is, in this hemiſphere, the Halleyan lines have regularly paſſed thoſe places firſt which lay moſt weſterly; and ſo in order thoſe which lay more to the eaſtward. For in the latter end of the ſixteenth, and the beginning of the ſeventeenth century, there was an eaſtern declination over moſt parts of Europe, while on the coaſt of North America a weſt declination prevailed; the line of no declination being then ſituated about the Azores. This line of no declination has ever ſince moved gradually eaſtward, the lines of eaſt declination receding before it, while thoſe of the weſt declination have regularly followed it.

4thly. In the ſouthern hemiſphere, however, it is quite otherwiſe; for about the latter end of the ſixteenth century, a line of no declination paſſed near to the Cape of Good Hope, upon the eaſt ſide of which there was weſt declination, and upon the weſt ſide thereof eaſt declination; each of which declinations, in going eaſtward or weſtward, gradually increaſed to a certain degree, and then in the ſame manner decreaſed to nothing, ſomewhere to the eaſtward of Java, one of the Eaſt India iſlands.

The declination in the Pacific ocean has not as yet (in 1775) been ſo fully aſcertained, only in general we find, that the declination is eaſterly over moſt part of that extenſive ocean. The line of no declination, which was then ſituated a little to the eaſtward of the Cape of Good Hope, has ever ſince been moving to the weſtward, and the lines of eaſt declination have gradually receded before it, while thoſe of the weſt declination have followed it with a proportional pace; ſo that at the Cape of Good Hope there is now a conſiderable weſt declination (about 22°), and the line of no declination has moved many degrees to the weſtward thereof.

5th. From the preceding obſervations then it plainly appears, that the Halleyan lines in the ſouthern hemiſphere do gradually move from eaſt to weſt, while the motion of thoſe lines in the northern hemiſphere is from weſt to eaſt; and here we ſhall reſt the matter for the preſent.

I juſt beg leave to obſerve, that in treating of this ſubject, I have all along only endeavoured to explain the manner in which magnetiſm acts upon this globe; yet if the preceding concluſion is admitted, *viz.* that the progreſſive motion of the lines of declination in the northern hemiſphere is conſtantly from weſt to eaſt, and in the ſouthern hemiſphere from eaſt to weſt, this diſcovery will be of as great uſe to us in framing, regulating, or judging of our future charts or tables of the declination, or variation of the mariners compaſs, and will anſwer the purpoſes of navigation as well, as if we were thoroughly acquainted with the primary cauſes of all the phenomena of magnetiſm.

THE

INDEX.

A

D

E

F *Ferruginous*

F

G

H

I

INDEX.

L

M

Stones,

FINIS.

WORKS *publiſhed by the ſame* AUTHOR.

A Treatiſe on the Nature and Properties of Air, and other permanently elaſtic Fluids; to which is prefixed an Introduction to Chymiſtry. Quarto, with Plates.

The Hiſtory and Practice of Aeroſtation. Octavo, with Plates.

A Treatiſe on Electricity, in Theory and Practice, with original Experiments. The Third Edition. Two Volumes Octavo, with Plates.

Two Mineralogical Tables, with an Explanation and Index.