WILLIAM GILBERT, M.D.—ELECTRICIAN.

WILLIAM GILBERT

OF COLCHESTER,

PHYSICIAN OF LONDON,

ON THE

LOADSTONE AND MAGNETIC BODIES,

AND ON

THE GREAT MAGNET THE EARTH.

A NEW PHYSIOLOGY,

DEMONSTRATED WITH MANY ARGUMENTS AND EXPERIMENTS.

A TRANSLATION BY

P. FLEURY MOTTELAY,

AUTHOR OF "THE CHRONOLOGICAL HISTORY OF ELECTRICITY, MAGNETISM, ETC."

"*Electrica, quae attrahunt eadem ratione ut electricum.*"

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GVILIELMI GILBERTI COLCESTRENSIS, MEDICI LONDINENSIS,

DE MAGNETE, MAGNETICISQVE CORPORIBVS, ET DE MAGno magnete tellure; Physiologia noua, *plurimis & argumentis, & experimentis* demonstrata.

LONDINI

EXCVDEBAT PETRVS SHORT ANNO MDC.

TRANSLATOR'S PREFACE.

I FIRST entered upon the translation of this, the earliest known published work treating of both magnetism and electricity, in the beginning of 1889. It was then my intention to place it before the public during the year following, appreciating as I did the demand for an English version which had been frequently reiterated by scientists generally in this country, in England, and upon the Continent of Europe. But the attention I was compelled to give, both here and abroad, to the preparation of my "Chronological History of Electricity and Magnetism" has unavoidably delayed the publication of the present volume.

The translation of *De Magnete* has been a task of no ordinary difficulty; it has brought up problems innumerable, the solution of which has involved much laborious research—as the result was meant to be a clear and competent presentation of the author in idiomatic English and not simply a substitution of English words for Latin. Nor would I have ventured to appear as the English interpreter of the great Gilbert, "father of the magnetic philosophy," but for the hearty encouragement and very material aid, in translating and otherwise, extended by many literary and scientific friends, amongst whom must be especially mentioned Mr. Joseph Fitzgerald, Mr. E. McMillan, Mr. Joseph Wetzler, Dr. Joseph V. Livingston, Hon. Park Benjamin, and Prof. Alfred M. Mayer. I am likewise indebted to Prof. Charles Sanders Peirce, to Mr. Latimer Clark, F.R.S., to Dr. Isaac H. Hall, and to Dr. Charlton T. Lewis for valuable suggestions as to the general treatment of the work, and, in the words of the celebrated English mathematician, Edward Wright, I doubt not that our united efforts "will find the heartiest approval among all intelligent men and children of magnetic science."

Not only does Gilbert frequently make use of what he terms "words new and unheard-of," besides attaching to many others a signification far different from that generally recognized at this day, but, what is worse, he retains to a great extent the terminology of the mediæval scholastic philosophers. That terminology the translator must perforce retain; no substitute is possible. Hence is found a multitude of uncouth words which, for the modern reader, require explanation. Of such it is unnecessary here to make any especial mention, since the copious general index to the present work will indicate very readily where they are to be found. It is known that in the philosophy of the schoolmen (as in that of Aristotle) form —*forma*—means that which added to matter—*materia*—constitutes the true nature of the thing. Matter *per se* is indifferent, indefinite; form gives it definiteness. The earth is *informed* with verticity—that is its prime distinction. When any portion of the earth loses verticity it loses its *forma*—is *deformate*. To restore to it verticity, is to *reformate* it, or to *informate* it. Portions of the earth that are *deformate* are, as it were, effete, excrementitious, waste matter. Gilbert states (Book II, Chapters II and IV) that the natural magnetic force (movement) comes from the prime *forma* of the earth, or rather the primary native strength (*vigor*). Elsewhere he tells us that the earth and the loadstone conform—*conformant*—magnetic movements (Book II, Chapter VI); and he speaks of substances conformated—*conformatum*—by the earth (Book III, Chapter IV), and of the globe of earth as of small account and deformate—*deformatum* (Book V, Chapter XII). He speaks besides of the formate soul—*formata anima* (Book V, Chapter XII); of air or water being informated—*informarentur*—by magnetic forms or spheres (Book V, Chapter XI); of iron being transformated—*transformatur* (Book III, Chapter XII); and he adds that iron will attract more properly if it is afformed—*afformatum* (Book II, Chapter IV); also that it will be better if the iron's "acquired verticity be, by some process, rather weakened or deformated"—*deformata* (Book III, Chapter XI).

England's great poet, John Dryden, tells us: "It is almost impossible to translate verbally and well at the same time; for the Latin (a most severe and compendious language) often expresses that in one word which either the barbarity or the narrowness of modern tongues cannot supply in more. . . . But since every language is so full of its own proprieties that what is beautiful in one is often barbarous, nay, sometimes nonsense, in another, it would be unreasonable to limit a translator to the narrow compass of his author's words; it is enough if he choose out some expression which does not vitiate the sense." While, in order to do this acceptably in the present instance, it has often been found necessary to adhere very closely (even literally) to the original lines, the "candid reader" will naturally observe that greater satisfaction has been vouchsafed where paraphrasing has been resorted to for the better comprehension, more particularly, of words of Gilbert's own coinage.

Following Dryden, I have translated with latitude, keeping in view the author's sense more particularly than his words, and amplifying without altering the former. Nor have I, in so doing, attempted, any more than did Gilbert, to impart "into the work any graces of rhetoric, any verbal ornateness." Like him, I have simply endeavored to treat "knotty questions about which little is known in such style and in such terms as are needed to make what is said clearly intelligible."

Such few passages of *De Magnete* as I have seen independently translated elsewhere will be found reproduced in their proper places, and wherever practicable I have followed the approved plan adopted in my "Chronological History," of quoting numerous authorities and inserting many extracts from the writings of different authors in support of the original matter. The extent to which this has been done is shown in the general index accompanying the present work.

I may add that I shall be under obligations to those calling attention to any errors, typographical or otherwise, that may be found herein, as well as to those whose helpful advice may make improvement possible in future editions.

P. FLEURY MOTTELAY.

NEW YORK, March 10, 1892.

BIOGRAPHICAL MEMOIR.

WILLIAM GILBERT—or Gilberd,[1] as he wrote it—was born in 1540 at Colchester, County Essex, England,[2] of which borough his father, Jerome (Hieron) Gilberd, was recorder—"a councillor of great esteem in his profession."[3] Very little that is reliable appears concerning his early years, but it is known that he passed through the Grammar School of his native place and immediately afterward (May 1558) entered St. John's College, Cambridge (whence, some say, he went to Oxford),[4] proceeding B.A. 1560, Fellow 1560–1561, M.A. 1564, mathematical examiner 1565–1566, M.D. 1569, and

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[1] "Gilbert or Gilberd. . . . The latter is used both in his own epitaph and his father's; and in the records of the town of Colchester: and, therefore, seems the truest." (*Biographia Britannica*, London 1757, Vol. IV, page 2202.)

[2] See the Map of Colchester at page 4, Vol. I, Book I, of Philip Morant's "Hist. and Antiq. of Essex," London 1768; also, a full description of the town at pages 266–361, Vol. I, of Thos. Wright's "Hist. and Top. of the County of Essex," London 1836, as well as at pages 286–322, Vol. V, of "The Beauties of England and Wales," by E. W. Brayley and John Britton, London 1810.

[3] Dr. Thomas Fuller, "Hist. of the Worthies of England," London 1840, page 515.

[4] Antony A. Wood, at pages 737–738, Vol. I, *Athenæ Oxonienses*, London 1813, says he was "educated at both the Universities but whether in Oxon. first or in Cambridge, I cannot justly tell"; and Thomas Wright ("Hist. and Top. of County of Essex," 1836, Vol. I, page 311) states that "he studied some time in the Universities of Oxford and Cambridge."

being elected a Senior Fellow of St. John's during the last-named year.

Immediately upon leaving college he travelled on the Continent, "where probably he had the degree of Doctor of Physic conferred upon him, for he doth not appear to have taken it either at Oxford or Cambridge,"[1] and where, as well as in England, he is said to have "practised as a physician with great success and applause." In 1573, he was elected a Fellow of the Royal College of Physicians, and filled therein many important offices, becoming, in turn, Censor (1581–1582, 1584–1587, 1589–1590), Treasurer (1587–1591, 1597–1599), Consiliarius (1597–1599), and President (1600). His skill had already attracted the attention of Queen Elizabeth, by whom he was appointed her physician-in-ordinary, and who showed him many marks of her favor, besides settling upon him an annual pension (said to be the only legacy left by her to any one) for the purpose of aiding him in the prosecution of his philosophical studies.

Gilbert's removal to court led to the dispersion of the members of a society or college which, it appears, frequently met at his residence at Colchester (see illustration). This house, anciently known as "Lanseles," "Timperley's," "Tympornell's" (Old Taxation),[1] was located "on St. Peter's Hill, between Upper Thames Street and Little Knight-Rider Street."

The early investigations of Gilbert were centred almost exclusively upon chemistry, he "attaining to great exactness therein," but this branch was ere long made to yield to the study of the phenomena of electricity and of magnetism, the

[1] Philip Morant, *loc. cit.*, Vol. I, Book II, page 117. See, likewise, Ree's Cyclopædia, 1819, Vol. XVI, article "Gilbert."

latter of which had practically lain dormant for two thousand years—since the days of Thales and Theophrastus. How well he succeeded in generalizing and classifying these phenomena, after a patient and exhaustive line of experiments, is best evidenced by the great work which he published during 1600 under the title of *De Magnete magneticisque corporibus, et de*

GILBERT'S HOUSE AT COLCHESTER.

magno magnete tellure; Physiologia nova, plurimis et argumentis et experimentis demonstrata. This book, "full of valuable facts and experiments ingeniously reasoned on" (J. F. W. Herschel), upon which Gilbert was actively engaged during eighteen years, is his best claim to recognition as the most distinguished man of science in England during the reign of the Virgin Queen.

"The year 1600," observes the English historian Henry Hallam,[1] "was the first in which England produced a remarkable work in Physical Science; but this was one sufficient to raise a lasting reputation for its author. Gilbert, a physician, in his Latin treatise on the Magnet not only collected all the knowledge which others had possessed on the subject, but became at once the father of experimental philosophy in this island, and, by a singular felicity and acuteness of genius, the founder of theories which have been revived after a lapse of ages, and are almost universally received into the creed of science. . . . Gilbert was one of the earliest Copernicans, at least as to the rotation of the earth, and, with his usual sagacity, inferred, before the invention of the telescope, that there are a multitude of fixed stars beyond the reach of our vision."

Gilbert's book created a powerful impression at the time, especially among the learned in other parts of Europe. Galileo expressed the highest admiration of the work and of its author, and, it is said, pronounced Gilbert "great to a degree that is enviable." It was, indeed, by the perusal of *De Magnete* that Galileo was induced to turn his mind to magnetism.[2] In his own country, Gilbert was scarcely so highly appreciated; even Bacon, though he praises Gilbert as a philosopher, speaks with little respect of his theory. After awhile his speculations came to be more esteemed, though perhaps not fully understood; but the great superiority of Gilbert over all who had previously treated of magnetism, and

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[1] "Introd. to the Litt. of Europe in the 15th, 16th, and 17th Centuries," London 1839, Vol. II, page 463.

[2] Dr. Munk, "Roll of the Roy. Col. of Phys.," 1878, page 78.

"the extent to which he had anticipated by his conjectures much of our present knowledge" has only been perceived since the study of magnetism has assumed something like its present systematic and comprehensive character.[1]

While Dr. Whewell observes[2] that "Gilbert's work contains all the fundamental facts of the science, so fully examined, indeed, that even at this day we have little to add to them," Dr. Thomas Thomson says[3] that *De Magnete* "is one of the finest examples of inductive philosophy that has ever been presented to the world. It is the more remarkable because it preceded the *Novum Organum* of Bacon, in which the inductive method of philosophizing was first explained." How far Gilbert was ahead of his time is best proved by the works of those who wrote on magnetism during the first few decades after his death. They contributed in reality nothing to the extension of this branch of physical science. Poggendorff, from whose "Geschichte der Physik" (page 286) this is extracted, calls Gilbert "the Galileo of Magnetism." By Dr. Priestley he was named "the father of modern electricity."

In an article written not long since, Mr. Conrad W. Cooke, of London, notes the high opinion of Gilbert's work entertained, more particularly, by Nathaniel Carpenter, William Barlowe, Francis Bacon, Galileo, and Humboldt, and he adds: "There is abundant testimony extant that this '*De Magnete*' of Gilbert's produced a profound sensation, not only in this country but throughout the then civilized world, and it is a singularly curious fact that the brilliancy of a reputation so great and so original should have been allowed in subsequent generations to have been lost sight of in the

[1] Engl. Cycl., Section "Biography," Vol. III, page 102.
[2] "Hist. of the Inductive Sciences," 1859, Vol. II, page 217.
[3] "History of the Royal Society," London 1812.

more blinding light of more recent knowledge and discoveries, and it is equally remarkable that a book so classical in its nature, so remarkable in its originality and prescience, and which was thought so much of during the periods which immediately followed its publication, should never have been translated into English, or indeed into any other language; and this is rendered still more curious by the fact that such a translation was actually called for at the time, and the want of it was considered remarkable as far back as the year 1618; and here it will be interesting to quote from the preface to a scarce old book, '*Magneticall Advertisements*,' written at that date by the Ven. William Barlowe,[1] Archdeacon of Salisbury, and a very intimate friend of Dr. Gilbert. 'Many of our nation,' he says, 'both Gentlemen and others of excellent witts and louers of these knowledges, not able to read Doctor Gilbert's booke in Latin haue bin (euer since the first publishing thereof) exceeding desirous to haue it translated into English, but hitherto no man hath done it, neither (to my knowledge) as yet goeth about any such matter, whereof one principall cause is that there are very few that understande his booke, because they haue not Load-stones of diuers formes, but especially round ones;' and the author gives a further supposition that 'a second cause may be for that there are diuers wordes of art in the whole course of this booke proper to this subject and fitt to the explication of his figures and diagrammes

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[1] Speaking of Wm. Barlowe, Anthony A. Wood says: "This was the person who had knowledge in the magnet 20 years before Dr. Will. Gilbert published his book of that subject, and therefore by those that knew him, he was accounted superior, or at least equal to that doctor for an industrious and happy searcher and finder out of many rare and magnetical secrets." (*Athenæ Oxonienses*, London 1813, Vol. II, page 375.) Under heading of Gilbert, the "British Museum Catalogue of Printed Books," 1888, has it that "Mag. Adv." was compiled partly from *De Magnete*.

which cannot be understood but by the helpe of the Mathematicks, and good trauelling in the Magneticall practice.' "

Dr. John Davy says[1] Gilbert's "work is worthy being studied, and I am surprised that an English edition (translation) of it has never been published." He also alludes to the well-known reproach thrown upon Gilbert's philosophy by Francis Bacon, who, in his *De Augmentis Scientiarum*, remarks that "Gilbert has attempted to raise a general system upon the magnet, endeavoring to build a ship out of materials not sufficient to make the rowing-pins of a boat."

On the other hand, Digby and Barlowe place Gilbert upon a level with Harvey, Galileo, Gassendi, and Descartes,[2] while the celebrated historian of the Council of Trent, Father Paul —Fra Paolo Sarpi,—who will not be thought an incompetent judge, names Gilbert, with Francis Vieta (the greatest French mathematician of the sixteenth century), as the only original writer among his contemporaries.[3]

It is deserving of notice that Gilbert was the first to use the terms "electric force," "electric emanations," and "electric attraction." He it was, also, who gave the name of "pole" to the extremities of the magnetic needle pointing to the poles of the earth, calling *south pole* the extremity that pointed toward the north, and *north pole* the extremity pointing toward the south. In the words of Sir David Brewster, Gilbert applies the term *magnetic* to all bodies which are acted upon by loadstones and magnets, in the same manner as they act upon each other, and he finds that all such bodies contain iron in some state or other. He considers the phenomena of

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[1] "Memoirs of the Life of Sir H. Davy," London 1836, Vol. I, page 309.

[2] "Nouvelle Biog. Générale," 1858, Tome VIII, page 494.

[3] Lettere di Fra Paolo, page 31; Hallam, "Introd. to Lit. . . . ", 1839, Vol. II, page 464.

electricity as having a considerable resemblance to those of magnetism, though he points out the differences by which the two classes of phenomena are marked.

To give here such an analysis as Gilbert's admirable work merits would be impracticable, but the short review of it made by Dr. John Robison[1] deserves full reproduction as follows: "In the introduction, he recounts all the knowledge of the ancients on the subject, and their supine inattention to what was so entirely in their hands, and the impossibility of ever adding to the stock of useful knowledge, so long as men imagined themselves to be philosophising, while they were only repeating a few cant words and the unmeaning phrases of the Aristotelian school. It is curious to mark the almost perfect sameness of Dr. Gilbert's sentiments and language with those of Lord Bacon. They both charge, in a peremptory manner, all those who pretend to inform others, to give over their dialectic labours, which are nothing but ringing changes on a few trite truths, and many unfounded conjectures, and immediately to betake themselves to experiment. He has pursued this method on the subject of magnetism, with wonderful ardour, and with equal genius and success; for Dr. Gilbert was possessed both of great ingenuity, and a mind fitted for general views of things. The work contains a prodigious number and variety of observations and experiments, collected with sagacity from the writings of others, and instituted by himself with considerable expense and labour. It would indeed be a miracle if all Dr. Gilbert's general inferences were just, or all his experiments accurate. It was untrodden ground. But, on the whole, this performance contains more real information than any writing of the age in

[1] "System of Mechanical Philosophy," London 1822, page 209.

which he lived, and is scarcely exceeded by any that has appeared since. We may hold it with justice as the first-fruits of the Baconian or experimental philosophy.

"This work of Dr. Gilbert's relates chiefly to the loadstone, and what we call magnets; that is, pieces of steel which have acquired properties similar to those of the loadstone. But he extends the term *magnetism*[1] and the epithet *magnetic*, to all bodies which are affected by loadstones and magnets, in a manner similar to that in which they affect each other. In the course of his investigations, indeed, he finds that these bodies are only such as contain iron in some state or other; and in proving this limitation he mentions a great variety of phenomena which have a considerable resemblance to those which he allows to be magnetical, namely, those which he called electrical, because they were produced in the same way that amber is made to attract and repel light bodies. He marks, with care, the distinctions between these and the characteristic phenomena of magnets. He seems to have known, that all bodies may be made electrical, while ferruginous substances alone can be made magnetical. It is not saying too much of this work of Dr. Gilbert's to affirm, that it contains almost everything that we know about magnetism. His unwearied diligence in searching every writing on the subject, and in getting information from navigators, and his incessant occupation in experiments, have left very few facts unknown to him. We meet with many things in the writings of posterior enquirers, some of them of high reputation, and of the present day, which are published and received as notable

[1] Humboldt states that in Gilbert "we do not find either the abstract expression *electricitas*, or the barbarous word *magnetismus* introduced in the eighteenth century." ("Cosmos," 1849, Vol. II, page 726, note.)

discoveries, but are contained in the rich collection of Dr. Gilbert. We by no means ascribe all this to mean plagiarism, although we know traders in experimental knowledge who are not free from this charge. We ascribe it to the general indolence of mankind, who do not take the trouble of consulting originals, where things are mixed with others which they do not want, or treated in a way, and with a painful minuteness, which are no longer in fashion. We earnestly recommend it to the perusal of the curious reader. He will (besides the philosophy) find more facts in it than in the two large folios of Scarella."

The manner in which "this great man arrived to discover so much of magnetical philosophy" and "all the knowledge he got on this subject," we are told by Sir Kenelm Digby,[1] "was by forming a little load-stone into the shape of the earth. By which means he compassed a wonderful designe, which was, to make the whole globe of the earth maniable; for he found the properties of the whole earth, in that little body; which he therefore called a terrella, or little earth;[2] and which he could manage and try experiences upon, at his will. And in like manner, any man that hath an aim to advance much in natural sciences, must endeavour to draw the matter he enquireth of, into some small modell, or into some kinde of manageable method; which he may turn and wind as he pleaseth. And then let him be sure, if he hath a competent understanding, that he will not misse his mark."

Amongst the many other ingenious contrivances frequently alluded to in his book, Gilbert mentions the *versorium*, an iron needle moving freely upon a point, with which he was enabled

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[1] "Treatise of Bodies," 1645, Chap. XX, page 225.

[2] See *De Magnete*, Book I, Chap. III.

to measure excited electricity. He is, besides, the inventor of "two most ingenious and necessarie Instruments for Sea men to find out thereby the latitude of any place upon sea or land, in the darkest night, that is without the helpe of Sunne, Moone or Starre." These instruments are described in Thomas Blunderville's quarto work entitled "The Theoriques of the seuen Planets, shewing their diuerse motions[1] . . . printed at London 1602."

Of the monumental *De Magnete*, Prof. Robison states[2] that he knew of but two British editions and that he had "seen five editions published in Germany and Holland before 1628." This would make seven editions in all, if the 1600 Amsterdam edition—which Kuhn alludes to—be included. Sir John Leslie, however, says[3] that "Gilbert's original work was republished at Ferrara in 1629, with a commentary by Cabaeus." Thus are eight distinct editions referred to. Yet, but

Two editions (1600, 1633) are named by: J. C. Brunet (Londini, Sedini); J. C. Poggendorff[5] and "International Encycl."[6] (London, Stettin); "Allgemeine Ency."[7] and "Biographie Universelle"[8] (London, Sedan);

Three editions (1600, 1628, 1633) are given by W. T. Lownd*as*,[9] S. A. Allibone,[10] J. G. T. Graesse,[11] S. P.

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[1] "Bibliotheca Britannica," Edinburgh 1824, Vol. I, Authors, by R. Watt, pages 124 and 414.

[2] "Edinb. Cyclop.," article Gilbert. See J. C. Poggendorff, "Geschichte der Physik," Leipsig 1879, page 279.

[3] Fifth Dissert. "Encycl. Brit.", page 741.

[4] "Manuel du Libraire," Paris 1861, Vol. II, page 1592.

[5] "Biog.-Liter. Handw.", Leipsig 1863, Vol. I, page 895.

[6] Vol. VI, page 679, 1892 ed.

[7] Leipzig 1858, Sec. I, page 229.

[8] Bruxelles 1843–1847, Vol. VII, page 253.

[9] "The Bibliog. Manual," 1859, Part IV, page 890.

[10] "Critical Dict. of Engl. Lit.", 1859, Vol. I, page 668.

[11] "Trésor de Livres Rares et Précieux," 1862.

Thompson[1] (Londini, Sedini); Dr. J. Lamont[2] (Londini, Stettin); British Museum Catalogue of Printed Books, London 1888 (Londini, Sedani);

Four editions are alluded to at page 201 of the (1880) Catalogue of the Ronalds Library, edited by Alfred J. Frost, viz., Londini 1600, Amsterdam 1600, Sedini 1628, 1633; and

Five editions appear in Mr. C. W. Cooke's article[3] as follows: London 1600, Stettin 1628, 1633, Franckfort 1629, 1638, the same being specified in the "Ninth Britannica,"[4] with the difference that Sedan takes the place of Stettin.

The other editions cannot be traced through any of the numerous catalogues of public and private libraries, or in the records of prominent sales at auction, which have been consulted.

The above has brought about the question as to the true significance of *Sedini*, with the result following:

SEDAN, on the Meuse, in France, is given the Latin name *Sidanum* by Mr. Bescherelle,[5] also *Sedanum* in the "Dict. Géog. Port.", 1809, page 617, as well as by Em. Bowen,[6] Henry Cotton,[7] and M. Deschamps.[8]

STETTIN, on the Oder, in Prussia, is called in Latin *Stetinum* ("Dict. Géog. Port.", 1809, page 652; Em. Bowen, *loc. cit.* Vol. I, page 701). See

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[1] "Gilbert of Colchester, an Eliz. Magn.", 1891, pages 43–44.
[2] "Handb. des Magnetismus," Leipzig 1867, page 434.
[3] London "Engineering" for the month of December, 1889.
[4] Volume X, page 592.
[5] "Grand Dict. de Géog. Univ.", 1857, Tome IV, page 560.
[6] "Compl. Syst. of Geog.", 1747, Vol. I, page 401.
[7] "Typog. Gazetteer," 1825, page 146.
[8] "Dict. de Géog.", 1870, page 1158.

Sedinum—likewise *Sideni, Sidini, Sudeni,* in "Lexicon Geog.", 1657, page 361; "Dict. Géog.", Nice 1791, page 308, "Dict. Géog. Univ.", 1832, pages 453–454; as well as by Larousse,[1] Cotton,[2] Deschamps,[3] and W. Smith.[4] Gilbert alludes to the *Sudini* of Prussia, Book 2, Chap. 2.

SEDINI, *Sedinu, Seduni, Sedunum* (French *Sion*, German *Sitten*), were names attaching to place and people along the banks of the Rhone in Switzerland (Phil. Brietio, "Parallela Geographiæ," 1648, Vol. I, page 347; Geo. Long, "Atlas of Class. Geog.", 1874, Map VII; A. G. Findlay, "Classical Atlas," 1853, Map XIII; Alex. Maclean, "Dict. of Am. Geog.", 1773; Deschamps, *loc. cit.* page 1161).

As the French would say, *il y en a un peu pour tous les goûts,* but since Wolfgang Lochman(n), the publisher of the editions imprinted Sedini 1628 and 1633, was a resident of Stettin (J. C. Poggendorff, "Biogr.-Liter. Handw.," 1863, Vol. I, page 1484), the natural inference to be drawn is that the imprint Sedini stands for Stettin, and not for Sedan as many have it.

In the present volume will be found photo-lithographic reproductions of three of the above-named title-pages. That of the 1600 Londini is taken from the copy of Mr. Charles L. Clarke, whereto allusion is made hereafter, while the 1628 Sedini is reproduced from the copy in the library of the English Institute of Electrical Engineers, and the 1633 Sedini from the copy belonging to Dr. Park Benjamin of New York City. The 1628 is the most elaborate

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[1] "Grand Dict. Univ.", 1875, Tome XIV, pages 477, 1099.
[2] H. Cotton, *loc. cit.* page 152.
[3] Deschamps, *loc. cit.* pages 1161, 1175.
[4] "Dict. of Gr. and Rom. Geog.", 1857, Vol. II, pages 995, 1042.

of all known Gilbert title-pages. As described by Prof. Sir Wm. Thomson (Lord Kelvin), it is "in the form of a monument, ornamented with commemorative illustrations of Gilbert's theory and experiments, and a fantastic indication of the earliest European mariner's compass, a floated loadstone, but floating in a bowl on the sea and left behind by the ship sailing away from it! In the upper left-hand corner is to be seen Gilbert's *terrella* and *orbis virtutis*.[1] The terrella is a little globe of loadstone, which he made to illustrate his idea that the earth is a great globular magnet. . . . The *orbis virtutis* is simply Gilbert's expression for what Faraday called the field of force, that is to say, the space round a magnet, in which magnetic force is sensibly exerted on another magnet, as, for instance, a small needle, properly placed for the test. Gilbert's word *virtue* expresses even more clearly than Faraday's word *force* the idea urged so finely by Faraday, and proved so validly by his magneto-optic experiment, that there is a real physical action of a magnet through all the space round it tho' no other magnet be there to experience force and show its effects." The meaning of the little bars bordering the terrella is explained in Gilbert's book (Lib. I, cap. iii, and Lib. V, cap. ii), where he alludes to the application of bits of fine iron wire as long as a barley-corn, etc., etc.

After the death of Queen Elizabeth, March 24, 1603, Gilbert was continued in his position as royal physician by King James I., but he survived his benefactress only a few months; he died, some say at Colchester, others at London, on the 30th November of the same year. He was buried in the chancel of the Church of the Holy Trinity in Colchester, where a monu-

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[1] See cuts of *Orbis Virtutis* in *De Magnete*, Book II, Chapters VI and XXVII, also Book V, Chap. II.

ment[1] was erected to him by his brothers, who placed upon it a Latin inscription[2] which appears at page 79 of Doctor Munk's "Roll of the Royal College of Physicians," London 1878. Dr. B. W. Richardson has translated the inscription as follows:

Ambrose and William Gilberd have placed this tomb In memory of brotherly piety, To William Gilberd, Senior, Gentleman, and doctor of medicine. This, the eldest son of Jerome Gilberd, Gentleman, was born in the town of Colchester, studied the art of medicine at Cambridge, practiced the same for more than thirty years at London, with singular credit and success. Hence called to Court, he was received with highest favor by Queen Elizabeth, to whom, and to her successor James, he served as chief physician. He composed a book celebrated among foreigners concerning the magnet for nautical science. He died in the year of the Human Redemption 1603, the last day of November, in the 63d year of his age.

The inscription is thus rendered by Thos. Wright, at pages 310–311, Vol. I, of his (London 1836) "Hist. and Topog. of the County of Essex:"

Ambrose and William Gilberd erected this monument to William Gilberd, senior, esq., and doctor of physic, in memory of his fraternal affection. He was the eldest son of Jerom Gilberd, Esq., born in the town of Colchester, studied physic at Cambridge, and practised at London more than thirty years with the greatest applause, and equal success. And being sent for to Court, he was received into the highest favor by Queen Elizabeth, to whom as also to her successor, James, he was principal physician. He wrote a book concerning the magnet, much celebrated by those engaged in nautical affairs. He died in the year of Human Redemption 1603 on the last day of November, in the 63d year of his age.

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[1] An engraving of this monument is given in Philip Morant's "History of Colchester," and it is described ("Dict. of Nat. Biog.", London 1890, Vol. XXI, page 338) as being "a panel surrounded by a frame of Jacobean pattern, surmounted by pinnacles bearing globes and 14 shields of armorial achievements."

[2] "The epitaph thereon is very unelegant and hardly latin. . . ." (*Biog. Brit.*, London 1757, Vol. IV, page 2203.)

Gilbert was never married. He bequeathed to the College of Physicians "all the books in his library, his globes, instruments and cabinets of minerals." These were, unfortunately, consumed in the great London fire of 1666. To the University of Oxford he left a portrait which he is said to have ordered made of himself for the purpose and which was "placed in the Gallery over the Schools."[1] In this portrait, which is believed to have been destroyed,[2] he appears standing in his doctor's robes "holding *in* his hand a globe inscribed *terrella*, whilst over his head is the inscription '1591, ætatis 48,' and, a little below his left shoulder, the words 'Magneticarum virtutum, primus indagator Gilbertus.'"[3]

The reader is shown in the frontispiece a copy of the only portrait of Gilbert known at this day. It was taken from Vol. II, page 33, of S. and E. Harding's "Biographical Mirrour," and is said to have been engraved by Clamp "from an original picture in the Bodleian Library, Oxford."[4] As will be seen, it lacks the inscriptions before spoken of and represents Gilbert holding his hand *upon* an ordinary globe. It was the central portion of this picture which was utilized by Mr. Arthur Ackland Hunt for his well-known historical painting, representing Gilbert making an experimental demonstration in electricity before Queen Elizabeth.

Speaking of Gilbert, Dr. Fuller writes: "One saith of him that he was *Stoicall*, but not *Cynicall*, which I understand

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[1] "The picture of this famous doctor, drawn to the life, is hanging in the school-gallery at Oxon" (*Athenæ Oxonienses*, by Anthony à Wood [1st edition, 1691–2], London 1813, Vol. I, page 738).

[2] Wood says "decayed and removed," at page 96, Vol. II, of the 1796 "Hist. and Antiq. of the Univ. of Oxford."

[3] Ninth "Encycl. Brit.", article Gilbert.

[4] Dr. Munk's "Roll of the Roy. Col. of Physicians," 1878, page 79; "Dict. of Nat. Biog.", London 1890, Vol. XXI, page 338.

Reserved, but not *Morose*, never married, purposely to be more beneficial to his brethren. Such his *Loyalty* to the Queen that, as if unwilling to survive, he dyed in the same year with her, 1603. His *Stature* was *Tall*, *Complexion Chearful*, an Happiness not ordinary in so hard a student and retired a person."

Besides Gilbert's folio *De Magnete*, there appeared at Amsterdam, in 1651, a quarto volume of 316 pages entitled *De Mundo Nostro Sublunari Philosophia Nova*, which was edited, some say by his brother William Gilbert Junior—according to others, by the eminent English scholar and critic John Gruter—from two MSS. found in the library of Sir Wm. Boswell, Knight. According to Dr. John Davy, "this work of Gilbert's, which is so little known, is a very remarkable one, both in style and matter; and there is a vigour and energy of expression belonging to it very suitable to its originality. Possessed of a more minute and practical knowledge of natural philosophy than Bacon, his opposition to the philosophy of the schools was more searching and particular, and at the same time probably little less efficient."[1] In the opinion of Prof. John Robison, *De Mundo* consists of an attempt to establish a new system of natural philosophy upon the ruins of the Aristotelian doctrine. We give an extract from the work, in a footnote to the present translation of Gilbert's *De Magnete*, Book VI, Chap. VII, and are also enabled to give a reproduction of the 1651 title-page made through the courtesy of Dr. Park Benjamin.

The only known writing of Gilbert in English is in the form of a letter dated 14th Februrary (? 1602) which appears at the end of William Barlowe's "Magneticall Advertisements or

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[1] "Memoirs of the Life of Sir Humphry Davy," London 1836, Vol. I, page 311.

divers observations concerning the loadstone," quarto, London 1616, and reads as follows:

To the Worshipfull my good friend, Mr. William Barlowe at Easton by Winchester.

Recommendations with many thanks for your paines and courtesies, for your diligence and enquiring, and finding diuers good secrets, I pray proceede with double capping your load-stone you speake of, I shall bee glad to see you, as you write, as any man, I will haue any leisure, if it were a moneth, to conferre with you, you have shewed mee more—and brought more light than any man hath done. Sir, I will commend you to my L. of Effingham, there is heere a wise learned man, a Secretary of Venice, he came sent by that State, and was honourably received by her Majesty, he brought me a lattin letter from a Gentle-man of Venice that is very well learned, whose name is Iohannes Franciscus Sagredus, he is a great Magneticall man, and writeth that hee hath conferred with diuers learned men of Venice and with the Readers of Padua, and reporteth wonderfull liking of my booke, you shall haue a coppy of the letter: Sir, I propose to adioyne an appendix of six or eight sheets of paper to my booke after a while, I am in hand with it of some new inuentions, and I would haue some of your experiments, in your name and inuention put into it, if you please, that you may be knowen for an augmenter of that art. So for this time in haste I take my leaue the xiiyth of February.

Your very louing friend,

W. GILBERT.

His intention to print the short appendix was never carried into effect.

Professor Silvanus P. Thompson states ("Gilbert of Colchester . . .", London 1891, page 40) that "with the exception of a single doubtful inscription, '*ex dono auctoris*,' in a single copy of *De Magnete*, not a line of his [Gilbert's] handwriting is known to exist, unless his hand wrote the signature '*Ye President and Societie*' at the end of a Petition, preserved amongst the manuscripts in the British Museum, addressed by the Royal College of Physicians in 1596 to the Lords of the Privy Council, complaining of the exactions of the Lord Mayor and Aldermen of London. It is pretty certain that the MS. copy of *De Mundo* in the British Museum is not in the author's handwriting; for in the Elzevir Print there is a note stating that the author's original manuscript was partly in English."[1] It is unfortunate that Prof. Thompson's attention should not at the time have been called to the fact that Mr. Bernard Quaritch's Rough List No. 99, for September 1889, offered at page 80—No. 747—a 1600 *De Magnete* "Presentation copy from the author, with inscription on title *Dedit Guil. Gilbertus Jo. Sherwood propriis manibus.*" This copy, which formerly belonged to Mr. Wm. Constable, F.R.S. and F.A.S., is now the property of Mr. Chas. L. Clarke, C.E., New York City, through whose courtesy the reproduction of the title bearing the inscription appears at page iii. A comparison of the writing in both inscriptions would prove interesting.

"Mahomet's Tombe at Mecha is said strangely to *hang* up, attracted by some invisible *Load-stone*, but the memory of the *Doctor* will never fall to the ground, which his incomparable Book *De Magnete* will *support* to Eternity."[2]

In his epistle[3] to Dr. Walter Charleton (physician in ordinary to King Charles I.), the celebrated English poet, John Dryden, predicts that

> "Gilbert shall live till loadstones cease to draw,
> Or British fleets the boundless ocean awe."

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[1] "A copy in MS. among the Royal collection in the British Museum. . . . It consists of five books and is written on paper." (Casley's Catalogue, page 212.) The work is alluded to at page 283 "Les Elzevier," Alph. Willems, Bruxelles 1880, also at page 203 of Ann. de Impr. Elsevirienne, Chas. Pieters, Gand 1851.

[2] Dr. Thomas Fuller, "The History of the Worthies of England," London 1840, page 515. See references to Mahomet's Shrine: in Gilbert's *De Magnete*, 1600, Book I, Chap. I; in Porta's "Natural Magick," 1658, Book VII, Chap. XXVII; in Sir Thomas Brown's *Pseudoloxia, Epidemica*, 1658, Book II, pages 78–79; in Cabaeus, *Philosophia Magnetica*, 1629, Lib. IV, Chap. XVIII, page 335.

[3] Epistle the Third, at page 15, Vol. XI, of the Works of John Dryden, London 1803.

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BOOK VI.

To the most learned Mr. William Gilbert, the distinguished London physician and father of the magnetic philosophy: a laudatory address concerning these books on magnetism, by Edward Wright.

Should there be any one, most worthy sir, who shall disparage these books and researches of yours, and who shall deem these studies trifling and in no wise sufficiently worthy of a man consecrated to the graver study of medicine, of a surety he will be esteemed no common simpleton. For that the uses of the loadstone are very considerable, yea admirable, is too well known even among men of the lowest class to call for many words from me at this time or for any commendation. In truth, in my opinion, there is no subject-matter of higher importance or of greater utility to the human race upon which you could have brought your philosophical talents to bear. For by the God-given favor of this stone has it come about that the things which for so many centuries lay hid—such vast continents of the globe, so infinite a number of countries, islands, nations and peoples—have been, almost within our own memory, easily discovered and oft explored, and that the whole circle of the globe has been circumnavigated more than once by our own Drake and Cavendish: which fact I wish to record for the undying remembrance of those men. For, by the showing of the magnetized needle, the points North, South, East and West and the other points of the compass are known to navigators, even while the sky is murky and in the deepest night; by this means seamen have understood toward what point they must steer their course, a thing that was quite impossible before the wondrous discovery of the north-pointing power of the loadstone. Hence sailors of old were often beset, as we learn from the histories, by an incredible anxiety and by great peril, for, when storms raged and the sight of sun and stars was cut off, they knew not whither they were sailing, neither could they by any means or by any device find out. Hence what must have been the gladness, what the joy of all mariners when first this magnetic pointer offered itself as a most sure guide on the route and as a God Mercury! But it was not enough for this magnetic Mercury simply to point out the way and, as it were, to show by the extended finger whither the course must be: it soon began even to indicate the distance of the place whither the voyage is made. For, since the magnetic pointer does not always regard the same northern spot in every locality, but usually varies therefrom, either to the east or to the west, tho' it nevertheless hath and holds ever the same variation in the same place, wherever that may be; it has come about that by means of this variation (as it is called) closely observed and noted in certain maritime regions, together with an observation of the latitude, the same places can afterward be found by navigators when they approach and come near to the same variation. Herein the Portuguese in their voyages to the East Indies have the surest tokens of their approaching the Cape of Good Hope, as is shown in the narrations of Hugo *Lynschetensis*[1] and our very learned fellow-countryman Richard Hakluyt; hereby, too, many of our skilled British navigators when voyaging from the Gulf of Mexico to the Azores,

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[1] Jan Hugo van Linscho(o)ten, Dutch voyager, 1563–1633.

can tell when they are come near to these islands, though, according to their marine charts, they may appear to be 600 English miles away. And thus, thanks to this magnetic indication, that ancient geographical problem, how to discover the longitude, would seem to be on the way to a solution; for, the variation of a seaboard place being known, that place can thereafter be very easily found as often as occasion may require, provided its latitude is not unknown.

Yet somewhat of inconvenience and difficulty seems to attach to this observation of the variation, for it cannot be made except when the sun or the stars are shining. Accordingly this magnetic Mercury of the sea, better far than Neptune himself or any of the sea gods or goddesses, proceeds still further to bestow blessings on all mariners; and not alone in the darkness of night and when the sky is murky does he show the true direction, but he seems even to give the surest indications of the latitude. For the iron pointer suspended freely and with the utmost precision in equilibrium on its axis, and then touched and excited with a loadstóne, dips down to a fixed and definite point below the horizon (e.g. in the latitude of London it dips nearly 72 degrees) and there stands. But because of the wonderful agreement and congruency manifested in nearly all and singular magnetic experiments, equally in the earth itself and in a terrella (i.e. a spherical loadstone), it seems (to say the least) highly probable and more than probable that the same pointer (similarly stroked with a loadstone) will, at the equator, stand in equilibrium on the plane of the horizon. Hence, too, it is highly probable that in proceeding a very short distance from south to north (or *vice versa*) there will be a pretty sensible change in the dip; and thus the dip being carefully noted once and the latitude observed, the same place and the same latitude may thereafter be very readily found by means of a dip instrument even in the darkest night and in the thickest weather.

Thus then, to bring our discourse back again to you, most worthy and learned Mr. Gilbert (whom I gladly acknowledge as my master in this magnetical philosophy), if these books of yours on the Loadstone contained nought save this one method of finding the latitude from the magnetic dip, now first published by you, even so our British mariners as well as the French, the Dutch, the Danes, whenever they have to enter the British sea or the strait of Gibraltar from the Atlantic Ocean, will justly hold them worth no small sum of gold.[1] And that discovery of yours, that the entire globe is magnetical, albeit to many it will seem to the last degree paradoxical, nevertheless is buttressed and confirmed by so many and so apposite experiments in Book II, Chapter XXXIV; Book III, Chapters IV and XII; and throughout nearly the whole of Book V, that no room is left for doubt or contradiction. I come therefore to the cause of magnetic variation—a problem that till now has perplexed the minds of the learned; but no one ever set forth a cause more probable than the one proposed now for the first time in these your books on the Loadstone. The fact that the magnetic needle points due north in the middle of the ocean and in the heart of continents—or at least

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[1] Hardly twenty years after the English artificer, Robert Norman, had, in 1576, devised the *inclinatorium*, which enabled him to determine the dip or inclination of the magnetic needle, Gilbert boasted that, by means of this instrument, he could ascertain a ship's place in dark starless nights. Gilbert commends the method as applicable *aëre caliginoso;* and Edward Knight, the English mathematician, in the introduction which he added to his master's great work, describes this proposal as "worth much gold." Having fallen into the same error with Gilbert of presuming that the isoclinal lines coincided with the geographical parallel circles, and that the magnetic and geographical equators were identical, he did not perceive that the proposed method had only a local and very limited application (Humboldt, *Cosmos*, 1849, Vol. I, page 172, and Vol. II, page 658).

in the heart of their more massive and more elevated parts—while near the coasts there is, afloat and ashore, an inclination of the needle toward those more massive parts, just as happens in a terrella that is made to resemble the earth globe in its greater elevation at some parts and shows that it is weak or decayed or otherwise imperfect elsewhere: all this makes exceedingly probable the theory that the variation is nothing but a deviation of the magnetic needle to those more powerful and more elevated regions of the globe. Hence the reason of the irregularity that is seen in the variations of the compass is easily found in the inequality and anomaly of those more elevated parts. Nor do I doubt that all those who have imagined or accepted certain "respective points" as well as they who speak of magnetic mountains or rocks or poles, will begin to waver as soon as they read these your books on the Loadstone and will of their own accord come over to your opinion.

As for what you have finally to say of the circular motion of the earth and the terrestrial poles, though many will deem it the merest theorizing, still I do not see why it should not meet with indulgence even among those who do not acknowledge the earth's motion to be spherical, seeing that even they cannot readily extricate themselves from the many difficulties that result from a diurnal motion of the whole heavens. For, first, it is not reasonable to have that done by many agents which can be done by fewer, or to have the whole heavens and all the spheres (if spheres there be) of the planets and fixed stars made to revolve for the sake of the diurnal motion, which may be accounted for by a daily rotation of the earth. Then, which theory is the more probable, that the equinoctial circle of the earth may make a rotatary movement of one quarter of an English mile (60 miles being equal to one degree on the earth's equator) in one second of time, i.e., in about as much time as it takes to make only one step when one is walking rapidly; or that the equator of the *primum mobile* in the same time, with inexpressible celerity, makes 5000 miles and that in the twinkling of an eye it makes about 50 English miles, surpassing the velocity of a flash of lightning, if they are in the right who most strenuously deny the earth's motion? Finally, which is the more probable, to suppose that this little globe of the earth has some motion, or with mad license of conjecture to superpose three mighty starless spheres, a ninth, a tenth, and an eleventh,[1] upon the eighth sphere of the fixed stars, particularly when from these books on the Loadstone and the comparison of the earth with the terrella it is plain that spherical motion is not so contrary to the nature of the earth as it is commonly supposed to be?

Nor do the passages quoted from Holy Writ appear to contradict very strongly the doctrine of the earth's mobility. It does not seem to have been the intention of Moses or the prophets to promulgate nice mathematical or physical distinctions: they rather adapt themselves to the understanding of the common people and to the current fashion of speech, as nurses do in dealing with babes; they do not attend to unessential minutiæ. Thus, Genesis i. 16 and Psalm cxxxvi. 7, 9, the moon is called a great luminary, because it so appears to us, though, to those versed in astronomy, it is known that very many stars, fixed and planetary, are far larger. So, too, from Ps. civ. 5,[2] no argument of any weight can, I think, be drawn to contradict the earth's mobility, albeit it is said that God established the earth on her foundations to the end it should never

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[1] See note, Book VI, Chap. III.

[2] Psalm civ. 5, "Who laid the foundations of the earth, that it should not be removed forever."

be moved; for the earth may remain forevermore in its own place and in the selfsame place, in such manner that it shall not be moved away by any stray force of transference, nor carried beyond its abiding place wherein it was established in the beginning by the divine architect. We, therefore, while we devoutly acknowledge and adore the inscrutable wisdom of the triune Godhead, having with all diligence investigated and discerned the wondrous work of his hands in the magnetic movements, do hold it to be entirely probable, on the ground of experiments and philosophical reasons not few, that the earth while it rests on its centre as its basis and foundation, hath a spherical motion nevertheless.

But, apart from these matters (touching which no one, I do believe, ever gave more certain demonstrations), no doubt your discussion if the causes of variation and of the dip of the needle beneath the horizon (to say nothing of sundry other points which 'twould take too long to mention) will find the heartiest approval among all intelligent men and "children of magnetic science" (to use the language of the chemists). Nor have I any doubt that, by publishing these your books on the Loadstone, you will stimulate all wide-awake navigators to give not less study to observation of dip than of variation. For it is highly probable, if not certain, that latitude, or rather the effect of latitude, can be determined much more accurately (even when the sky is darkest) from the dip alone, than longitude or the effect of longitude can be found from the variation even in the full light of day or while all the stars are shining, and with the help of the most skilfully and ingeniously contrived instrument. Nor is there any doubt that those most learned men, Petrus Plantius[1] (a most diligent student not so much of geography as

[1] Peter Plancius, Dutch theologian and astronomer, 1552–1622.

of magnetic observations) and Simon Stevinius,[2] a most eminent mathematician, will be not a little rejoiced when first they set eyes on these your books and therein see their own λιμνευρετικήν or method of finding ports so greatly and unexpectedly enlarged and developed; and of course they will, as far as they may be able, induce all navigators among their own countrymen to note the dip no less than the variation of the needle.

Let your magnetic Philosophy, most learned Mr. Gilbert, go forth then under the best auspices—that work held back not for nine years only, according to Horace's Counsel, but for almost other nine; that Philosophy which by your multitudinous labors, studies, vigils, and by your skill and at your no inconsiderable expense has been after long years at last, by means of countless ingenious experiments, taken bodily out of the darkness and dense murkiness with which it was surrounded by the speculations of incompetent and shallow philosophizers; nor did you in the mean time overlook, but did diligently read and digest whatever had been published in the writings whether of the ancients or the moderns. Let it not be afraid to face the prejudiced censure of any supercilious and dastardly philosophaster who, by enviously faulting another's work or by fraudulently taking the credit to himself, strives to win a most unsubstantial renown; for

> *Ingenium magni livor detrectat Homeri,*
> (Envy detracts from the genius of mighty Homer;

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[2] Simon Stevin—Stevinus—celebrated Flemish mathematician (1548–1628), published in 1586 his well-known work on statics and hydrostatics, in the preface of which he endeavors to prove that the Dutch language is more ancient than any other. This work was soon followed by others, including his *De Motu Cœli*, and, in 1599, by his Dutch treatise on navigation, translated in Latin by Grotius and published in Leyden. See references made at page 486 of the Ronalds Library Catalogue, likewise note Book IV, Chap. IX, of the present work.

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Quisquis es, ex illo, Zoile, nomen habes.
whoever thou art, from him, Zoilus, dost thou derive thy fame.)[1]

Your work, I say, that has been kept back for so many years, your New Physiology of the Loadstone and of the Great Magnet (i.e. the Earth)—a philosophy never to be sufficiently admired; let it go forth into the light of publicity; for, believe me,

Siquid habent veri vatum præsagia,
(If the presages of poets have aught of truth)[1]

these your books on the Loadstone (*De Magnete*) will do more to perpetuate your memory than would the monument of any Magnate (*Magnatis cujusvis*) erected over your grave.

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[1] Ovid's *Remedia Amoris*, Bohn, London 1852, page 475, tr. of Mr. Henry T. Riley, who adds: It was unknown of what parentage and country Zoilus was. He compiled a work in dispraise of Homer, and was called by the ancients 'Homeromastix,' 'the scourge of Homer.

[2] "The Metamorphoses of Ovid," XV, 878 (tr. by Mr. Henry T. Riley), Bohn, London 1851, page 553.

AUTHOR'S PREFACE.

TO THE CANDID READER, STUDIOUS OF THE MAGNETIC PHILOSOPHY.

SINCE in the discovery of secret things and in the investigation of hidden causes, stronger reasons are obtained from sure experiments and demonstrated arguments than from probable conjectures and the opinions of philosophical speculators of the common sort; therefore to the end that the noble substance of that great loadstone, our common mother (the earth), still quite unknown, and also the forces extraordinary and exalted of this globe may the better be understood, we have decided first to begin with the common stony and ferruginous matter, and magnetic bodies, and the parts of the earth that we may handle and may perceive with the senses; then to proceed with plain magnetic experiments, and to penetrate to the inner parts of the earth. For after we had, in order to discover the true substance of the earth, seen and examined very many matters taken out of lofty mountains, or the depths of seas, or deepest caverns, or hidden mines, we gave much attention for a long time to the study of magnetic forces—wondrous forces they, surpassing the powers of all other bodies around us, though the virtues of all things dug out of the earth were to be brought together. Nor did we find this our labor vain or fruitless, for every day, in our experiments, novel, unheard-of properties came to light: and our Philosophy became so widened, as a result of diligent research, that we have attempted to set forth, according to magnetic principles, the inner constitution of the globe and its genuine substance, and in true demonstrations and in experiments that appeal plainly to the senses, as though we were pointing with the finger, to exhibit to mankind Earth, mother of all.

And even as geometry rises from certain slight and readily understood foundations to the highest and most difficult demonstrations, whereby the ingenious mind ascends above the æther: so does our magnetic doctrine and science in due order first show forth certain facts of less rare occurrence; from these proceed facts of a more extraordinary kind; at length, in a sort of series, are revealed things most secret and privy in the earth, and the causes are recognized of things that, in the ignorance of those of old or through the heedlessness of the moderns, were unnoticed or disregarded. But why should I, in so vast an ocean of books whereby the minds of the studious are bemuddled and vexed; of books of the more stupid sort whereby the common herd and fellows without a spark of talent are made intoxicated, crazy, puffed up; are led to write numerous books and to profess themselves philosophers, physicians, mathematicians, and astrologers, the while ignoring and contemning men of learning: why, I say, should I add aught further to this confused world of writings, or why should I submit this noble and (as comprising many things before unheard of) this new and inadmissible philosophy to the judgment of men who have taken oath to follow the opinions of others, to the most senseless corrupters of the arts, to lettered clowns, grammatists, sophists, spouters, and the wrong-headed rabble, to be denounced, torn to tatters and heaped with contumely. To you alone, true philosophers, ingenuous minds, who not only in books but in things themselves look for knowledge, have I dedicated these foundations of magnetic science—a new style of philosophizing. But if any see fit not to agree with the opinions here expressed and not to accept certain of my paradoxes; still let them note the great multitude of experiments and discoveries—these it is chiefly that cause all philosophy to flourish; and we have dug them up and demonstrated them with much pains and sleepless nights and great money expense. Enjoy them you, and, if ye can, employ them for better purposes. I know how hard it is to impart the air of newness to what is old, trimness to what is gone out of fashion; to lighten what is dark; to make that grateful which excites disgust; to win belief for things doubtful; but far more difficult is it to win any standing for or to establish doctrines that are novel, unheard-of, and opposed to everybody's opinions. We care naught, for that, as we have held that philosophy is for the few.

We have set over against our discoveries and experiments larger and smaller asterisks according to their importance and their subtility. Let whosoever would make the same experiments, handle the bodies carefully, skilfully and deftly, not heedlessly and bunglingly; when an experiment fails, let him not in his ignorance condemn our discoveries, for there is naught in these Books that has not been investigated and again and again done and repeated under our eyes. Many things in our reasonings and our hypotheses will perhaps seem hard to accept, being at variance with the general opinion; but I have no doubt that hereafter they will win authoritativeness from the demonstrations themselves. Hence the more advanced one is in the science of the loadstone, the more trust he has in the hypotheses, and the greater the progress he makes; nor will one reach anything like certitude in the magnetic philosophy, unless all or at all events most of its principles are known to him.

This natural philosophy (*physiologia*) is almost a new thing, unheard-of before; a very few writers have simply published some meagre accounts of certain magnetic forces. Therefore we do not at all quote the ancients and the Greeks as our supporters, for neither can paltry Greek argumentation demonstrate the truth more subtilly nor Greek terms more effectively, nor can both elucidate it better. Our doctrine of the loadstone is contradictory of most of the principles and axioms of the Greeks. Nor have we brought into this work any graces of rhetoric, any verbal ornateness, but have aimed simply at treating knotty questions about which little is known in such a style and in such terms as are needed to make what is said clearly intelligible. Therefore we sometimes employ words new and unheard-of, not (as alchemists are wont to do) in order to veil things with a pedantic terminology and to make them dark and obscure, but in order that hidden things which have no name and that have never come into notice, may be plainly and fully published.

After the magnetic experiments and the account of the homogenic parts of the earth, we proceed to a consideration of the general nature of the whole earth; and here we decided to philosophize freely, as freely, as in the past, the Egyptians, Greeks, and Latins published their dogmas; for very many of their errors have been handed down from author to author till our own time; and as our sciolists still take their stand on these foundations, they continue to stray about, so to speak, in perpetual darkness. To those men of early times and, as it were, first parents of philosophy, to Aristotle, Theophrastus, Ptolemæus, Hippocrates, Galen, be due honor rendered ever, for from them has knowledge descended to those that have come after them: but our age has discovered and brought to light very many things which they too, were they among the living, would cheerfully adopt. Wherefore we have had no hesitation in setting forth in hypotheses that are provable, the things that we have through a long experience discovered. Farewell.[1]

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[1] See the rendering of this Preface by Dr. B. W. Richardson and Mr. James Menzies, which appeared in "The Asclepiad" under the title of "The first electrician, William Gilbert, M.D."

EXPLANATION OF SOME TERMS USED IN THIS WORK.

Terrella. A spherical loadstone or natural magnet.[1]

Verticity.[2] Polar strength—activity (or what in Gilbert's day was understood as energy); not gyrating, vertiginous, but turning power: nor is it polar revolution, but a directing virtue, an innate turning vigor (*virtus convertens*).[3, 4]

Electrics. Bodies that attract in the same way as amber.

Excited magnetic body. One (such as iron or steel) that acquires magnetism from a loadstone or natural magnet.

Magnetized versorium. An iron bar or needle resting on a point (electroscope[5]) and put in motion—excited—by the loadstone or natural magnet.

Non-magnetized versorium (the electroscope itself). Made of any metal, for use in electrical experiments.

Armed loadstone. One that is furnished with an iron helmet or cap.[6]

Meridionally. In the direction of a meridian.

Paralleletically. In the direction of a parallel of latitude.

Cuspis (point). The end of a magnetized versorium.

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[1] See Kenelm Digby's allusion to terrella in the Biographical Memoir, also *De Magnete*, Book I, Chap. III.

[2] See *De Magnete*, Book I, Chap. X.

[3] See *De Magnete*, Book II, Chap. VI, also Prof. Sir Wm. Thomson's allusion to the *orbis virtutis* in the Biographical Memoir.

[4] "Therefore true it is, and conformable by every experiment, that Steel and good Iron never excited by the Load-stone, discover in themselves a verticity; that is, a directive or polary facultie whereby, conveniently placed, they do septentrionate at one extream, and Australize at another" (Thomas Brown, *Pseudoloxia Epidemica*, 1658, Book II, Chapter II, page 63).

[5] Humboldt says ("Cosmos," 1849, Vol. II, page 726) that Gilbert measured the strength of excited electricity by means of a small needle "not made of iron . . . ." *De Magnete* states that the *versorium* was made of any metal (*ex quouis metallo*) (Verborum, eighth line, and Book II, Chap. II, page 48), and alludes (Book III, Chap. I, page 115) to the construction of a *versorium* of two pieces of curved iron (*ex duobus curvis ferramentis*).

[6] See *De Magnete*, Book II, Chap. XVII.

Crotch. Name sometimes given to the end not touched and excited, although in some instruments both ends are commonly so designated, according as they are most convenient for excitation by the loadstone.[1]

Cork. Bark of the cork-tree.

Radius (of a loadstone's sphere). A right line drawn in the shortest way from the surface of a spherical loadstone to the surface of a body, and which when produced passes through the centre of the loadstone.

Sphere of influence. The entire space over which the force of a loadstone extends.[2]

Sphere of coition. The entire space over which the smallest magnetic body moves toward a loadstone.

Ostensio. Physical demonstration (opposed to theory).

Magnetic coition.[3] This phrase is used rather than *attraction* because magnetic movements do not result from attraction of one body alone but from the coming together of two bodies harmoniously (not the drawing of one by the other)—*Ὁμοδρομή*, the coition is always vigorous, even though heavy substances make opposition.

Declinatorium. A bar or needle movable vertically on its axis and that is excited with a loadstone; used in the dip instrument.

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[1] See *De Magnete*, Book II, Chap. XXXII.

[2] See note 3, page xxxi.

[3] See *De Magnete*, Book II, Chap. I, *et seq.*

WILLIAM GILBERT.

BOOK FIRST.

CHAPTER I.

WRITINGS OF ANCIENT AND MODERN AUTHORS CONCERNING THE LOADSTONE: VARIOUS OPINIONS AND DELUSIONS.

IN former times when philosophy, still rude and uncultured, was involved in the murkiness of errors and ignorances, a few of the virtues and properties of things were, it is true, known and understood: in the world of plants and herbs all was confusion, mining was undeveloped, and mineralogy neglected. But when, by the genius and labors of many workers, certain things needful for man's use and welfare were brought to light and made known to others (reason and experience meanwhile adding a larger hope), then did mankind begin to search the forests, the plains, the mountains and precipices, the seas and the depths of the waters, and the inmost bowels of earth, and to investigate all things. And by good luck at last the loadstone was found, as seems probable, by iron-smelters or by miners in veins of iron ore. On being treated by the metallurgists, it quickly exhibited that strong powerful attraction of iron—no latent nor obscure property, but one easily seen of all; one observed and commended with many praises. And after it had come forth as it were out of darkness and out of deep dungeons and been honored of men on account of its strong and marvellous attraction of iron, then many ancient philosophers and physicians discoursed of it, and briefly (but briefly only) made it matter of record: as, for instance, Plato in the *Io*, Aristotle only in his first book *De Anima;* likewise Theophrastus the Lesbian, Dioscorides, Caius Plinius secundus, Julius Solinus. These record only that the loadstone attracts iron: its other properties were all hid. But lest the story of the loadstone should be jejune and too brief, to this one sole property then known were appended certain figments and falsehoods which in the early time no less than nowadays were by precocious sciolists and copyists dealt out to mankind to be swallowed. For example, they asserted that a loadstone rubbed with garlic does not attract iron; nor when it is in presence of a diamond.[1] The like of this is found in Pliny and in Ptolemy's *Quadripartitum;* and errors have steadily been spread abroad and been

[1] "As to what some writers have related, that a load-stone will not attract iron if there be a diamond near (Pliny, Book XXXVII, Chap. IV) and that onions and garlic will make it lose its vertue; these are contradicted by a thousand experiments which I have tried. For I have shown that this stone will attract iron through the very thickest diamonds and through a great many thick skins which an onion is made up of (Rohault's 'Syst. Nat. Phil.,' 1728, Vol. II, page 186). That garlic does not hinder the action of the load-stone is likewise shown by Porta, 'Nat. Magick,' 1658, Book VII, Chap. XLVIII, and by Sir Thos. Brown, at page 74 of his *Pseudoloxia Epidemica* published in the same year, but the contrary is shown by Sir Hugh Plat in *The Jewell House of Arte and Nature,* originally published in 1594." Consult, also, Plutarch, *Quæst. Conviv.* Lib. II, Quæst 7); Barthol. de Glanvil, *Lib. de Prop.*, Lyons 1480, folio, Lib. XVI; Pietro d'Abano (*Conciliator Differentiarum,* LI, Venice ed. 1526); Ibn Roschd's Comment. on Aristotle, 1550, T. 4, p. 143 t.; Nic. de Cusa, *Opera*, Basilæ 1565, p. 175; Cardan, *De Subtil.*, Lib. VII, Op. T. III, Basilæ ed. 1582; Porta, "Nat. Magick," 1658, Book VII, Chap. LV, page 215.

accepted—even as evil and noxious plants ever have the most luxuriant growth—down to our day, being propagated in the writings of many authors who, to the end that their volumes might grow to the desired bulk, do write and copy all sorts about ever so many things of which they know naught for certain in the light of experience. Such fables about the loadstone even Georgius Agricola, a man that has deserved well indeed of letters, has inserted as truthful history in his books *De Natura Fossilium*, putting his trust in others' writings.[1] Galen, in the ninth book of his *De Simplicium Medicamentorum Facultatibus*, recognizes its medicinal virtue, and its natural power of attracting iron, in the first book of his *De Naturalibus Facultatibus;* but he knew not the cause, any more than Dioscorides before him, nor did he seek further. But his translator Matthiolus furbishes again the garlic and diamond story, and further brings in the fable of Mahomet's shrine having an arched roof of magnets so that the people might be fooled by the trick of the coffin suspended in air, as though 'twere some divine miracle. But this is shown to be false by the reports of travellers. Pliny, however, records that the architect Chinocrates began to put an arched roof of loadstone on the temple of Arsinoē at Alexandria, so that her effigy in iron might seem to be suspended in air: in the meantime the architect died, as also Ptolemy, who had ordered the work to be done in honor of his sister.[2] But little

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[1] See account of the life and writings of George Agricola in the sixth chapter of "The History of Chemistry," by Dr. Thomas Thomson, who calls him one of the most extraordinary men as well as one of the greatest promoters of chemistry that have ever existed, and who pronounces Agricola's *De Re Metallica* as, beyond comparison, the most valuable chemical work which the sixteenth century produced.

[2] "So it is reported by Ruffinus, that in the Temple of Serapis there was an iron chariot suspended by Loadstones in the ayr; which stones removed, the chariot fell and dashed into pieces. The like doth Beda report of Bellerophon's

has been written by the ancients about the causes of the attraction of iron: some trifling remarks of Lucretius and others are extant; other authors barely make slight mention of the attraction of iron: all these are berated by Cardan for being so heedless and indifferent about so notable a matter, so broad a field of philosophizing, and for not giving a fuller account or a more developed philosophy; yet Cardan himself in his ponderous volumes has handed down to posterity, beyond a few commonplaces and quotations from other writers and false discoveries, naught that is worthy of a philosopher.[1] Of later authors, some tell only of its efficacy in medicine, as Antonius Musa Brasevolus, Baptista Montanus, Amatus Lusitanus, as did before them Oribasius in book 13th of the *De Facultate Metallicorum*, Avicenna, Serapio Mauritanus, Abohali (Hali Abbas), Santes de Ardoniis, Petrus Apponensis, Marcellus, Arnaldus. Only a few points touching the loadstone are very briefly mentioned by Marbodeus Gallus, Albertus, Matthæus Silvaticus, Hermolaus Barbatus, Camillus Leonhardus, Cornelius Agrippa, Fallopius, Joannes Langius, Cardinal de Cusa, Hannibal Roserius Calaber: by all these the subject is handled in the most careless way, while they repeat only the figments and ravings of others. Matthiolus compares the attractive virtues of the loadstone, which pass through iron, to the mischief of the torpedo, whose poison

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horse, which, framed of iron, was placed between two Loadstones, with wings expansed, pendulous in the ayr" (Thom. Brown, *Pseudoloxia Epidemica*, 1658, Book II, page 79). Consult: Ath. Kircheri, *Magnes; Sive de arte magnetica*, 1643, Lib. II, Pars IV, Problema VI; Vincentii Burgundi *Spec. Mai.*, T. 1, L. VIII, C. 34, Douai ed. 1624; Alb. Magnus, *De Mineralibus*, LII, Tr. III, c. vi, p. 243, Lione 1651; Ausonio L. Ampelius, *Lib. Memorialis*, c. viii, Paris 1827; J. H. Martin, "Observ. et Théories . . .," Rome, 1865, pp. 5, 6, 7.

[1] For a better list than Cardan's, of authors who have written on the loadstone, consult "Petri Peregrini . . . Achillem T. Gasserum . . . Augsburgi . . . 1558."

passes through bodies and spreads in an occult way. Gulielmus Puteanus in his *Ratio Purgantium Medicamentorum* discusses the loadstone briefly and crudely. Thomas Erastus, knowing naught of the nature of the loadstone, draws from it weak arguments against Paracelsus. Georgius Agricola, like Encelius and other writers on metals, simply describes it. Alexander Aphrodiseus, in his *Problemata*, judges the question of the loadstone to be incapable of explication. Lucretius Carus, the Epicurean poet, deems the attraction to be due to this, that as there is from all things an efflux of minutest bodies, so there is from iron efflux of atoms into the space betwixt the iron and the loadstone—a space emptied of air by the loadstone's atoms (seeds); and when these begin to return to the loadstone, the iron follows, the corpuscles being entangled with each other. Something similar is said by Joannes Costæus, following Plutarch. Thomas Aquinas, in his *Physica*, Bk. 7, treating briefly of the loadstone, gets at the nature of it fairly well: with his godlike and perspicacious mind he would have developed many a point had he been acquainted with magnetic experiments. Plato holds the magnetic virtue to be divine. But when, some three or four hundred years ago, the magnetic movement to the north and the south was discovered or recognized anew, many learned men, each according to his own gifts, strove to honor with admiration and praise or to explain with feeble reasonings a property so curious and so necessary for the use of mankind. Of more recent authors, very many have striven to discover the cause of this direction and movement to north and south, and to understand this so great miracle of nature and lay it open to others: but they wasted oil and labor, because, not being practical in the research of objects in nature, being acquaint only with books, being led astray by certain erroneous physical systems, and having made no magnetical experiments, they constructed certain raciocinations on a basis of mere opinions, and old-womanishly dreamt the things that were not. Marcilius Ficinus chews the cud of ancient opinions, and to give the reason of the magnetic direction seeks its cause in the constellation Ursa: in the loadstone, says he, the potency of Ursa prevails and hence it is transferred into the iron. Paracelsus declares that there are stars which, gifted with the loadstone's power, do attract to themselves iron. Levinus Lemnius describes and praises the mariner's compass, and on certain grounds infers its antiquity; he does not divulge the hidden miracle which he makes profession to know. The people of Melfi, in the kingdom of Naples, first, 'tis said, constructed a mariner's compass; and, as Flavius Blondus says, the townsmen do not without reason boast, they were so taught by one Joannes Goia, a fellow-citizen, in the year 1300.[1] This town is in the Kingdom of Naples, not far from Salerno, and near the promontory of Minerva. The sovereignty of the place was conferred by Charles V. on Andrea Doria, the great naval commander, in recognition of his splendid achievements. And that nothing ever has been contrived by the art of man nor anything been of greater advantage to the human race than the mariner's compass is certain: but many infer from ancient writings and from certain arguments and conjectures, that the compass was discovered earlier and received among the arts of navigation. Knowledge of the mariner's compass

[1] In his "Essay on Several Important Subjects," London 1676, Joseph Glanvill remarks (page 33): "I think there is more acknowledgement due to the name of this obscure fellow, that hath scarce any left, than to a thousand Alexanders and Cæsars, or to ten times the number of Aristotles and Aquinas. And he really did more for the increase of knowledge, and advantage of the world, by this one experiment, than the numerous *subtile disputers* that have lived ever since the Erection of the School of Wrangling."

appears to have been brought into Italy by the Venetian Paolo [*Paulum Venetum*—Marco Polo] who about the year 1260 learned the art of the compass in China,[1] still I do not want to strip the Melfitani of so great an honor, seeing that by them compasses were first commonly made in Mediterranean lands. Goropius ascribes the invention to the Cimbri or Teutons, on the ground that the thirty-two names of the winds inscribed on the compass are pronounced in German by all mariners, whether they be British or Spaniards, or Frenchmen. But the Italians give them names in their own vernacular. Some think that Solomon, King of Judea, was acquaint with the compass and taught the use of it to his pilots for their long voyages when they brought from the Western Indies such a quantity of gold: hence Arias Montanus holds that the regions in Peru that abound in gold got their name from the Hebrew word *Paruaim*. But it is more probable that the gold came from the coast of lower Ethiopia, or, as others declare, from the region called Cephala. The story seems less true for the reason that the Phœnicians, next neighbors of Judea, most skilful navigators in early times

[1] It appears to be a remarkable fact that Gilbert, the earliest classical writer on terrestrial magnetism, who cannot be supposed to have had the slightest knowledge of Chinese literature, should regard the mariner's compass as a Chinese invention, which had been brought to Europe by Marco Polo. The idea of the introduction of the compass by the last named, whose travels occurred in the interval between 1271 and 1295, and who, therefore, returned to Italy after the mariner's compass had been mentioned as a long-known instrument by Guyot de Provins in his politico-satirical poem ("La Bible," 1190), as well as by Jacques de Vitry ("Historiæ Hierosolimitanæ," Cap. 89), and Dante ("Paradiso," Cant. XII), is not supported by any evidence. Before Marco Polo set out on his travels in the middle of the thirteenth century, Catalans and Basques already made use of the compass (Humboldt, "Cosmos," Vol. II, pages 625, 656; Raymond Lully, in his "De Contemplatione," "Fenix de las maravillas del orbe," and "Arte de Naveguar;" Azuni, "Boussole," page 69; Miller, "History Philos. Ill.", London 1849, Vol. I, pages 179-180).

(whose talents, labor, and counsels Solomon employed in building ships and in his expeditions as well as in other ways), were ignorant of magnetic aids, of the use of the mariner's compass: for were it used by them, doubtless the Greeks, the Italians, and all the Barbarians would have known of a thing so necessary and so celebrated through common use; nor would things famous, most easily known, and of the highest necessity, ever perish in oblivion; on the contrary, the knowledge would have been handed on to posterity, or some memorial in writing would survive.

Sebastian Cabot first discovered that the magnetized iron (needle) varied.[1] Gonzales Oviedo first made mention in his history that in the meridian of the Azores there is no variation. [Jean François] Fernel, in his book *De Abditis Rerum Causis*, says that in the loadstone is a hidden and abstruse cause: elsewhere he says this cause is celestial; and he does but explain the unknown by the more unknown. This search after hidden causes is something ignorant, beggarly, and resultless. The ingenious Fracastorio, a philosopher of no common stamp,[2] asks what gives direction to the loadstone

[1] At page 150 of the 1869 London edition of Mr. J. F. Nicholls' Life of Seb. Cabot, it is said the latter represented to the King of England that the variation of the compass was different in many places, and was not absolutely regulated by distance from any particular meridian; also, that he could point to a spot of no variation, and that those whom he trained as seamen, as Chancellor and Stephen Burrough were particularly attentive to this problem, noting it at one time thrice within a short space ("Biddle," Memoir of Sebastian Cabot, 1831; Humboldt, in both his "Examen Critique" and his "Cosmos," treating of "Oceanic Discoveries").

[2] Hieronymus Fracastorio, the great cotemporary of Columbus, to whom Gilbert alludes so frequently, was one of the most learned men of his time (1483–1553). From his early youth, he devoted himself to the study of the sciences, medicine especially, and he is said to have been made professor of logic at the University of Padua when only nineteen years of age. The first edition of his complete works appeared at Venice in 1555. Edward Biot tells us that it was Fracastorio and Peter Appian, who first made generally known in

[needle], and imagines the existence of hyperborean magnetic mountains, attracting objects of magnetic iron. This opinion, in some degree accepted by others also, many authors follow in their writings, their geographical maps, their marine charts, and their descriptions of the globe: dreaming [imagining to themselves the existence of] magnetic poles and mighty cliffs, apart from the earth's poles. Of date two hundred years or more earlier than Fracastorio, is a small work attributed to one Petrus Peregrinus, a pretty erudite book considering the time: many believe it owes its origin to the opinions of Roger Bacon, Englishman of Oxford.[1] In this work the arguments touching the magnetic direction are drawn from the celestial poles and from the heaven itself. From this book of Petrus Peregrinus, Joannes Taisner Hannonius[2] extracted the matter

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Europe the peculiar fact, noticed by the Chinese astronomers as early as 837, that the tails of comets are always turned away from the sun, so that their line of prolongation passes through its centre (Humboldt, "Cosmos," 1849, Vol. I, page 86, and Vol. II, page 697).

[1] Roger Bacon, sometimes called Friar Bacon, flourished after the distinguished Albertus Magnus (who, strangely enough, is omitted by Olaus Borrichius in his list of alchymistical writers), and was by far the most illustrious and best informed of all the alchymists. In one of his numerous works he dwells upon the mariner's compass as a *miraculum in parte notum*. Alexander von Humboldt remarked that Roger Bacon, Albertus Magnus, as well as the Arabian philosophers Avicenna and Averroes, passed for the representatives of all the knowledge of their time.

[2] Joannes Taisner of Ath in Hainault (hence Hannonius) is mentioned (Ronald's Catalogue, page 493) as the author of "...*De Natura Magnetis et ejus effectibus* . . . ," Coloniæ 1562, an English translation of which, by Richarde Eden, was published in London about 1579. The first Gasser's printed edition of Petrus Peregrinus is dated Augsburg 1558. To Peregrinus is ascribed the first mention of the double polarity of the magnet (Nicolas Cabeo, *Phil. Magnetica*, Ferrara 1629, Lib. II, C. 3, 8), as well as the designation of the word *poles* for points of greatest energy in the magnet (Bertelli Barnabita, "Sopra P. Peregrino . . . ," Roma 1868, pp. 34, 62, 63, 70, 71). As is already known, the last claim has by others been made for Gilbert. Taisner's *De Natura*, again alluded to by Gilbert (Book II, Chap. XXXV), is said by Bertelli and others to be a more manifest plagiarism upon Peregrinus than even that of Antonius Fantis of Treviso. (Nic. Cabeo, *Phil. Magn.*, 1629, page 23.)

of a little volume, which he published for new. Cardan makes much of the star in the tail of Ursa Major; the cause of variation he assigns to its rising, thinking that variation is always certain at the rising of the star. But the difference of variation for change of locality, and the mutations in many places—mutations that even in the southern regions are irregular—preclude this exclusive dominance of one star at its northern rising. The College of Coimbra seeks the cause in some region of the heavens nigh to the pole; Scaliger, in the 131st of his *Exercitationes* on Cardan's work *De Subtilitate*, brings in a celestial cause to himself unknown, and terrestrial loadstones that have nowhere been discovered; and seeks the cause not in the "siderite mountains" but in that force which formed them, to wit, in the part of the heavens which overhangs that northern point. This opinion the learned author dresses in abundant verbiage and crowns with many subtile observations in the margin: but his reasons are not so subtile. Martinus Cortesius holds that the seat of the attraction is beyond the poles, and that it is the heavens in motion. One Bessard, a Frenchman, studies the pole of the Zodiac, but to as little purpose. Jacobus Severtius, of Paris, after quoting a few observations of others, fashions new errors about loadstones of different regions being different in direction, as also about the eastern and western parts of a loadstone. Robert Norman, an Englishman, posits a point and place toward which the magnet looks (but whereto it is) not drawn: toward which magnetized iron, according to him, is collimated, but which does not attract it: Franciscus Maurolycus[1] discusses a few problems regarding the loadstone, adopting the current opinions of others; he believes that the variation is caused by

[1] An account of Francis Maurolycus appears in a note, Book I, Chap. XVII, of present work.

a certain magnetic island mentioned by Olaus Magnus. Josephus Costa, knowing nothing whatever of the subject, nevertheless pours out empty words about the loadstone. Livio Sanuto in his *Geography* (written in Italian) discourses at length of the prime magnetic meridian, of the magnetic poles, whether they are terrestrial or celestial; treats also of an instrument for finding the longitude; but as he does not understand the nature of the loadstone, he does but add errors and obscurities to his otherwise excellent treatise. Fortunius Affaitatus has some rather silly philosophizing about attraction of iron and the turning toward the poles. Very recently Baptista Porta, a philosopher of no ordinary note, makes the 7th book of his *Magia Naturalis* a very storehouse and repertory of magnetic wonders; but he knows little about the movements of the loadstone, and never has seen much of them; much of what he has learned about its obvious properties, either from Messer Paolo, the Venetian, or through his own studies, is not very accurately noted and observed; the book is full of most erroneous experiments, as will appear in fitting place; still I hold him worthy of praise for that he essayed so great a task (even as he has essayed many another task, and successfully too, and with no inconsiderable results), and that he has given occasion for further researches.

All these philosophers, our predecessors, discoursing of attraction on the basis of a few vague and indecisive experiments and of reasonings from the recondite causes of things; and reckoning among the causes of the direction of the magnet, a region of the sky, celestial poles, stars, asterisms; or mountains, cliffs, vacant space, atoms, attractional or collimational regions beyond the heavens, and other like unproved paradoxes, are world-wide astray from the truth and are blindly wandering. But we do not propose just now to overturn with arguments either these their errors and impotent reasonings, or the other many fables about the loadstone, or the fairy-tales of mountebanks and story-tellers; as, for example, the questions raised by Franciscus Rueus about the loadstone, whether it is an imposture of cacodæmons; or the assertion that a loadstone placed unawares under the head of a sleeping woman drives her out of the bed if she be an adulteress; or that by its fume and vapor the loadstone is of use to thieves, as though the stone were by nature given to promote thefts; or that it withdraws bolts and opens locks, as Serapio insanely imagines; or that iron held by a loadstone's attraction, being placed in a balance, adds nought to the weight of the loadstone, as though the weight of the iron were absorbed by the virtue of the loadstone; or that, as Serapio and the Moors report, there are in Indian seas certain sharp-pointed rocks abounding in loadstone, the which draw every nail out of ships that land alongside them and hold the vessels: this story, Olaus Magnus does not fail to recite: he tells of mountains in the North possessing such power of attraction, that ships have to be constructed with wooden pegs, so that as they sail by the magnetic cliffs there be no iron nails to draw out.[1] Nor will

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[1] Olaus Magnus, *Historia de Gentibus Septentrionalibus*, Romae 1555, Book II, Chap. XXVI, page 89. This is likewise alluded to by Porta in his *Magia Naturalis*, 1658 ed., Book VII, Chap. I, page 191, and 1664 ed., Book VII, Chap. I, page 288.

"Of Rocks Magnetical there are likewise two relations; for some are delivered to be in the Indies and some in the extremity of the North and about the very Pole. The Northern account is commonly ascribed unto Olaus Magnus, Arch-Bishop of Upsale, who out of his Predecessor, Joannes, Saxo, and others compiled a history of some Northern Nations; but this assertion we have not discovered in that work of his which commonly passeth among us; and should believe his Geography herein no more then that in the first line of his book; when he affirmeth that Biarmia (which is not 70 degrees in latitude) hath the Pole for its Zenith, and Equinoctial for the Horizon" (Thomas Brown, *Pseudoloxia Epidemica*, 1658, Book II, page 78). Consult, also, Claudius Ptolowe take the trouble to refute such stories as that a white loadstone may be used as a philter; or that, as Abohali (Hali Abbas) rashly asserts, when held in the hand it cures pains of the feet and cramps; or that, as Pictorius sings, it gives one favor and acceptance with princes or makes one eloquent; that, as Albertus Magnus says, there are two species of loadstones, one pointing north, the other south; or that iron is directed toward the northern stars by a force communicated from the polar stars, even as plants, like the sunflower, follow the sun; or, as the astrologer Lucas Gauricus held, that beneath the tail of Ursa Major is a loadstone; Lucas further assigns the loadstone (as the sardonyx and the onyx) to the planet Saturn, but also to Mars (with the diamond, jasper, and ruby), so that the loadstone, according to him, is ruled by two planets; further, Lucas says that the loadstone belongs to the sign Virgo; and with a veil of mathematical erudition does he cover many similar disgraceful stupidities. Gaudentius Merula advises that on a loadstone be graven the image of a bear, when the moon looks to the north, so that being suspended by an iron thread it may win the virtue of the celestial Bear; Ficinus writes, and Merula copies, that the loadstone draws iron and makes it point north, because it is of higher order than iron in the Bear. Others tell that in daytime the loadstone possesses the power of attracting iron, but that at night this power is feeble or rather null; Ruellius writes that the loadstone's force, when failing or dulled, is restored by the blood of a buck; it has been said that a buck's blood frees the magnet from the diamond's sorcery, giving back its lost power

mæus, *Geographia*, Lib. vii, c. 2; Klaproth *Boussole*, Paris 1834, p. 116, etc.; Taisnier's *De Natura*, 1562, Eden tr. p. 12; "Beati Alb. Magni, Ratisboniensis . . . ," Lib. viii, Lugduni 1651; J. H. Martin, "Observ. et Théories," Rome 1865, p. 304.

when the magnet is bathed in the blood—this, because of the variance between that blood and the diamond;[1] Arnoldus de Villanova fancies that the loadstone frees women from witchcraft and puts demons to flight; Marbodaeus, a Frenchman, fugleman of vain imaginings, says that it can make husbands agreeable to wives and may restore wives to their husbands; Caelius Calcagninius in his *Relationes* says that a magnet pickled with salt of the sucking-fish has the power of picking up a piece of gold from the bottom of the deepest well. In such-like follies and fables do philosophers of the vulgar sort take delight; with such-like do they cram readers a-hungered for things abstruse, and every ignorant gaper for nonsense. But when the nature of the loadstone shall have been in the discourse following disclosed, and shall have been by our labors and experiments tested, then will the hidden and recondite but real causes of this great effect be brought forward, proven, shown, demonstrated; then, too, will all darkness vanish; every smallest root of error, being plucked up, will be cast away and will be neglected; and the foundations of a grand magnetic science being laid will appear anew, so that high intellects may no more be deluded by vain opinions.

There are other learned men who on long sea voyages have observed the differences of magnetic variation; as that most accomplished scholar Thomas Hariot, Robert Hues, Edward Wright, Abraham Kendall, all Englishmen; others have invented and published magnetic instruments and ready methods of observing, necessary for mariners and those who make long voyages: as William Borough in his little work the *Variation of the Compass*, William Barlo (Barlowe) in his

[1] Consult: Simon, *Clavis Sanationis*, Padua 1474; C. G. Solino, *Polyhistor*, p. 154, Lyons ed. 1538; Vincentii Burgundi, *Spec. Mai.* T. 1, Lib. 8, c. 40, Douai ed. 1624.

Supplement, Robert Norman in his *New Attractive*—the same Robert Norman, skilled navigator and ingenious artificer, who first discovered the dip of the magnetic needle.[1] Many others I pass by of purpose: Frenchmen, Germans, and Spaniards of recent time who in their writings, mostly composed in their vernacular languages, either misuse the teachings of others, and like furbishers send forth ancient things dressed with new names and tricked in an apparel of new words as in prostitutes' finery; or who publish things not even worthy of record; who, pilfering some book, grasp for themselves from other authors, and go a-begging for some patron, or go a-fishing among the inexperienced and the young for a reputation; who seem to transmit from hand to hand, as it were, erroneous teachings in every science and out of their own store now and again to add somewhat of error.

CHAPTER II.

THE LOADSTONE: WHAT IT IS: ITS DISCOVERY.

THIS stone is commonly called magnet, either after its finder (*not* Pliny's mythical herdsman—copied from Nicander —the hobnails of whose brogues and the point of whose staff

[1] Whewell thus renders the passage (" Hist. Ind. Sc.", 1859, Vol. II, page 218): " Other learned men have, in long navigations, observed the differences of magnetic variations, as Thomas Hariot, Robert Hues, Edward Wright, Abraham Kendall, all Englishmen: others have invented magnetic instruments and convenient modes of observation, such as are requisite for those who take long voyages, as William Borough in his Book concerning the variation of the compass, William Barlo in his Supplement, Robert Norman in his 'New Attractive.' This is that Robert Norman (a good seaman and an ingenious artificer) who first discovered the *dip* of magnetic iron." This important discovery was made in 1576 (" Enc. Met.", page 738). Read paragraph 366 of J. F. W. Herschel's "Prelim. Disc.", 1855.

were held fast in a magnetic region while he was pasturing his cattle), or after the district Magnesia in Macedonia,[1] abounding in loadstones; or after the City of Magnesia in Ionia of Asia Minor, on the river Maender; hence Lucretius writes, *Quem Magneta vocant patrio de nomine Graï, Magnetum quia sit patriis in montibus ortus.*[2] It is called Heracleus from the City Heraclea,[3] or after that unconquerable hero Hercules, because of its great strength and its power and dominion over iron which is the subduer of all things; it is also called Sideritis, as though one should say Ferrarius (*Ferrarius lapis*—ironstone). It was not unknown to the earliest writers, whether among the Greeks, as Hippocrates and others, or (as I believe) among the Jews and the Egyptians; for in the most ancient iron mines, in particular the most famous mines of Asia, the loadstone, brother uterine of iron, was oft dug out in company with that ore. And if those things be true which are told

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[1] Magnesia. Many authors erroneously allude to a *city or town* called Magnesia—in the country of Magnesia—in Thessaly, one of the number being the learned Dr. W. Smith, who further states ("Dict. of Greek and Roman Geogr.", 1857, Vol. II, page 1170) that the Thessalian Magnetes—Magnesians—are said to have founded both the Ionian and the Lydian Magnesias. The celebrated historian Barthold George Niebuhr, in his "Lectures on Ancient Ethnography and Geography," states (transl. of Dr. L. Schmitz, London 1853, Vol. I, page 168) that the "town of Magnesia never existed, it is a mere blunder, . . . not mentioned by either Scylax, Herodotus, or Demosthenes," and, furthermore, that the province of Magnesia was governed by the Macedonians, and that it is not probable it was ever incorporated by the Romans with either Thessaly or Macedonia.

[2] Transl.—Which the Greeks call *magnetes*, from the name of its country, for it had its origin in the native hills of the Magnesians.

[3] Heraclea, a town of uncertain site in Lydia, perhaps not far from (the Lydian) Magnesia at the foot of Mount Sipylus (*ad Sipylum*) (Dr. W. Smith, "Dict. of Greek and Roman Geogr.", 1857, Vol. I, page 1049). Gilbert has alluded to the celebrated Magnesia in Ionia (*ad Maendrum*), but it is uncertain which of the two Magnesias is really meant (Ninth "Encycl. Brit.", Vol. XV, page 219, note). At page 470, Vol. VI, of the "Dict. Géogr. Univ.", Paris 1829, it is said that it was the Magnesia ad Sipylum—Manika-Mansa—which gave its name to the Magnes, and this view is taken by many authors.

about the people of China, neither were they in primitive times ignorant of magnetic experiments, for even in their country are seen the most excellent magnets in the world. The Egyptians, as Manetho relates, give it the name of 'the bone of Horus,' calling the potency that presides over the revolution of the sun Horus, as the Greeks called it Apollo. But later, as Plato declares, Euripides gave to it the name *magnet*. It is mentioned and praised by Plato in the *Io*, by Nicander of Colophon, Theophrastus, Dioscorides, Pliny, Solinus, Ptolemy, Galen, and other investigators of nature. But considering the great differences of loadstones, their dissimilitude in hardness, softness, heaviness, lightness, density, firmness, friableness: in color and in all other qualities; these writers have not handed down any sufficient account of it. The history of the magnet was overlooked by them, or, if written, was incompletely given, because in olden time objects of many kinds and foreign products never before seen were not brought in by traders and mariners as they are wont to be brought in now, when all manner of commodities—stones, woods, spices, herbs, metals, and metallic wares—are eagerly sought for all over the earth; neither was mining carried on everywhere in early times as it is now.

The difference between loadstones rests on their respective power: hence one loadstone is male, another female: so the ancients were wont to distinguish many objects of the same species. Pliny quotes from Sotacus five kinds, viz.: the loadstones of Ethiopia, Macedonia, Boeotia, Troas, and Asia, respectively, which were the chief sorts known to the ancients.[1]

[1] Porta has it: "The Ethiopian, the Magnesian from Magnesia near Macedonia, as the way lies to the Lake Bœbis, on the right hand; the third in Echium of Bœtia, the fourth about *Alexandria* at Troaderum; the fifth in Magnesia of Asia" ("Nat. Mag.," Book VII, Chap. I).

But we recognize as many kinds as there are in the whole world regions differing in soil; for in every clime, in every province, in all kinds of land, either the loadstone is found or lies unknown because of its deep site or its inaccessible situation; or, because of its weaker and less potent virtues, it is not recognized by us the while we see it and touch it.[1]

For the ancients, the differences were based on the color: The magnets from Magnesia in Macedonia were red and black, those from Bœotia red rather than black, those from the Troad black without strength, those from Asian Magnesia white, without power of attracting iron, and resembling pumice. A strong loadstone and one that under experiment demonstrates its power, nowadays generally resembles unpolished iron and usually is found in iron mines: sometimes it is found also forming a continuous vein by itself: such loadstones are imported from the East Indies, China, and Bengal, and they are of the color of iron, or of a dark blood-red or liver color. These are the most excellent and often are of great size and weight, as if broken off a great rock; or again they are as if complete in themselves. Some of these, though they may weigh but one pound, will lift 4 ounces, or half a pound, or even an entire pound of iron. In Arabia are found red loadstones shaped like tiles, not as heavy as those imported from China, yet strong and good. Rather black loadstones are found in Ilva, an island of the Etrurian sea; with these occur also white loadstones like those from the mines of Caravaca in Spain: but they are of inferior strength. Black loadstones also are found, and these, too, are rather inferior in strength, for example, those met with in the iron mines of Norway and in the coast region

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[1] Consult Johann S. T. Gehler's "Physikalisches Wörterbuch," article "Magnetismus."

along the Cattegat. Blue-black and dusky-blue loadstones are likewise powerful and highly prized.[1] But there are others of a lead color, fissile or not fissile, that can be split up like slate; I have also loadstones resembling an ashy-gray marble, mottled like gray marble: these take a high polish. In Germany, are loadstones perforated like the honeycomb: these are lighter than the other sorts, yet they are powerful. The metallic loadstones are those which are smelted into the best of iron; the rest are not easily smelted, but are burnt.

There are loadstones that are very heavy, as there are others very light; some are very powerful and carry masses of iron; others are weaker and less powerful; some so faint and void of strength that they can hardly attract ever so small a piece of iron, nor do they repel an opposite magnetized body. Others are firm and tough, nor are they easy to work; others are friable. Again, some are dense and hard like corundum, or light or soft like pumice; porous or solid; smooth and uniform, or irregular and corroded. Now hard as iron, nay sometimes harder to cut or to file than iron; again as soft as clay. Not all magnets can properly be called stones: some there are that represent rather rocks; others are rather metallic ores; others are like clods of earth. So do they vary and differ from one another, and some possess more, others less, of the peculiar magnetic virtue. For they differ according to the nature of the soil, and the different mixtures of clays and humors; according to the lie of the land and the decay of this highest substance born to Earth: decay due to the concurrence of many

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[1] "They are proved to be the best which are most of blewe or heavenly colour" (Taisnier, *De Natura*, 1562, Eden tr. p. 11).—"It is certain, that the bluer they are, the better they are" (Porta, "Natural Magick," 1658, Chap. VII, page 191). Consult *Epistola P. Peregrini De Magnete*, Cap. III, and Barthol. de Glanvil, *Lib. de Prop.*, Lyons 1480, fol., Lib. XVI, Cap. LXII.

causes and the never-ceasing vicissitude of rise and decline and the mutations of bodies. Nor is this stone, endowed as it is with such power, a rarity: there is no country wherein it may not be found in one form or other. But were men to seek it more diligently and at greater expense, and could they in the face of difficulties mine it, it might be obtained everywhere, as later we will prove. In many regions are found and are now opened mines of powerful loadstones unknown to ancient authors, in Germany, for example, where none of them ever said that loadstones were mined; and yet since the time within the memory of our fathers when the business of mining began there to be developed, in many parts of Germany powerful loadstones of great virtues have been taken out of the earth, as in the Black Forest near Helceburg: in Mt. Misena not far from Schwarzberg; some of considerable strength from the region betwixt Schneeberg and Annaberg in the Joachimsthal, as was observed by Cordus; also near Pela in Franconia; in Bohemia from the iron mines near Lesse; and in other places, as we are informed by Georgius Agricola and other men learned in the art of mining. The like is to be said of other countries in our time; for this stone, famous for its virtues, as to-day it is well known throughout the world, so is produced in every land; it is, so to speak, a native of all countries. In East India, in China, in Bengal, along the banks of the Indus, it is plentiful, also in certain marine rocks; in Persia, too, in Arabia and the isles of the Red Sea; in many parts of Ethiopia, as was anciently Zimiri, mentioned by Pliny; in Asia Minor around Alexandria, Boeotia, Italy, the island Elba, Barbary; in Spain, still in many localities as of old; in England quite recently a vast quantity was found in a mine owned by a gentleman, named Adrian Gilbert, as also in Devonshire and in the Forest of Dean; in Ireland too, in Norway, Denmark, Sweden, Lapland.

Livonia, Prussia, Poland, Hungary.[1] For albeit the terrestrial globe, various humors and diversities of soils being produced by the perpetual vicissitude of generation and decay, is ever to a greater and greater depth beneath the surface in the lapse of ages efflorescing, and is being clothed as it were with a diversified and perishable covering and wrappage; still from its interior arises in many places a progeny nigher to the more perfect body, and makes its way into the sunlit air. But the weak loadstones and those of less strength, which thus have been deprived of their virtue by being soaked with humors, are visible everywhere, in every country-side; great masses of these are to be found in every quarter, without tunnelling mountains or sinking mines, and without any of the toils and difficulties of mining, as we will show in the sequel. These we will so manipulate according to a simple process, that their languid and dormant properties shall be made manifest.

The magnet is called by the Greeks *Ἡράκλειος*, as by Theophrastus, and *Μαγνῆτις* and *Μάγνης*, as by Euripides, quoted by Plato in the *Io;* by Orpheus it is called also *Μαγνῆσσα* and *Σιδήριτης* (*quasi* ironstone); by the Latins it is called *Magnes Herculeus;* by the French *Aimant*, a corruption of *adamas;* by the Spaniards *Piedramant;* by the Italians *Calamita;* by the English **Loadstone and Adamant stone;** by the Germans *Magness* and *Siegelstein.* Among the English, French, and Spaniards, it has its common name from *adamas*, and this is probably because at some time those people were led astray by the term *siderites*, which was applied both to the diamond and the magnet.[2] The magnet is called *Σιδηρίτης* because

[1] "The most powerful native magnets are found in Siberia, and in the Hartz; they are also obtainable on the Island of Elba" (Dana). See Gilbert, Book IV, Chap. V.

[2] Consult Vincentii Burgundi, *Spec. Mai.*, Douai ed. 1624, T. I, LVIII, C. 34, 39–41; Alb. Magnus, *De Mineral.*, Op. T. II, Lione 1651, Tr. II. C. I.

of its property of attracting iron; and the diamond is called *Σιδηρίτης* from the glistening of polished iron. Aristotle merely names the loadstone in his work *De Anima*, I.: *"Εοικε δὲ καί Θαλῆς ἐξ ὧν ἀπομνεμονεύουσί, κινητικόν τι τὴν ψυχὴν ὑπολαμβάνειν, εἴπερ τὸν λιθὸν ψυχὴν ἔφη ἔχειν, ὅτι τὸν σιδηρὸν κινεῖ.* (Thales, too, seems, from what they relate, to regard the soul as somewhat producing motion, for he said that this stone has a soul, since it moves iron.) The name magnet is also given to another stone differing widely from the siderites, and having the look of silver: in its nature this stone resembles amianth (asbestus), and in form differs from that inasmuch as it consists, like mica, of laminæ; the Germans call it *Katzensilber* and *Talk.*

CHAPTER III.

THE LOADSTONE POSSESSES PARTS DIFFERING IN THEIR NATURAL POWERS, AND HAS POLES CONSPICUOUS FOR THEIR PROPERTIES.

THE many qualities exhibited by the loadstone itself, qualities hitherto recognized yet not well investigated, are to be pointed out in the first place, to the end the student may understand the powers of the loadstone and of iron, and not be confused through want of knowledge at the threshold of the arguments and demonstrations. In the heavens, astronomers give to each moving sphere two poles; thus do we find

page 227, and C. XI, page 233; C. G. Solino, *Exercitationes Plin.*, Rhenum, 1689, page 109. The Macedonian *diamond*, as well as the *adamas cyprius* and *siderites*, were obviously not diamonds, but soft stones (Thomson, "Hist. of Chem.", 1830, Vol. I, page 98).

two natural poles of excelling importance even in our terrestrial globe, constant points related to the movement of its daily revolution, to wit, one pole pointing to Arctos (Ursa) and the north; the other looking toward the opposite part of the heavens. In like manner the loadstone has from nature its two poles, a northern and a southern; fixed, definite points in the stone, which are the primary termini of the movements and effects, and the limits and regulators of the several actions and properties. It is to be understood, however, that not from a mathematical point does the force of the stone emanate, but from the parts themselves; and all these parts in the whole—while they belong to the whole—the nearer they are to the poles of the stone the stronger virtues do they acquire and pour out on other bodies. These poles look toward the poles of the earth, and move toward them, and are subject to them. The magnetic poles may be found in every loadstone, whether strong and powerful (male, as the term was in antiquity) or faint, weak, and female; whether its shape is due to design or to chance, and whether it be long, or flat, or four-square, or three-cornered, or polished; whether it be rough, broken-off, or unpolished: the loadstone ever has and ever shows its poles. *
But inasmuch as the spherical form, which, too, is the most perfect, agrees best with the earth, which is a globe, and also is the form best suited for experimental uses, therefore we purpose to give our principal demonstrations with the aid of a globe-shaped loadstone, as being the best and the most fitting. Take then a strong loadstone, solid, of convenient size, uniform, hard, without flaw; on a lathe, such as is used in turning crystals and some precious stones, or on any like instrument (as the nature and toughness of the stone may require, for often it is worked only with difficulty), give the loadstone the form of a ball. The stone thus prepared is a true homogeneous off-

spring of the earth and is of the same shape, having got from art the orbicular form that nature in the beginning gave to the earth, the common mother; and it is a natural little body endowed with a multitude of properties whereby many abstruse and unheeded truths of philosophy, hid in deplorable darkness, may be more readily brought to the knowledge of mankind. To this round stone we give the name *Μικρόγη* (microge) or Terrella (earthkin, little earth).[1]

To find, then, poles answering to the earth's poles, take in your hand the round stone, and lay on it a needle or a piece of iron wire: the ends of the wire move round their middle point, and suddenly come to a standstill. Now, with ochre or with chalk, mark where the wire lies still and sticks. Then move the middle or centre of the wire to another spot, and so to a third and a fourth, always marking the stone along the length of the wire where it stands still: the lines so marked will exhibit meridian circles, or circles like meridians on the stone or terrella; and manifestly they will all come together at the poles of the stone. The circles being continued in this way, the poles appear, both the north and the south, and betwixt these, midway, we may draw a large circle for an equator, as is done by the astronomer in the heavens and on his spheres and by the geographer on the terrestrial globe; for the line so drawn on this our terrella is also of much utility in our demonstrations and our magnetic experiments. Poles are also found in the round stone, in a versorium, in a piece of iron touched with a loadstone and resting on a needle or point (attached at its base to the terrella), so that it can freely revolve, as in the figure.

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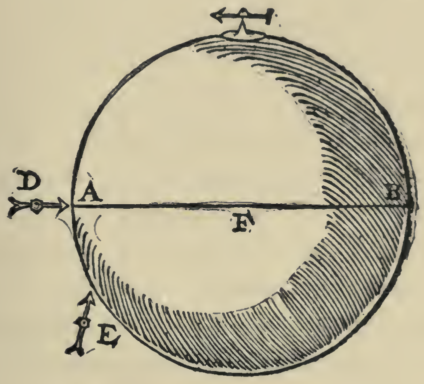
[1] Sir Kenelm Digby, "A Treatise of Bodies," London 1645, Chap. XX, page 225.

On top of the stone *AB* is set the versorium in such a way that its pointer may remain in equilibrium: mark with chalk the direction of the pointer when at rest. Then move the instrument to another spot and again mark the direction in which the pointer looks; repeat this many times at many different points and you will, from the convergence of the lines of direction, find one pole at the point *A*, the other at *B*. A pointer also indicates the true pole if brought near to



the stone, for it eagerly faces the stone at right angles, and seeks the pole itself direct and turns on its axis in a right line toward the centre of the stone. Thus the pointer *D** regards *A* and *F*, the pole and the centre, but the pointer *E* looks not straight either toward the pole *A* or the centre *F*. A bit of fine iron wire as long as a barley-corn is laid on the stone and is moved over the zones and the surface of the stone till it stands perpendicularly erect; for at the poles, whether N. or S., it stands erect; but the farther it is from the poles (towards the equator) the more it inclines. The poles thus found, you are to mark with a sharp file or a gimlet.

CHAPTER IV.

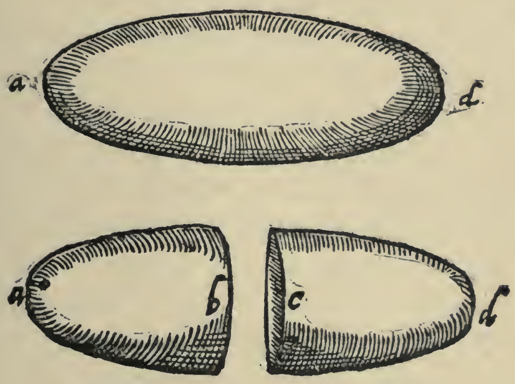
WHICH POLE IS THE NORTH: HOW THE NORTH POLE IS DISTINGUISHED FROM THE SOUTH POLE.

ONE of the earth's poles is turned toward Cynosura and steadily regards a fixed point in the heavens (save that it is unmoved by the precession of the fixed stars in longitude, which movement we recognize in the earth, as we shall later show); the other pole is turned toward the opposite aspect of the heavens, an aspect unknown to the ancients, but which is adorned with a multitude of stars, and is itself a striking spectacle for those who make long voyages. So, too, the loadstone possesses the virtue and power of directing itself toward the north and the south (the earth itself co-operating and giving to it that power) according to the conformation of nature, which adjusts the movements of the stone to its true locations. In this manner it is demonstrated: Put the magnetic stone (after you have found the poles) in a round wooden vessel—a bowl or a dish; then put the vessel holding the magnet (like a boat with a sailor in it) in a tub of water or a cistern where it may float freely in the middle without touching the rim, and where the air is not stirred by winds (currents) which might interfere with the natural movement of the stone: there the stone, as if in a boat floating in the middle of an unruffled surface of still water, will straightway set itself, and the vessel containing it in motion, and will turn in a circle till its south pole shall face north and its north pole, south. For, from a contrary position, it returns to the poles; and though with its first too strong impetus it passes beyond, still, as it comes back again and again, at last it rests at the poles or in the meridian (save that, according to the place, it diverges a very little from those points, or from the meridional line, the cause of which we will define later). As often as you move it out of its place, so often, by reason of the extraordinary power with which nature has endowed it, does it seek again its fixed and determinate points. Nor does this occur only when the poles of the loadstone in the float are made to lie evenly in the plane of the horizon; it takes place also even though one pole, whether north or south, be raised or depressed 10, 20, 30, 40, or 80 degrees from the plane of the horizon; you shall see the north part of the stone seek the south, and the south part the north; so that if the pole of the stone be but one degree from the zenith and the centre of the heavens, the whole stone revolves until the pole finds its own place; and though the pole does not point exactly to its seat, yet it will incline toward it, and will come to rest in the meridian of its true direction. And it moves with the same impetus whether the north pole be directed toward the upper heavens, or whether the south pole be raised above the horizon. Yet it must always be borne in mind that though there are manifold differences between stones, and one far surpasses another in virtue and efficiency, still all loadstones have the same limits and turn to the same points. Further, it is to be remembered that all who hitherto have written about the poles of the loadstone, all instrument-makers, and navigators, are egregiously mistaken in taking for the north pole of the loadstone the part of the stone that inclines to the north, and for the south pole the part that looks to the south: this we will hereafter prove to be an error. So ill-cultivated is the whole philosophy of the magnet still, even as regards its elementary principles.

CHAPTER V.

ONE LOADSTONE APPEARS TO ATTRACT ANOTHER IN THE NATURAL POSITION; BUT IN THE OPPOSITE POSITION REPELS IT AND BRINGS IT TO RIGHTS.

FIRST we have to describe in popular language the potent and familiar properties of the stone; afterward, very many subtile properties, as yet recondite and unknown, being involved in obscurities, are to be unfolded; and the causes of all these (nature's secrets being unlocked) are in their place to be demonstrated in fitting words and with the aid of apparatus. The fact is trite and familiar, that the loadstone attracts iron; in the same way, too, one loadstone attracts another. Take the stone on which you have designated the poles, *N.* and *S.*, and put it in its vessel so that it may float; let the poles lie just in the plane of the horizon, or at least in a plane not very oblique to it; take in your hand another stone the poles of which are also known, and hold it so that its south pole shall lie toward the north pole of the floating stone, and near it alongside; the floating loadstone will straightway follow the other (provided it be within the range and dominion of its powers), nor does it cease to move nor does it quit the other till it clings to it, unless, by moving your hand away, you manage skilfully to prevent the conjunction. In like manner, if you oppose the north pole of the stone in your hand to the south pole of the floating one, they come together and follow each other. For opposite poles attract opposite poles. But, now, if in the same way you present N. to N. or S. to S., one stone repels the other; and as though a helmsman were bearing on the rudder it is off like a vessel making all sail, nor stands nor stays as long as the other stone pursues. One stone also will range the other, turn the other around, bring it to right about and make it come to agreement with itself. But when the two come together and are conjoined in nature's order, they cohere firmly. For example, if you present the north pole of the stone in your hand to the Tropic of Capri-



corn (for so we may distinguish with mathematical circles the round stone or terrella, just as we do the globe itself) or to any point between the equator and the south pole: immediately the floating stone turns round and so places itself that its south pole touches the north pole of the other and is most closely joined to it. In the same way you will get like effect at the other side of the equator by presenting pole to pole; and thus by art and contrivance we exhibit attraction and repulsion, and motion in a circle toward the concordant position, and the same movements to avoid hostile meetings. Furthermore, in one same stone we are thus able to demonstrate all this: but also we are able to show how the self-same part of one stone may by division become either north or south. Take the oblong stone *ad* in which *a* is the north pole and *d* the south. Cut the stone in two equal parts, and put part *a* in a vessel and let it float in water.

You will find that *a*, the north point, will turn to the south as before; and in like manner the point *d* will move to the north, in the divided stone, as before division. But *b* and *c*, before connected, now separated from each other, are not what they were before. *b* is now south while *c* is north. *b* attracts *c*, longing for union and for restoration of the original continuity. They are two stones made out of one, and on that account the *c* of one turning toward the *b* of the other, they are mutually attracted, and, being freed from all impediments and from their own weight, borne as they are on the surface of the water, they come together and into conjunction. But if you bring the part or point *a* up to *c* of the other, they repel one another and turn away; for by such a position of the parts nature is crossed and the form of the stone is perverted: but nature observes strictly the laws it has imposed upon bodies: hence the flight of one part from the undue position of the other, and hence the discord unless everything is arranged exactly according to nature. And nature will not suffer an unjust and inequitable peace, or an unjust and inequitable peace and agreement, but makes war and employs force to make bodies acquiesce fairly and justly. Hence, when rightly arranged, the parts attract each other, i.e., both stones, the weaker and the stronger, come together and with all their might tend to union: a fact manifest in all loadstones, and not, as Pliny supposed, only in those from Ethiopia. The Ethiopic stones if strong, and those brought from China, which are all powerful stones, show the effect most quickly and most plainly, attract with most force in the parts nighest the pole, and keep turning till pole looks straight on pole. The pole of a stone has strongest attraction for that part of another stone which answers to it (the *adverse* as it is called); e.g., the north pole of one has strongest attraction for, has the most vigorous pull on, the south part of another: so too it attracts iron more powerfully, and iron clings to it more firmly, whether previously magnetized or not. Thus it has been settled by nature, not without reason, that the parts nigher the pole shall have the greatest attractive force; and that in the pole itself shall be the seat, the throne as it were, of a high and splendid power; and that magnetic bodies brought near thereto shall be attracted most powerfully and relinquished with most reluctance. So, too, the poles are readiest to spurn and drive away what is presented to them amiss, and what is inconformable and foreign.[1]

CHAPTER VI.

THE LOADSTONE ATTRACTS IRON ORE AS WELL AS THE SMELTED METAL.

THE most potent virtue of the loadstone and the one * valued by the ancients is the attraction for iron; for Plato mentions that the magnet, so called by Euripides, draws to itself iron, and not only attracts iron rings but also endows them with the power of doing as the stone itself, to wit, of attracting other rings, and that thus sometimes a long chain of iron objects, as nails, or rings, is made, the several parts hang-

[1] Dr. J. Lamont's "Handbuch des Magnetismus," Leipzig 1867, page 15.

ing from one another. The best iron (such as that which from its uses is called *acies*, and from the country of the Chalybes, *chalybs*) is most readily and strongly attracted by a good magnet;[1] but inferior iron, iron that is impure, rusty, not well purged of dross, and not worked over in the second furnace is attracted more weakly; and any iron is more faintly attracted if covered and smeared with thick, greasy, tenacious fluids. The loadstone also attracts iron ores—rich ores and those of the color of iron; poor ores and those without much pure metal it does not attract unless they receive special treatment. The loadstone loses some part of its attractive power, and, as it were, enters on the decline of old age, if it be too long exposed in open air and not kept in a case, with a covering of iron filings or iron scales: hence it must be packed in such material. Nothing withstands this unimpairable virtue, except what destroys the form of the body or corrodes it; no, not a thousand adamants made into one. Nor do I believe in the *theamedes*, or that it has a power the opposite of the loadstone's,[2] albeit Pliny, that eminent author and best of compilers (for he has handed down to posterity the observations and discoveries of others and not always or mainly his

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[1] See Aristotle's reference to the iron of the Chalybes at page 20. Dr. Thomson informs us the general opinion of the ancients was that the method of smelting iron ore had been brought to perfection by the Chalybes, a small nation located near the Black Sea (Xenophon's Anabasis, V. 5), and that the name *chalybs*, occasionally used for steel, was derived from that people. Porta, at Book XIII, Chap. I, of his "Natural Magick," says: "Justine, the historian, reports that in Gallicia of Spain, the chiefest matter for iron is found, ... and there is no weapon approved amongst them that is not made of the River Bibilis, or tempered with the water of Chalybes. And hence are those people that live neer this River called Chalybes; and they are held to have the best iron. Yet Strabo saith that the Chalybes were people in Pontus near the River Thermodon." See Gilbert, Book I, Chap. VIII.

[2] "Iron is attracted by the magnet and repelled by another stone, the *theamedes*" (Pliny, *Hist. Nat.*, XX, 1). See, likewise, Cardan, *De Subtil.*, Norimb. 1600, folio, Lib. VII, page 386.

own), copies out of other writers the theamedes fable, now from repetition become a familiar story among the moderns. The story is that in India are two mountains near the river Indus, and that one of them—consisting of loadstone—possesses the power of holding everything containing iron; while the other, consisting of theamedes, repels the same. Hence if you should have iron nails in the soles of your shoes, it would be impossible to lift your foot if you were standing on one of the mountains, and impossible to stand on the other at all. Albertus Magnus writes that in his time a loadstone was found that on one side drew iron to itself and on the other side repelled it.[1] But Albertus's observation was faulty, for every loadstone attracts on one side magnetized iron, on the other repels, and attracts magnetized iron more powerfully than non-magnetized.

CHAPTER VII.

WHAT IRON IS; WHAT ITS MATTER; ITS USE.

HAVING declared the origin and nature of the loadstone, we hold it needful first to give the history of iron also, and to point out properties of iron as yet not known, before we come to the explication of difficulties connected with the loadstone,

[1] Somewhat in this connection, Gilbert has already (Book I, Chap. I) alluded to Albertus Magnus, of whom mention was made in note 1, page 9. In his *De Mineralibus*—Lyons ed. 1651, Treat. III, Lib. II, Cap. VI, p. 243—Albertus says, "One angle . . . is to the *zoron* (north). . . . but another angle of the magnet opposite to it attracts to the *aphron* (south)." Consult Cardan, *De Subtil.*, Lugduni 1663; Salmanasar, Book II ("Of the Egyptian Hermitus, 19 stars, and 15 stones, and 15 herbs, and 15 figures"), "On one side (the magnet) attracts iron, on the other repels it;" Pietro d'Abano, *Conciliator Differentiarum* Mantuæ, 1472, Diff. 51, page 104, "Know that a magnet is discovered which attracts iron on one side and repels it on the other."

and to the demonstrations; before we come to the consideration of its uniting and according with iron. Iron is, by all, classed among metals; it is of bluish color, very hard, grows red hot before fusion, is very hard to fuse, spreads under the hammer, and is resonant. Chemists say that, if fixed earthy sulphur be combined with fixed earthy mercury and these two bodies present not a pure white but a bluish-white color, if the sulphur prevail, iron results. For those hard masters of the metals, who in many various processes put them to the torture, by crushing, calcining, smelting, subliming, precipitating, distinguish this, on account both of the earthy sulphur and the earthy mercury, as more truly the child of earth than any other metal; for neither gold, nor silver, nor lead, nor tin, nor even copper do they hold to be so earthy; and therefore it is treated only in the hottest furnaces with the help of bellows; and when thus smelted if it becomes hard again it cannot be smelted once more without great labor; and its slag can be fused only with the utmost difficulty. It is the hardest of metals, subduing and breaking them all, because of the strong concretion of the more earthy substance. Hence we shall better understand what iron is when we shall have developed, in a way different from that of those who have gone before us, what are the causes and the matter of metals. Aristotle supposes their matter to be an exhalation. The chemists in chorus (unison) declare that sulphur and quicksilver are the prime elements. Gilgil, the Mauretanian, holds the prime element to be ash moistened with water; Georgius Agricola, a mixture of water with earth; and his opinion differs nought from Gilgil's thesis. But our opinion is that metals have their origin and do effloresce in the uppermost parts of the globe, each distinct by its form, as do many other minerals and all the bodies around us. The globe of the earth is not made of ash or of inert dust. Nor is fresh water an element, but only a less complex consistence of the earth's evaporated fluids. Unctuous bodies (*pinguia corpora*), fresh water void of properties, quicksilver, sulphur: these are not the principles of the metals: they are results of another natural process; nor have they a place now or have they had ever, in the process of producing metals. The earth gives forth sundry humors, not produced from water nor from dry earth, nor from mixtures of these, but from the matter of the earth itself: these are not distinguished by opposite qualities or substances. Nor is the earth a simple substance, as the Peripatetics imagine. The humors come from sublimed vapors that have their origin in the bowels of the earth. And all waters are extractions from the earth and exudations, as it were. Therefore Aristotle is partly in the right when he says that the exhalation which condenses in the earth's veins is the prime matter of metals: for exhalations are condensed in situations less warm than the place of their origin, and owing to the structure of lands and mountains, they are in due time condensed, as it were, in wombs, and changed into metals. But they do not of themselves alone constitute the veins of ore; only they flow into and coalesce with solider matter and form metals. When, therefore, this concreted matter has settled in more temperate cavities, in these moderately warm spaces it takes shape, just as in the warm uterus the seed or the embryo grows. Sometimes the exhalation coalesces only with matter homogeneous throughout, and hence some metals are now and then but not often obtained pure and not needing to be smelted. But other exhalations, being mixed with foreign earths, must be smelted; and thus are treated the ores of all metals, which are freed from all their dross by the action of fire; when smelted into the metallic state they are fluid and then are freed from earthly impurities but not from the true substance of the earth. But that there is gold, or silver, or copper, or that any other metals exist, does not happen from any *quantitas* or proportion of matter nor by any specific virtues of matter, as the chemists fondly imagine; but it happens when, earth cavities and the conformation of the ground concurring with the fit matter, those metals take from universal nature the forms by which they are perfected, just as in the case of all other minerals, all plants and all animals: else the kinds of metals would be vague and undefined: in fact the varieties are very few, hardly ten in number. But why nature should be so grudging in the number of metals, or why there should be even so many metals as are recognized by man, were not easy to explain, though simpletons and raving astrologers refer to the several planets their respective metals.[1] But neither do the planets agree with the metals nor the metals with the planets, either in number or in properties. For what is common between Mars and iron, save that, like many other implements, swords and artillery are made of iron? What has copper to do with Venus? Or how does tin, or zinc, relate to Jupiter? These were better dedicated to Venus. But a truce to old wives' talk. Thus exhalations are the remote cause of the generation of metals; the proximate cause is the fluid from the exhalations: like the blood and the semen in the generation of animals. But these exhalations and the fluids produced from

[1] In his account of Geber (Abou-Moussah-Dschafar-Al-Soli), "the patriarch of chemistry," Dr. Thos. Thomson says this Arabian philosopher was acquainted with the metals *gold, silver, copper, iron, tin,* and *lead,* and that they are usually distinguished by him under the respective names of *Sol, Luna, Venus, Mars, Jupiter,* and *Saturn.* He adds: "Whether these names of the planets were applied to the metals by Geber, or only by his translators, I cannot say; but they were always employed by the Alchymists, who never designated the metals by any other appellations" ("Hist. of Chem.", 1830, Vol. I, pages 117, 118).

them enter bodies often and change them into marchasites[1] and they pass into veins (we find many instances of timber so transformed), into appropriate matrices within bodies, and these metals are formed; oftenest they enter the more interior and more homogeneous matter of the globe, and in time there results a vein of iron, or loadstone is produced, which is nothing but a noble iron ore; and for this reason and also on account of its matter being quite peculiar and distinct from that of all other metals, nature very seldom or never mingles with iron any other metal, though the other metals are very often commingled in some small proportion and are produced together. Now, when these exhalations or fluids happen to meet efflorescences altered from the homogeneous matter of the globe—sundry precipitates, and salts, in suitable matrices (operant forms)—the other metals are produced (a specificating nature operating in that place). For within the globe are hidden the principles of metals and stones, as at the earth's surface are hidden the principles of herbs and plants. And earth dug from the bottom of a deep pit, where there appears to be no chance of any seed being formed, produces, if strewn on the top of a very high tower, green herbage and unbidden grasses, the sun and the sky brooding over earth; the earth regions produce those things which in each are spontaneous; each region produces its own peculiar herbs and plants, its own metals.

Do you not see how Tmolus sends fragrant saffron, India its ivory, the Sabaens their frankincense, the naked Chalybes iron, Pontus the malodorous castor, Epirus the mares that have won at Olympia? (Virgilius, *Georgica*, Book I, pages 56–59.)

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[1] Marchasites, marcasites—the crystallized form of iron pyrites. What substance Geber designated by the name of marchasite (fire-stone, as Porta calls it—"Nat. Magick," Book V, Chap. IV) is not known to Dr. Thomson, who suspects it to have been a sulphide of antimony long in common use throughout Asia.

What the chemists (as Geber and others) call the fixed earthy sulphur in iron, is nothing else but the homogenic matter of the globe held together by its own humor, hardened by a second humor: with a minute quantity of earth-substance not lacking humor is introduced the metallic humor. Hence it is said very incorrectly by many authors that in gold is pure earth, in iron impure; as though natural earth and the globe itself were become in some incomprehensible sense impure. In iron, especially in best iron, is earth in its true and genuine nature. In the other metals is not so much earth as, instead of earth and precipitate, condensed and (so to speak) fixed salts, which are efflorescences of the Earth, and which also differ in firmness and consistence. In mines they ascend in great volume, with double humor from the exhalations; in the subterranean spaces they are consolidated into metallic ores; so too they are produced together, and in virtue of their place and of the surrounding bodies, they acquire, in natural matrices, their specific forms. Of the various bodily constitutions of loadstones, their different substances, colors, and properties, we have spoken before: but now after having declared the cause and origin of metals, the matter of iron, not in the smelted metal but in the ore from which that is obtained by smelting, has to be examined. Iron, that from its color appears pure, is found in the earth; yet it is not exactly metallic iron, not quite suitable for the different uses of iron. Sometimes it is found covered with a white moss-like substance, or with a coating of other stones. Such ore is often seen in the sands of rivers: such is the ore from Noricum (the region south of the Danube, watered by the Inn [*Œnus*] and the Drave [*Drau*]; mostly comprised in the modern Austria). Iron ore, nearly pure, is often mined in Ireland: from this the smith, without the labor of the furnace, forges in his shop iron implements.

From an ore of liver color is very often obtained in France an iron with bright scales (*bracteæ*)[1]; such iron is made in England without the scales; carpenters use it instead of chalk. In Sussex, in England, is a rich ore of dark, and one of pale ashy color; both of these ores when made red hot for some time, or when kept in a moderate fire, take the color of liver: in Sussex also is a dark-colored ore in square masses, with a black rind of harder material. The liver-like ore is often mixed with other stones in various ways, as also with perfect loadstone, which yields the best iron. There is likewise rust-colored ore, ore of a lead color mixed with black, simply black, or black mixed with cobalt; there is also an ore with admixture of pyrites or sterile plumbago. One kind of ore resembles jet, another the precious stone *hæmatites*. The stone *smiris* (emery; corundum) used by workers in glass for glass-cutting and called by the English *emerelstone* and by the Germans *smeargel* (*schmergel*), is of iron, albeit iron is smelted from it with difficulty; it attracts an unmagnetized needle. It is often found in deep silver and iron mines. Thomas Erastus tells of having been informed by a certain learned man, of iron ores, in color resembling metallic iron, but quite soft and greasy, capable of being moulded with the fingers like butter; we have seen ores of about the same kind that were found in England: they resemble Spanish soap. Besides the numberless forms of stony ores, there is a substance like iron rust deposited from ferriferous water: it is got from mud, loam, and from ochre. In England, a good deal of iron is obtained in the furnace from

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[1] At page 280, Vol. I, of Thomson's "Hist. of Chem.", London 1830, will be found an account of the difficulty experienced by Réaumur in removing the scales from the iron imported from Germany into France. Elsewhere, he tells us that the rust of iron and the scales of iron were used by the ancients as astringent medicines. See note at Book II, Chap. XXIII, of the present work.

sand stones and clayey stones that appear to contain not so much iron as sand, marl, or other mud. In Aristotle's book *De Admirandis Narrationibus* we read:

'Tis said the iron of the Chalybes and the Myseni has quite a peculiar origin, being carried in the gravel of the streams. Some say that, after being merely washed, it is smelted in the furnace; others that is washed repeatedly, and as often the residue treated with fire in the furnace, together with the stone pyrimachus (a stone refractory to the action of fire), which occurs there in great abundance. Thus do many sorts of substances contain in themselves strikingly and most plentifully this ferric and telluric element. Many, too, and most plentiful in every soil are the stones and earths and the various bodies and compounds, which contain iron (though not in such abundance) and yield it in the furnace fire, but which are rejected by the metallurgist as not workable with profit; and there are other earths that give evidence of the presence of iron in them; these, being very poor in the metal, are not smelted at all, and not being esteemed they are not known.

The kinds of manufactured iron differ very much from one another. For one kind has great tenacity; and that is the best. There is a medium kind. Another kind is brittle; that is the worst. Sometimes the iron, on account of the excellence of the ore, is made into steel; as in Noricum at present. From the best iron also, worked over and over again, and purged of all impurities, or plunged red-hot into water, is produced what the Greeks call *στομωμα*[1] and the Latins *acies* and *aciarium* (steel), and which is variously called Syrian, Parthian,

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[1] *Stomoma* was also the name given to an oxide of copper, which was gradually formed upon the surface of metal, when it was kept in a state of fusion. Such oxides of copper were used as external applications, seemingly as escharotics (Dr. Thomson's Chemistry, 1830, Vol. I, page 60).

Norican, Comese and Spanish; in other places it takes its name from the water in which it is repeatedly immersed, as at Como in Italy, and Bilbao and Tariassone in Spain. Steel sells at a far higher price than iron. And, on account of its superiority, it is in better accord with the magnet. It is often made from powerful loadstone, and it acquires the magnetic virtue readily, retains it a long time unimpaired and fit for all magnetic experiments.

The iron, after it has been smelted in the first furnace, is then treated with various processes in great forges or mills, the metal under mighty blows acquiring toughness, and dropping its impurities. When first smelted it is brittle and by no means perfect. Therefore, here in England, when great cannons are cast, in order that they may be able to withstand the explosive force of the ignited gunpowder, the metal is specially purged of impurities: while fluid it is made to pass a second time through a narrow opening, and thus is freed of recremental substances. Smiths, with the use of certain liquids and hammer-strokes, toughen the iron laminæ from which are made shields and coats of mail not penetrable by any musket-ball. Iron is made harder by skill and tempering; but skill also makes it softer and as pliant as lead. It is made hard by certain waters into which it is plunged at white heat, as in Spain. It is made soft again either by fire alone when, without hammering and without the use of water, it is allowed to grow cool; or by being dipped in grease; or it is variously tempered, to serve the purposes of the different arts, by being smeared with special preparations. This art is described by Baptista Porta in book 13 of the *Magia Naturalis.*

Thus is this ferric and telluric substance contained in and extracted from various kinds of stones, ores, and earths; thus too does it differ in appearance, form, and efficiency; and by various processes of art it is smelted and purified and made to serve man's uses in all sorts of trades and in all sorts of tools, as no other body can serve. One kind of iron is suitable for breastplates, another withstands cannon balls, another protects against swords or the curved blades called cimetars; one kind is used in making swords, another in forging horseshoes. Of iron are made nails, hinges, bolts, saws, keys, bars, doors, folding-doors, spades, rods, pitchforks, heckles, hooks, fish-spears, pots, tripods, anvils, hammers, wedges, chains, manacles fetters, hoes, mattocks, sickles, hooks for pruning vines and, for cutting rushes (*scirpiculæ*), shovels, hoes, weeding-hooks, ploughshares, forks, pans, ladles, spoons, roasting-spits, knives, daggers, swords, axes, Celtic and Gallic darts (*gessæ*), Macedonian pikes (*sarissæ*), lances, spears, anchors and many nautical implements; furthermore, bullets, javelins, pikes, corselets, helmets, breastplates, horseshoes, greaves, wire, strings of musical instruments, armchairs, portcullises, bows, catapults, and those pests of humanity, bombs, muskets, cannon-balls, and no end of implements unknown to the Latins. I have recounted so many uses in order that the reader may know in how many ways this metal is employed. Its use exceeds that of all other metals a hundredfold; it is smelted daily; and there are in every village iron forges. For iron is foremost among metals and supplies many human needs, and they the most pressing: it is also far more abundant in the earth than the other metals, and it is predominant. Therefore it is a vain imagination of chemists to deem that nature's purpose is to change all metals to gold, that being brightest, heaviest, strongest, as though she were invulnerable, would change all stones into diamonds because the diamond surpasses them all in brilliancy and in hardness. Iron ore, therefore, as also manufactured iron, is a metal slightly different from the primordial homogenic telluric body because of the metallic humor it has imbibed; yet not so different but that in proportion as it is purified it takes in more and more of the magnetic virtues, and associates itself with that prepotent form and duly obeys the same.

CHAPTER VIII.

IN WHAT COUNTRIES AND REGIONS IRON IS PRODUCED.

IRON mines are very numerous everywhere—both the ancient mines mentioned by the earliest writers and the new and modern ones. The first and greatest were, I think, in Asia, for in the countries of Asia, which naturally abound in iron, government and the arts did most flourish; and there were the things needful for man's use first discovered and sought for. It is related that iron existed in the neighborhood of Andria; in the land of the Chalybes, on the banks of the river Thermodon in Pontus; in the mountains of Palestine on the side toward Arabia; in Carmania. In Africa, there was an iron mine in the island of Meroe. In Europe, iron was found in the hills of Britain, as Strabo writes; in hither Spain, in Cantabria; among the Petrocorii and the Cabi Bituriges in Gaul, were smithies in which iron was made. In Germany was a mine near Luna, mentioned by Ptolemy; the Gothinian iron is spoken of by Cornelius Tacitus; and the iron of Noricum is famed in poesy; there was also iron in Crete and in Eubœa. Many other mines, neither meagre nor scant, but of vast extent, were overlooked by writers or were unknown to them. Pliny calls hither Spain and the whole region of the Pyrenees an iron country; and he says that, in the part of Cantabria washed by the ocean, there is a mountain steep and high which (wonderful to tell) is all iron. The earliest mines were iron mines, not mines of gold, silver, copper or lead: for iron is more sought after for the needs of man; besides, iron mines are plainly visible in every country, in every soil, and they are less deep and less encompassed with difficulties than other mines. But were I simply to enumerate modern iron mines and those worked in our own time, a very large book would have to be written, and paper would fail me before iron: yet each one of these mines could supply 1000 forges. For among minerals there is no other substance so plentiful: all metals and all stones distinct from iron ore are surpassed by ferric and ferruginous substances. For you cannot easily find a district, hardly a township, throughout all Europe, if you search thoroughly, that has not a rich and plentiful vein of iron, or that does not yield an earth either saturated with iron-rust or at least slightly tinctured with it. That this is so, is easily shown by any one versed in metallurgy and chemistry.

Besides iron and its ore, there is another ferric substance, which, however, does not yield the metal, because the thin humor is burnt up by the fierce fires and is converted into dross like that separated from the metal when first smelted. Such is the white clay and argillaceous earth which is seen to make up great part of our British island; this, if treated with strong heat, either exhibits a ferric and metallic body, or is transformed into a ferric vitrification: this fact can be verified in houses built of brick, for the bricks that in the kiln are laid nearest to the fires, and are there burnt, show ferric vitrification at their other end, which grows black. Furthermore, all those earths when prepared, are attracted by the magnet like iron. Lasting and plentiful is the earth's product of iron.

Georgius Agricola says that nearly all mountainous regions are full of its ores; and we, ourselves, do know that a rich iron ore is often dug in the lowlands and plains throughout England and Ireland, as Agricola tells of iron being dug in the meadows near the town of Saga[1] out of ditches not more than two feet deep. Nor is iron lacking, as some say, in the West Indies; but, there, the Spaniards, intent on gold, avoid the toilsome manufacture of iron and do not search for rich iron ores and mines. It is probable that nature and the terrestrial globe cannot repress, but is ever sending forth into the light a great quantity of its own native substance, and that this action is not entirely impeded by the pressure of the mingled substances and efflorescences at the circumference. But iron is produced not only in the common mother (the globe of Earth), but sometimes is also in the air, in the uppermost clouds from the earth's vapors. It rained iron in Lucania the year that Marcus Crassus met his death. They tell, too, of a mass of iron, resembling slag, having fallen out of the air in the Nethorian forest near Grina, which is said to have weighed several pounds; and that it could not be carried to that village it was so heavy, and could not be taken on a wagon because there were no roads. This happened before the Civil War of the Saxons, waged by the Dukes. A similar occurrence is mentioned by Avicenna. In the Torinese, it once rained iron at several points, some three years before that province was conquered by the King. In the year 1510, as Cardan relates in

[1] "The like wee reade of at Saga in Ligys, where they digge over their iron mines every tenth yeare. . . . But whosoever readeth that which Francis Leandro hath written touching the iron mineralls in the Ile of Elba, will cleave perhaps to a third conceit, for he avoucheth that the trenches out of which the oare there is digged, within twenty or thirty yeares, become alike full againe of the same mettall as at first" (Geo. Hakewill's "Apologie," 1635, Lib. II, Sec. 7, pages 164–165).

his book *De Rerum Varietate*, there fell from the sky, upon a field near the river Abdua, 1200 stones, one of which weighed 120, another 30 or 40, pounds, all of them the color of iron and exceedingly hard. These occurrences, because they happen seldom, seem to be portents, like the earth-rains and stone-showers mentioned in the annals of the Romans. But that it ever rained other metals is not mentioned; for it does not appear that gold, silver, lead, tin, or zinc ever fell from heaven. But copper has sometimes been observed to fall from the clouds—a metal differing not much from iron: and this cloud-gendered iron and copper are seen to be imperfect metals, absolutely infusible and unforgeable. For the earth, in its eminences, abounds in store of iron, and the globe contains great plenty of ferric and magnetic matter. Exhalations of such matter sent forth with some violence may, with the concurrence of powerful agencies, become condensed in the upper regions, and so may be evolved a certain monstrous progeny of iron.

CHAPTER IX.

IRON ORE ATTRACTS IRON ORE.

* LIKE the other metals, iron is obtained from various substances—stones, earths, and such-like concretions, called by miners ores, or veins, because they are produced in fissures of the earth. Of the diversity of ores we have already spoken. A piece of crude iron ore of the color of iron and *rich*, as miners say, when floated in a bowl or other vessel in water (as in the case of the loadstone *supra*) is usually attracted by a

like piece of ore held in the hand and brought near to it, but it is not attracted strongly and with rapidity as a loadstone is drawn by a loadstone, but slowly and weakly. Stony ores, and those of an ashy, brown, ruddy, etc., color, neither attract one another nor are attracted even by a powerful loadstone, any more than so much wood or lead or silver or gold would be. Take some pieces of such ores and roast or rather heat them in a moderate fire so that they may not suddenly split or fly to pieces, and retain them ten or twelve hours in the fire, which is to be kept up and moderately increased; then suffer them to cool, according to the method given in Book III, *Of Direction:* these stones so manipulated, the loadstone now attracts; they show mutual sympathy, and, when arranged according to artificial conditions, they come together through the action of their own forces.

CHAPTER X.

IRON ORE HAS AND ACQUIRES POLES, AND ARRANGES ITSELF WITH REFERENCE TO THE EARTH'S POLES.

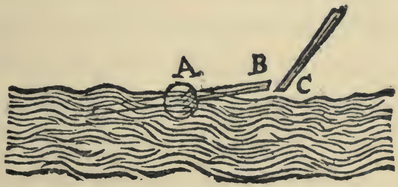
MEN are deplorably ignorant with respect to natural things, * and modern philosophers, as though dreaming in the darkness, must be aroused and taught the uses of things, the dealing with things; they must be made to quit the sort of learning that comes only from books, and that rests only on vain arguments from probability and upon conjectures. For the science of iron (than which nought is more in use among us), as of many other bodies, remains unknown—iron, I say, whose rich ore, by an inborn force, when floated in a vessel on water, assumes, like the loadstone, a north and south direction, coming to a standstill at those points, whence if it be turned away, it goes back to them again in virtue of its inborn activity. But of less perfect ores which, however, under the guise of stone or earth contain a good deal of iron, few possess the power of movement; yet when treated artificially with fire, as told in the foregoing chapter, these acquire polar activity, strength (*verticity*, as we call it); and not only such ores as miners seek, but even earths simply impregnated with ferruginous matter, and many kinds of rock, do in like manner (provided they be skilfully placed), tend and glide toward those positions of the heavens, or rather of the earth, until they reach the point they are seeking: there they eagerly rest.

CHAPTER XI.

WROUGHT-IRON, NOT MAGNETIZED BY THE LOADSTONE, ATTRACTS IRON.

* IRON is extracted in the first furnace from the ore, which is converted or separated partly into metal, partly into dross, by the action of very great heat continued for eight, ten, or twelve hours. The metal flows out, leaving behind the dross and useless substances, and forms a great long mass, which under the blows of a large hammer is cut into pieces: from these, after being reduced in another furnace and again put on the anvil, the workmen form cubical masses, or more usually bars, which are sold to merchants and blacksmiths: from these blocks or bars are everywhere made in smiths' shops various implements.

This we call wrought-iron, and, as every one knows, it is attracted by the loadstone. But we, steadily trying all sorts of experiments, have discovered that mere iron itself, magnetized by no loadstone, nor impregnated with any extraneous force, attracts other iron, though it does not seize the other iron as eagerly nor as suddenly pulls it to itself as would a strong loadstone. That this is so you may learn from the following experiment: A small piece of cork, round, and the size of a filbert, has an iron wire passed through it to the middle of the wire: float this in still water and approach (without contact) to one end of that wire, the end of another wire: wire attracts wire, and when the one is withdrawn slowly the other follows, yet this action takes place only within fit limits. In the figure, *A* is the cork holding the wire, *B* one end of the



wire rising a little out of the water, *C* the end of the second wire, which pulls *B*. You may demonstrate the same thing with a larger mass of iron. Suspend in equilibrium with a slender silken cord a long rod of polished iron, such as are used to support hangings and curtains; bring within the distance of half a finger's length of one end of this as it rests still in the air, some oblong mass of polished iron with suitable end: the balanced rod returns to the mass; then quickly withdraw your hand with the mass in a circular track around the point of equilibrium of the suspended rod, and the cord holding the rod will travel in a circle.

CHAPTER XII.

A LONG PIECE OF IRON, EVEN NOT MAGNETIZED, ASSUMES A NORTH AND SOUTH DIRECTION.

* ALL good and perfect iron, if it be drawn out long, acts like a loadstone or like iron rubbed with loadstone: it takes the direction north and south—a thing not at all understood by our great philosophers who have labored in vain to demonstrate the properties of the loadstone and the causes of the friendship of iron for the loadstone. Experiment can be made either with large or small objects of iron, either in air or in water. A straight rod of iron six feet in length and as thick as one's finger is (as described in the foregoing chapter) suspended in exact equilibrium with a fine but strong silk thread. The thread, however, should be composed of several silk filaments, twisted differently and not all in one direction. Let the experiment be made in a small room with doors and windows all closed, to prevent currents of air in the room: hence it is not well to experiment on windy days or when a storm is brewing. The rod of iron freely acts according to its property and moves slowly until at last coming to a stop at its goals it points north and south, like magnetized iron in a sun-dial, a common magnetic compass, and the mariner's compass. You may, if you are curious of such experiments, suspend at once from slender threads, iron rods, or wires, or knitting-needles: you shall find them all in accord unless there is some flaw in the conduct of this interesting experiment; for unless you make all the preparations precisely and exactly, your labor will be vain.

Test the thing in water also: here the result is more sure and more easily obtained. Pass through a round cork an iron wire two or three fingers long, more or less, so that it may just float in water: the moment you put it in the water it turns round on its centre, and one end of the wire travels to the north, the other to the south: the cause of this, you will find later, when we treat of the reasons of the loadstone's directions. And* it is well to know and to hold fast in memory, that as a strong loadstone and iron magnetized by the same, point not always toward the true pole, but exactly to the point of variation; likewise will a weaker loadstone and iron that directs itself by its own force, and not by force derived from the impress of any magnet; so, too, all iron ores, and all substances imbued with any ferric matter and duly prepared, turn to the same point in the horizon—to the place of variation of the locality concerned (if variation exist there), and there they remain and rest.

CHAPTER XIII.

SMELTED IRON HAS IN ITSELF FIXED NORTH AND SOUTH PARTS, MAGNETIC ACTIVITY, VERTICITY, AND FIXED VERTICES OR POLES.

Iron takes a direction toward north and south, but not* with the same point directed toward either pole; for one end of a piece of iron ore or of an iron wire steadily and constantly points to the north and the other to the south, whether it be suspended in air, or floating in water, and whether the specimens be iron bars or thin wires. Even an iron rod or wire ten, twenty, or more ells in length will point with one extremity to the north, with the other to the south. And if you cut off a part, if the farther end of that piece is boreal (northern), the farther end of the other piece, with which it was before joined, will be austral (southern). And so, if you divide the rod or wire into several pieces, you shall know the poles even before you make an experiment by floating the pieces in water. In all these fragments a boreal end attracts an austral, and repels a boreal, and *vice versa*, according to magnetic law. But, herein, manufactured iron so differs from loadstone and iron ore, that in a ball of iron of whatever size—*e.g.*, bombs, cannon-balls, culverin balls, falcon balls—polarity (verticity) is less easily acquired and less readily manifested than in the loadstone itself, in ore, and in a round loadstone; but in iron instruments of any length the force is at once seen: the cause of which, as also the modes of acquiring polarity and poles without a loadstone, together with the account of all other recondite facts touching verticity, we will set forth when we come to treat of the *movement of direction*.

CHAPTER XIV.

OF OTHER PROPERTIES OF THE LOADSTONE AND OF ITS MEDICINAL VIRTUE.

DIOSCORIDES tells that loadstone blended in water is administered in a dose of three oboli[1] to expel gross humors. Galen writes that it has virtues like those of bloodstone.

[1] Obolus, the sixth part of a drachm.

Others say that loadstone causes mental disturbance and makes people melancholic, and often is fatal. Gartias ab Horto does not think it injurious or unwholesome. The people of East India, he says, declare that loadstone taken in small quantity preserves youthfulness: for this reason the elder King Zeilam (Zeilan) is said to have ordered made of loadstone some pans for cooking his food (*victus*). "The man who was ordered to do this thing told me," says Gartias.[1] Many are the varieties of loadstone, produced by different mixtures of earths, metals, and humors; therefore are they totally different in their virtues and effects, according to the neighborhoods of places and the nearness of adhering bodies, and the pits themselves—unclean matrices, as it were. Hence one loadstone is able to purge the bowels, and another loadstone to stay the purging; with a sort of fumes, it can gravely affect the mind; it may corrode the stomach and produce in it serious disease: for such disorders, quacks prescribe gold and emerald, practising the vilest imposture for lucre's sake. Pure loadstone also may be harmless; and not only that, but many correct excessive humors of the bowels and putrescence of the same, and may bring about a better temperature: such loadstones are the Oriental ones from China, the more compact loadstones of

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[1] GARCIA D'ORTA, "Coloquios dos simples . . . . pello doutor GARCIA DORTA" (*sic*)—Goa 1563. The name of the Portuguese author of this rare work —who was physician to the Spanish Viceroy (Brown's "Vulgar Errors," Book II, page 81)—appears as GARCIA AB HORTO in the abridged Latin translation made by Charles de l'Ecluse, Antwerp 1567, 1574, 1579, 1593, under title "Aromatum et Simplicium . . . ," and it is rendered in French GARCIE DU JARDIN, by Antoine Colin in his "Histoire des Drogues," Lyon 1619, whilst in other versions it is given as GARCIA DEL HUERTO. For the passage above alluded to by Gilbert, see, more particularly, the last (1593) edition, article *De Magnete*, Lib. I, Cap. LVI, pages 178, 179. Hakewill observes ("Apologie," 1635, Lib. II, page 165), "Remarkable indeed that is which GARZIAS AB HORTO writes concerning the load-stone in *Simpl Indiæ*, Lib. I, Cap. XLVII."

Bengal: these kinds of loadstone are not distasteful nor ungrateful to the senses. Plutarch and Caius Ptolemy, and all the copyists that came after them, believe that loadstone rubbed with garlic does not attract iron. Hence some writers conjecture that garlic is of service against the harmful action of loadstone: in this way does many an untrue and vain opinion in philosophy take its rise in fables and falsehoods.[1] Not a few physicians have thought that loadstone has power to extract an iron arrow-head from a human body: but a loadstone attracts when it is whole, not when reduced to powder, deformed, buried in a plaster; for it does not with its matter attract in such case, but serves rather to heal the ruptured tissues by exsiccation, so causing the wound to close and dry up, whereby the arrow-head becomes fixed in the wound. Thus do pretenders to science vainly and preposterously seek for remedies, ignorant of the true causes of things. Headaches, despite the opinion of many, are no more cured by application of a loadstone, than by putting on the head an iron helmet or a steel hat. Administration of loadstone to dropsical persons is either an error of the ancients or a blundering quotation of their transcribers, albeit a loadstone may be found capable of purging the bowels, after the manner of sundry metallic substances: but the effect would be due to some vice of the stone, not to its magnetic force. Nicolaus puts into his "divine plaster" a good deal of loadstone, as do the Augsburg doctors in their "black plaster" for fresh wounds and stabs; because of the exsiccating effect of the loadstone without corrosion, it becomes an efficacious and useful remedy, Paracelsus, in like manner and for the same end, makes loadstone an ingredient of his plaster for stab-wounds.

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[1] See note, Book I, Chap. I, of present work.

CHAPTER XV.

THE MEDICINAL POWER OF THE IRON.

IT will not be alien to our purpose to treat briefly of the medicinal power of iron; for it is beneficial in many diseases of the human system, and by its virtues, both natural and acquired through fit and skilful preparation, it brings about wonderful changes in the human body; so that we may more clearly describe its nature through its medicinal power and by means of a few well-known experiments; to the end that even those prentices of medicine who abuse this most excellent medicinal agent may learn to prescribe it more judiciously, for the curing of patients, not as is too often the case, to their destruction. The best iron, i.e., *stomoma*, *chalybs*, *acies*, or *aciarium* (steel), is reduced by filing to a fine powder; this powder has strongest vinegar poured on it, is dried in the sun, again treated with vinegar, and once more dried. Then it is washed in spring water or other water at hand, and dried. It is again pulverized and pounded fine on porphyry, sifted through a fine sieve, and kept for use. It is given chiefly in cases of lax and over-humid liver, and in cases of tumid spleen after suitable evacuations; hence young women of pale, muddy, blotchy complexion are by it restored to soundness and comeliness, for it is highly exsiccative and harmlessly astringent. But some, who in every internal disorder always recognize obstructions of liver and spleen, think it beneficial in such cases, as removing obstructions; and herein they accept the opinions chiefly of certain Arabic writers. Hence in cases of dropsy, schirrus of the liver, of chronic jaundice, and hypochondriac melancholia, or complaints of the œsophagus, they prescribe it, or add it to electuaries, often to the sure destruction of many a patient.[1] Fallopius recommends a preparation of iron of his own for schirrus of the spleen; but he is much mistaken, for though loadstone is exceedingly beneficial where the spleen is lax and tumid on account of humors, so far is it from curing a spleen thickened to a schirrus, that it makes the mischief far worse; for agents that are greatly siccative and that absorb humors, transform viscera that have been thickened by schirrus, into the hardness almost of a stone. Some there are who dry it at a high temperature in an oven, burning it till its color is changed to red: it is then called "saffron of Mars,"[2] and is a very powerful exsiccant and quickly penetrates the intestines. Further, they prescribe violent exercise so that the remedy may enter the heated intestines and reach the part affected. Hence it is reduced to a very fine powder; else it would remain in the œsophagus and in the chyle and would not penetrate to the intestines. Therefore this dry, earthly medicament is proved by the most conclusive tests to be, after due evacuations, a remedy in diseases arising from humor (when the intestines are running and overflowing with morbid fluids). A preparation of steel is indicated for tumid spleen; chalybeate waters also reduce the spleen, albeit, as a rule, iron is of frigid efficiency and a constringent rather than a resolvent; but it does this neither by heat nor by cold, but by its own dryness

[1] "The magnet .... gives comfort and grace, and is a cure for many complaints, it is of great value in disputes. When pulverized, it cures many burns. It is a remedy for dropsy" (J. Sermone .... di F. Sacchetti ...., § 18). According to Dias, "the magnet reconciles husbands to their wives," and Platea remarks that "it is principally of use to the wounded," while Avicenna says it "is a remedy against spleen, the dropsy, and alopecian."

[2] See Book II, Chap. XXIII.

when mixed with a penetrant fluid; in this way it dissipates humors, thickens the villi; strengthens the fibres and when they are lax makes them contract; then the natural warmth in the organs thus strengthened becoming stronger does the rest; but should the liver be indurated and impaired through age or chronic obstruction, or should the spleen be dried up and thickened into a schirrhus, under which complaints the flesh parts of the members become atrophied, and water collects all over the body under the skin—in such cases the preparation of steel does but hasten a fatal result and makes the mischief worse. Some recent authorities prescribe, as a highly commended and celebrated remedy for dried-up liver, an electuary of iron slag described by Razes (Rhazes—Abu Bekr Arrasi) in book ninth *Ad Almansorem*, or of prepared steel filings: bad and pernicious counsel. But now if they never will learn from our philosophy, at least daily experience and the decline and death of their patients will convince them, slow and sluggish as they are. Whether iron be warm or cold is a question over which many contend. Manardus, Curtius, Fallopius, and others bring many arguments for both sides: every one judges according to his own way of looking at it. Some will have it cold, saying that iron has the power of refrigeration, since Aristotle in the *Meteorologica* declares it to belong to the class of bodies that become concreted through cold by emission of all their warmth. Galen, too, says that iron gets its consistency from cold; further, that it is an earthy body and dense. It is declared to be cold also because it is astringent, and because chalybeate water stills thirst; they mention also the sensation of coolness produced by thermic chalybeate waters. But others hold it to be warm, since Hippocrates says that chalybeate waters issuing from places where iron exists are warm. Galen says that in all metals there is much substance or essence of fire. Razes will have it that iron is warm and dry in the third degree. The Arabs hold that iron opens the spleen and the liver: hence it is warm. Montagnana recommends it for frigid complaints of uterus and œsophagus. And thus do sciolists wrangle with one another, and confuse the minds of learners with their questionable cogitations, and debate over the question of goat's wool, philosophizing about properties illogically inferred and accepted: but these things will appear more plainly when we come to treat of causes, the murky cloud being dispersed that has so long involved all philosophy. Iron filings, iron scales, iron dross, do not, says Avicenna, lack harmful quality (perhaps when they are not properly prepared, or are taken in too large doses), hence they produce violent intestinal pains, roughness in the mouth and on the tongue, marasmus, and drying up of the members. But mistakenly and old womanishly does Avicenna declare that the true antidote of this ferric poison is a drachm of loadstone taken in a draught of the juice of dog's mercury or of beet-root; for loadstone too is of a twofold nature, and often is injurious and fatal in its effects; neither does it withstand iron, for it attracts it; nor is it able to attract when drunk as a powder in liquid; rather does it cause the self-same mischiefs.

CHAPTER XVI.

THAT LOADSTONE AND IRON ORE ARE THE SAME, AND THAT IRON IS OBTAINED FROM BOTH, LIKE OTHER METALS FROM THEIR ORES; AND THAT ALL MAGNETIC PROPERTIES EXIST, THOUGH WEAKER, BOTH IN SMELTED IRON AND IN IRON ORE.

So far we have been telling of the nature and properties of loadstone, as also of the properties and nature of iron; it now remains that we point out their mutual affinities—their consanguinity, so to speak—and that we show the two substances to be very nearly allied. In the uppermost part of the terrestrial globe or its superficies of detritus—its rind as it were—these two bodies come into being and are generated in the same matrix, in one bed, like twins. Strong loadstones are mined from separate deposits, and weaker loadstones also have their own beds. Both occur in iron mines. Iron ore occurs usually by itself, unaccompanied by strong loadstone (for the more perfect loadstones occur more rarely). A strong loadstone looks like iron: from it is often made the best iron, which the Greeks call *stomoma*, the Latins *acies*, and the Barbarians, not inappropriately, *aciare* or *aciarium*. This stone attracts and repels other loadstones, and governs their directions; points to the earth's poles, attracts molten iron, and does many other wonderful things, some of which we have already mentioned, but many more remain yet to be pointed out. A weak loadstone will do the same, but less forcefully: and iron ore, and also smelted iron (if they be prepared), show their virtues

* in all magnetic experiments, no less than do weak magnets; and the inert iron ore, endowed with no magnetic powers, that is taken out of the mine, becomes awake when treated in the furnace and fittingly prepared, and then is a loadstone * in power and properties. Sometimes ironstone or iron ore exerts attractive action the moment it comes from the mine, and without being prepared in any way; native iron, also, or ore of iron color, attracts iron and makes it point to the poles. Thus the form, appearance, and essence are one. For to me there seems to be greater difference and unlikeness between a very strong loadstone and a weak one that is hardly able to attract a single particle of iron filings; between a hard, firm, and metallic loadstone and one that is soft, friable, clayey, with so great a difference between them in color, substance, qualities and weight; than between the best ore, rich in iron, or iron that from the first is metallic, on the one hand, and the best loadstone on the other. Nay, the two are usually not to be distinguished by any signs, nor can miners tell one from the other, for they agree in all respects. Further, we see both the finest magnet and iron ore visited as it were by the same ills and diseases, aging in the same way and with the same indications, preserved by the same remedies and protective measures, and so retaining their properties: so, too, the one adds to the other's power and intensifies and increases it, when the two are artificially connected. For they are both impaired by the action of acrid liquids as though by poisons; the aqua fortis of the chemists does equal injury to both; exposed for a long time to the action of the atmosphere they both, in equal degree, age as it were and decline; each is saved from impairment by being kept in the *débris* and scrapings of the other, and a suitable piece of steel or iron being applied to its pole, the magnetic power is intensified by the steadfast union. A loadstone

is kept in iron filings not as though it fed on iron, or as though it were a living thing needing victual, as Cardan philosophizes; neither because thus it is protected from the injurious action of the atmosphere (wherefore both the loadstone and iron are kept in bran by Scaliger; though Scaliger is mistaken here, for they are not best preserved so, and loadstone and iron in some of their forms last a long time); but because each is kept unimpaired in filings of the other and their extremities do not become weak, but are cherished and preserved. For as in their native sites and mines, similar bodies surrounded by other bodies of the same kind, e.g., the minor interior parts of some great mass, endure for ages whole and undecayed; so loadstone, and iron ore, when buried in a like material, do not part with their native humor, and do not become weak, but retain their original properties. A loadstone packed in iron filings, as also iron ore in scrapings of loadstone, and manufactured iron in the same or in iron filings, lasts longer. Thus these two associated bodies possess the true, strict form of one species, though, because of their outwardly different aspect and the inequality of the self-same innate potency, they have hitherto been by all held to be different, and by sciolists to be specifically different, for sciolists have not understood that in both substances reside exactly the same potencies, differing however in strength. They are in fact true parts and intimate parts of the globe, retaining nature's primal powers of mutual attraction, of mobility, and of ordering themselves according to the position of the globe itself: these powers they impart to each other, enhancing each other's powers, confirming them, taking them from each other, and holding them. The stronger invigorates the weaker, not as if it imparted of its own substance or parted with aught of its own strength, neither by injecting into that other any physical substance; but the dormant power of one is awakened by the other's without expenditure. For if with one loadstone you magnetize one thousand compass needles for mariners' use that loadstone not less powerfully attracts iron than it did before; with one stone weighing a pound any one can suspend in air 1000 pounds of iron. For if one were to drive into a wall a number of iron nails weighing all together 1000 pounds, and were to apply to them an equal number of other nails properly magnetized by contact with a loadstone, the nails would plainly hang suspended in air through the power of one single stone. Hence this is not the action, work, or outlay of the loadstone solely, for the iron, which is something extracted from loadstone, a transformation of loadstone into metal, and which gains force from the loadstone and (whatever ore it may have been derived from) by its proximity strengthens the loadstone's magnetic power, at the same time enhances its own native force by the proximity of the loadstone and by contact therewith, even though solid bodies intervene between them. Iron touched by loadstone renovates other iron by contact and gives it magnetic direction; and that does the same for a third piece of iron. But if you rub with loadstone any other metal, or wood, or bone, or glass, as they will not move toward a fixed and determinate quarter of the heavens, nor will be attracted by a magnetized body; so they cannot impart by attrition or by infection any magnetic property either to other bodies or to iron itself. Loadstone differs from iron ore, as also from some weak loadstones, in that when reduced in the furnace to a ferric and metallic molten mass, it does not always assume readily the fluid condition and become changed to metal, but sometimes is burnt into ash in the large furnaces: this, either because of a certain admixture of sulphurous matter, or because of its own excellence and more simple nature; or because of the resemblance it bears to nature, and the form it has in common with that mother of all; for earths, ferruginous stones, and loadstones rich in metal, are much loaded and disfigured with drossy metallic humors and with foreign earthy admixtures in their substance, like most weak magnets from the mines; hence they are farther removed from the common mother and are degenerate, and in the furnace they are more easily melted and give a softer sort of iron and no good steel. Most loadstones, if they be not unduly burnt, yield in the furnace the best of iron. But in all these prime qualities iron ore agrees with loadstone, for both, being more akin to the earth and more nearly associated to it than any other bodies around us, possess within themselves the magnetic, genuine, homogenic and true substance of the terrestrial globe, less tainted and impaired by foreign impurities, and less mixed with the efflorescences on the earth's surface and the *débris* of generations of organisms. And on this ground does Aristotle seem, in book fourth of his *Meteora*, to distinguish iron from all other metals. Gold, says he, silver, copper, tin, lead, pertain to water; but iron is earthy. Galen, in the fourth book *De Facultatibus Simplicium Medicamentorum*, says that iron is an earthy and dense body. So, according to our reasoning, loadstone is chiefly earthy; next after it comes iron ore or weak loadstone; and thus loadstone is by origin and nature ferruginous, and iron magnetic, and the two are one in species. Iron ore in the furnace yields iron; loadstone in the furnace yields iron also, but of far finer quality, which is called steel; and the better sort of iron ore is weak loadstone, just as the best loadstone is the most excellent iron ore in which we will show that grand and noble primary properties inhere. It is only in weaker loadstone, or iron ore, that these properties are obscure, or faint, or scarcely perceptible to the senses.

CHAPTER XVII.

THAT THE TERRESTRIAL GLOBE IS MAGNETIC AND IS A LOADSTONE; AND JUST AS IN OUR HANDS THE LOADSTONE POSSESSES ALL THE PRIMARY POWERS (FORCES) OF THE EARTH, SO THE EARTH BY REASON OF THE SAME POTENCIES LIES EVER IN THE SAME DIRECTION IN THE UNIVERSE.

BEFORE we expound the causes of the magnetic movements and bring forward our demonstrations and experiments touching matters that for so many ages have lain hid—the real foundations of terrestrial philosophy—we must formulate our new and till now unheard-of view of the earth, and submit it to the judgment of scholars. When it shall have been supported with a few arguments of *prima facie* cogency, and these shall have been confirmed by subsequent experiments and demonstrations, it will stand as firm as aught that ever was proposed in philosophy, backed by ingenious argumentation, or buttressed by mathematical demonstrations. The terrestrial mass which together with the world of waters produces the spherical figure and our globe, inasmuch as it consists of firm durable matter, is not easily altered, does not wander nor fluctuate with indeterminate movements like the seas and the flowing streams; but in certain hollows, within certain bounds, and in many veins and arteries, as it were, holds the entire volume of liquid matter, nor suffers it to spread abroad and be dissipated. But the solid mass of the earth has the greater volume and holds preeminence in the constitution of our globe. Yet the water is associated with it, though only as something supplementary and as a flux emanating from it; and from the beginning it is intimately mixed with the smallest particles of earth and is innate in its substance. The earth growing hot emits it as vapor, which is of the greatest service to the generation of things. But the strong foundation of the globe, its great mass, is that terrene body, far surpassing in quantity the whole aggregate of fluids and waters whether in combination with earth or free (whatever vulgar philosophers may dream about the magnitudes and proportions of their elements); and this mass makes up most of the globe, constituting nearly its whole interior framework, and of itself taking on the spherical form. For the seas do but fill certain not very deep hollows, having very rarely a depth of a mile, and often not exceeding 100 or 50 fathoms. This appears from the observations of navigators who have with line and sinker explored their bottoms. In view of the earth's dimension, such depressions cannot much impair the spheroidal shape of the globe. Still the portion of the earth that ever comes into view for man or that is brought to the surface seems small indeed, for we cannot penetrate deep into its bowels, beyond the *débris* of its outermost efflorescence, hindered either by the waters that flow as through veins into great mines; or by the lack of wholesome air necessary to support the life of the miners; or by the enormous cost of executing such vast undertakings, and the many difficulties attending the work. Thus we cannot reach the inner parts of the globe, and if one goes down, as in a few mines, 400 fathoms, or (a very rare thing) 500 fathoms, it is something to make every one wonder. But how small, how almost null, is the proportion of 500 fathoms to the earth's diameter, 6,872 miles, can be easily understood. So we do only see portions of the earth's circumference, of its prominences; and everywhere these are either loamy, or argillaceous, or sandy; or consist of organic soils or marls; or it is all stones and gravel; or we find rock-salt, or ores, or sundry other metallic substances. In the depths of the ocean and other waters are found by mariners, when they take soundings, ledges and great reefs, or bowlders, or sands, or ooze. The Aristotelian element, earth, nowhere is seen, and the Peripateties are misled by their vain dreams about elements. But the great bulk of the globe beneath the surface and its inmost parts do not consist of such matters; for these things had not been were it not that the surface was in contact with and exposed to the atmosphere, the waters, and the radiations and influences of the heavenly bodies; for by the action of these are they generated and made to assume many different forms of things, and to change perpetually. Still do they imitate the inner parts and resemble their source, because their matter is of the earth, albeit they have lost the prime qualities and the true nature of terrene matter; and they bear toward the earth's centre and cohere to the globe and cannot be parted from it save by force. Yet the loadstone and all magnetic bodies—not only the stone but all magnetic, homogenic matter—seem to contain within themselves the potency of the earth's core and of its inmost viscera, and to have and comprise whatever in the earth's substance is privy and inward: the loadstone possesses the actions peculiar to the globe, of attraction, polarity, revolution, of taking position in the universe according to the law of the whole; it contains the supreme excellencies of the globe and orders them: all this is token and proof of a certain eminent combination and of a most accordant nature. For, if among bodies one sees aught that moves and breathes and has senses and is governed and impelled by reason, will he not, knowing and seeing this, say that here is a man or something more like man than a stone or a stalk? The loadstone far surpasses all other bodies around us in the virtues and properties that pertain to the common mother of all; but those properties have been very little understood and noted by philosophers. Toward it, as we see in the case of the earth, magnetic bodies tend from all sides, and adhere to it: it has poles—not mathematical points, but natural points of force that through the co-operation of all its parts excel in prime efficiency; such poles exist also in the same way in the globe, and our forefathers always sought them in the heavens. Like the earth, it has an equator, a natural line of demarkation between the two poles; for of all the lines drawn by mathematicians on the terrestrial globe, the equator (as later will appear) is a natural boundary, and not merely a mathematical circle. Like the earth, the loadstone has the power of direction and of standing still at north and south; it has also a circular motion to the earth's position, whereby it adjusts itself to the earth's law. It follows the elevations and depressions of the earth's poles, and conforms precisely to them: according to the position of the earth and of the locality, it naturally and of itself elevates its poles above the horizon, or depresses them. The loadstone derives properties from the earth *ex tempore*, and acquires verticity; and iron is affected by the verticity of the globe as it is affected by a loadstone. Magnetic bodies are governed and regulated by the earth, and they are subject to the earth in all their movements. All the movements of the loadstone are in accord with the geometry and form of the earth and are strictly controlled thereby, as will later be proved by conclusive experiments and diagrams; and the greater part of the visible earth is also magnetic, and has magnetic movements, though it is defaced by all sorts of waste matter and by no end of transformations. Why, then, do we not recognize this primary and homogeneous earth-substance, likest of all substances to the inmost nature, to the very marrow, of the earth itself, and nearest to it? For not any of the other mixed earths—those suitable for agriculture,—not any of the metalliferous veins, no stones, no sands, no other fragments of the globe that come under our notice, possess such stable, such distinctive virtues. Yet we do not hold the whole interior of this our globe to be of rock or of iron, albeit the learned Franciscus Maurolycus[1] deems the earth in its interior to consist throughout of rigid rock. For not every loadstone that we find is a stone, being sometimes like a clod of earth, or like clay, or like iron; consisting of various materials compacted into hardness, or soft, or by heat reduced to the metallic state; and in the earth's surface formations, according to circumstances of place, of the bodies around it, and of its matrix in the mine, a magnetic substance is distinguished by divers qualities and by adventitious accretions, as we see in marl, in some stones, and in iron ores. But the true earth-matter we hold to be a solid body homogeneous with the globe, firmly coherent, endowed with a primordial and (as in the other globes of the universe) an energic form. By being so fashioned, the earth has a fixed verticity, and necessarily revolves with an innate whirling motion: this motion the loadstone alone of all the bodies around us possesses genuine and

[1] Francis Maurolico—Maurolycus, Marullo (1494–1575)—was abbot of Messina, where he publicly taught mathematics, and was quite a voluminous writer upon different scientific subjects, his works including very able treatises, more particularly on the sphere, on astronomical instruments, etc. A full account of his life and writings was issued at Messina (Messanæ) in 1613, the date and place likewise of his very interesting magnetical book entitled "Problemata mechanica, cum appendice et ad magnetem, et ad pixidem nauticam pertinentia."

true, less spoilt by outside interferences, less marred than in other bodies,—as though the motion were an homogeneous part taken from the very essence of our globe. This pure native iron is produced when homogenic portions of the earth's substance coalesce to form a metallic vein; loadstone is produced when they are transformed into metallic stone or a vein of the finest iron or steel; so, too, rather imperfect homogenic material collects to form other iron ores—just as many parts of the earth, even parts that rise above the general circumference, are of homogenic matter, only still more debased. Native iron is iron fused and reduced from homogenic matters, and coheres to earth more tenaciously than the ores themselves. Such, then, we consider the earth to be in its interior parts; it possesses a magnetic homogenic nature. On this more perfect material (foundation) the whole world of things terrestrial, which, when we search diligently, manifests itself to us everywhere, in all the magnetic metals and iron ores and marls, and multitudinous earths and stones; but Aristotle's "simple element," and that most vain terrestrial phantasm of the Peripatetics,—formless, inert, cold, dry, simple matter, the substratum of all things, having no activity,—never appeared to any one even in dreams, and if it did appear would be of no effect in nature. Our philosophers dreamt only of an inert and simple matter. Cardan thinks the loadstone is not a stone of any species, but that it is, as it were, a perfect portion of a certain kind of earth that is absolute, whereof a proof is its abundance, for there is no place where it is not found. He says that this kind of conceptive, generative earth, possessed of an affinity like that of the marriage tie, is perfected when it has been placed in contact with, or received the fecundating influence of, the masculine or Herculean stone, it having been, moreover, shown in a previous proposition (*Libro de Proportionibus*) that the loadstone is true earth.[1]

A strong loadstone shows itself to be of the inmost earth, and in innumerable experiments proves its claim to the honor of possessing the primal form of things terrestrial, in virtue of which the earth itself remains in its position and is directed in its movements. So a weak loadstone, and all iron ore, all marls and argillaceous and other earths (some more, some less, according to the difference of their humors and the varying degrees in which they have been spoilt by decay), retain, deformed, in a state of degeneration from the primordial form, magnetic properties, powers, that are conspicuous and in the true sense telluric. For not only does metallic iron turn to the poles, not only is one loadstone attracted by another and made to revolve magnetically, but so do (if prepared) all iron ores and even other stones, as slates from the Rhineland, the black slates (*ardoises*, as the French call them) from Anjou, which are used for shingles, and other sorts of fissile stone of different colors; also clays, gravel, and several sorts of rock; and, in short, all of the harder earths found everywhere, provided only they be not fouled by oozy and dank defilements like mud, mire, heaps of putrid matter, or by the decaying remains of a mixture of organic matters, so that a greasy slime oozes from them, as from marl,—they are all attracted by the loadstone, after being prepared simply by the action of fire and freed from their excrementitious humor; and as by the loadstone, so, too, are they magnetically attracted and made to point to the poles by the earth itself, therein differing from all

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[1] Consult Cardan's Works, Lugduni (Lyons), 1663 ed., Vol. II, *De Exemplo....*, pages 539, 546, Vol. III, Lib. V, Cap. XVII–XIX, Vol. X, Cap. VI, page 12.

other bodies; and by this innate force they are made to conform to the ordering and planning of the universe and the earth, as later will appear. Thus every separate fragment of the earth exhibits in indubitable experiments the whole impetus of magnetic matter; in its various movements it follows the terrestrial globe and the common principle of motion.

BOOK SECOND.

CHAPTER I.

OF MAGNETIC MOVEMENTS.

Of opinions touching the loadstone and its varieties; of its poles and its recognized faculties (*facultatibus*); of iron and its properties; of the magnetic substance common to loadstone and iron and the earth itself,—we have treated briefly in the foregoing book. Now remain the magnetic movements and their broader philosophy as developed by experiments and demonstrations. These movements are impulsions of homogeneous parts toward one another or toward the primary conformation of the whole earth. Aristotle admits only two simple movements of his elements—from the centre and toward the centre; light objects upward, heavy objects downward: so that in the earth there is but one motion of all its parts toward the centre of the world,—a wild headlong falling. We, however, will elsewhere consider what this 'light' may be, and will show how erroneously it is inferred by the Peripatetics from the simple motion of the elements; we shall also inquire what 'heavy' means.[1] But now we have to inquire into the causes of the other movements depending on its true form: these we see clearly in all magnetic bodies; these also we find existing in the earth and all its homogenic parts; further, we find that they are in accord with the earth, and are bound up in its forces. Now five movements or differences of movement are perceived by us: COITION[2] (commonly called attraction), an impulsion to magnetic union; DIRECTION[3] toward the earth's poles, and verticity of the earth toward determinate points in the universe, and the standstill there; VARIATION,[4] deflection from the meridian,—this we call a perverted motion; DECLINATION[5] (inclination or dip), a descent of the magnetic pole beneath the horizon; and circular movement, or REVOLUTION.[6] Of each of these we will treat separately, and will show how they all proceed from a congregant nature, or from verticity or from volubility. Jofrancus Offusius distinguishes several magnetic movements, the first to the centre, the second to the pole, traversing 77 degrees, the third to iron, the fourth to a loadstone. The first is not always to the centre, for only at the poles is it in a right line to the centre, if the motion is magnetic, otherwise it is only the movement of matter toward its mass and toward the earth. The second, of 77 degrees to the pole, is no movement, but a direction or a variation to the earth's pole. The third and the fourth are magnetic, and are but one movement. Thus this author recognizes no true magnetic movement but coition

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[1] See Plato's *Timæus* (tr. of Mr. Henry Davis), London 1849, Vol. II, pages 372–374.

[2] See Book II, Chap. II, *et seq.*

[3] See Book III.

[4] See Book IV.

[5] See Book V.

[6] See Book VI, Chap. III, *et seq.*

toward iron or loadstone, commonly known as attraction. There is another movement in the earth as a whole, which does not take place toward the terrella or the parts, *i.e.*, the movement of coacervation and that movement of matter called by philosophers a " right movement:" of that elsewhere.

CHAPTER II.

OF MAGNETIC COITION; AND, FIRST, OF THE ATTRACTION EXERTED BY AMBER, OR MORE PROPERLY THE ATTACHMENT OF BODIES TO AMBER.

GREAT has ever been the fame of the loadstone and of amber in the writings of the learned: many philosophers cite the loadstone and also amber whenever, in explaining mysteries, their minds become obfuscated and reason can no farther go.[1] Over-inquisitive theologians, too, seek to light up God's mysteries and things beyond man's understanding by means of the loadstone and amber: just as light-headed metaphysicians, when they utter and teach their vain imaginings, employ the loadstone as a sort of Delphic sword and as an illustration of all sorts of things. Medical men also (at the bidding of Galen), in proving that purgative medicines exercise attraction through likeness of substance and kinships of juices (a silly error and gratuitous!), bring in as a witness the loadstone, a substance

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[1] Dr. Wm. Whewell remarks that the manner in which Gilbert expresses himself shows us how mysterious the fact of attraction then appeared, so that, as he says, "the magnet and amber were called in aid by philosophers as illustrations, when our sense is in the dark in abstruse inquiries; and when our reason can go no further" (" Hist. of Ind. Sc.", 1859, Vol. II, page 192).

of great authority and of noteworthy efficiency, and a body of no common order. Thus in very many affairs persons who plead for a cause the merits of which they cannot set forth, bring in as masked advocates the loadstone and amber. But all these, besides sharing the general misapprehension, are ignorant that the causes of the loadstone's movements are very different from those which give to amber its properties; hence they easily fall into errors, and by their own imaginings are led farther and farther astray. For in other bodies is seen a considerable power of attraction, differing from that of the loadstone,—in amber, for example. Of this substance a few words must be said, to show the nature of the attachment of bodies to it, and to point out the vast difference between this and the magnetic actions; for men still continue in ignorance, and deem that inclination of bodies to amber to be an attraction, and comparable to the magnetic coition. The Greeks call this substance *ἤλεκτρον*, because, when heated by rubbing, it attracts to itself chaff; whence it is also called *ἅρπαξ*, and from its golden color, *χρυσοφόρον*.[1] But the Moors call it *carabe*, because they used to offer it in sacrifices and in the

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[1] The ancients were acquainted with but two electrical bodies—amber, (*electron*), which has given the denomination of the science; and *lyncurium*, which is either the tourmaline or the topaz (Dr. Davy, "Mem. Sir Hum. Davy," 1836, Vol. I, page 309). From a recent article treating of gems, the following is extracted: The name of the precious stone inserted in the ring of Gyges has not been handed down to us, but it is probable that it was the topaz, whose wonders Philostrates recounts in the life of Apollonius. An attribute of the sun and of fire, the ancients called it the *gold magnet*, as it was credited with the power of attracting that metal, indicating its veins, and discovering treasures. Heliodorus, in his story of Theagenes and Caricles, says that the topaz saves from fire all those who wear it, and that Caricles was preserved by a topaz from the fiery vengeance of Arsaces, Queen of Ethiopia. This stone was one of the first talismans that Theagenes possessed in Egypt. The topaz at present symbolizes Christian virtues, faith, justice, temperance, gentleness, clemency.

worship of the gods; for in Arabic *carab* means oblation, not *rapiens paleas* (snatching chaff), as Scaliger would have it, quoting from the Arabic or Persian of Abohali (Hali Abbas).[1] Many call this substance *ambra* (amber), especially that which is brought from India and Ethiopia.[2] The Latin name *succinum* appears to be formed from *succus*, juice.[3] The Sudavienses or Sudini call the substance *geniter*, as though *genitum terra* (produced by the earth). The erroneous opinion of the ancients as to its nature and source being exploded, it is certain that amber comes for the most part from the sea: it is gathered on the coast after heavy storms, in nets and through other means, by peasants, as by the Sudini of Prussia; it is also sometimes found on the coast of our own Britain. But it seems to be produced in the earth and at considerable depth below its surface, like the rest of the bitumens; then to be washed out by the sea-waves, and to gain consistency under the action of the sea and the saltness of its waters. For at first it was a soft and viscous matter, and hence contains, buried in its mass forevermore (*æternis sepulchris relucentes*), but still (shining) visible, flies, grubs, midges, and ants. The ancients as well as moderns tell (and their report is confined by experience) that amber attracts straws and chaff. The same is done by jet, a stone taken out of the earth in Britain, Germany, and many other regions: it is a hard concretion of black bitumen,—a sort of transformation of bitumen to stone.

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[1] Salmasius says that the word *karabe*, the Arabian word for *amber*, signifies the power of attracting straws. (Note, first page article "Electricity" in the Encyclopædia Britannica.)

[2] Consult the very interesting tables given by Joannes Zahn, at page 51, Chap. VII, Vol. II, of his "Specula physico-mathematico-historica notabilium....", Norimbergæ 1696.

[3] Pliny considers amber as the juice of a tree concreted into a solid form (Dr. Thos. Thomson, "Hist. of Chem.", 1830, Vol. I, page 101).

Many modern authors have written about amber and jet as attracting chaff and about other facts unknown to the generality, or have copied from other writers: with the results of their labors booksellers' shops are crammed full. Our generation has produced many volumes about recondite, abstruse, and occult causes and wonders, and in all of them amber and jet are represented as attracting chaff; but never a proof from experiments, never a demonstration do you find in them.[1] The writers deal only in words that involve in thicker darkness subject-matter; they treat the subject esoterically, miracle-mongeringly, abstrusely, reconditely, mystically. Hence such philosophy bears no fruit; for it rests simply on a few Greek or unusual terms—just as our barbers toss off a few Latin words in the hearing of the ignorant rabble in token of their learning, and thus win reputation—bears no fruit, because few of the philosophers themselves are investigators, or have any first-hand acquaintance with things; most of them are indolent and untrained, add nothing to knowledge by their writings, and are blind to the things that might throw a light upon their reasonings. For not only do amber and (gagates or) jet,[2] as they suppose, attract light corpuscles (substances): the same is done by diamond, sapphire, carbuncle, iris stone,* opal, amethyst, vincentina, English gem (Bristol stone, *bristola*), beryl, rock crystal.[3] Like powers of attracting are

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[1] "Stuffed the booksellers' shops by copying from one another extravagant stories concerning the attraction of magnets and amber without giving any reason from experiment" (Dr. Wm. Whewell, "Hist. of Ind. Sciences," 1859, Vol. II, page 192).

[2] The gagates, from the account given of it by Pliny, was obviously pit-coal or jet (Thomson's Chemistry, Vol. I, page 101). Cardan states, *Gagates non lapis est* (Lugduni ed. 1663, Vol. X, page 528).

[3] Sir David Brewster was the discoverer of the pyro-electrical condition of the diamond, the garnet, the amethyst, etc. See Mottelay's "Chronological History" at A.D. 1717 and 1820, and the references to rock-crystal, etc., throughout the remainder of present chapter.

possessed by glass, especially clear, brilliant glass; by artificial gems made of (paste) glass or rock crystal, antimony glass, many fluor-spars, and belemnites. Sulphur also attracts, and likewise mastich, and sealing-wax [of lac], hard resin, orpiment (weakly).[1] Feeble power of attraction is also possessed in favoring dry atmosphere by sal gemma [native chloride of sodium], mica, rock alum.[2] This we may observe when in mid-winter the atmosphere is very cold, clear, and thin; when the electrical effluvia of the earth offer less impediment, and * electric bodies are harder: of all this later. These several bodies (electrics) not only draw to themselves straws and chaff, but all metals, wood, leaves, stones, earths, even water and oil; in short, whatever things appeal to our senses or are solid: yet we are told that it attracts nothing but chaff and twigs. Hence Alexander Aphrodiseus incorrectly declares the question of amber to be unsolvable, because that amber does attract chaff, yet not the leaves of basil; but such stories are

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[1] Whewell quotes: "Not only amber and agate attract small bodies, as some think, but diamond, sapphire, carbuncle, opal, amethyst, Bristol gem, beryl, crystal, glass, glass of antimony, spar of various kinds, sulphur, mastic, sealing-wax;" and adds that Gilbert mentioned other substances ("Hist. Ind. Sc.", 1859, Vol. II, page 192).

[2] The passage is thus rendered by Humboldt: "The force of attraction belongs to a whole class of very different substances, as glass, sulphur, sealing-wax, and all resinous substances, rock crystal, and all precious stones, alum, and rock salt" ("Cosmos," 1849, Vol. II, page 726).

Dr. Thos. Brown says (*Pseudoloxia Epidemica*, 1658, page 87): "Unto these Cabeus addeth white Wax, Gum Elimi, Gum Guaici, Pix Hispanica and Gipsum. And unto these we add Gum Anine, Benjamin, Talcum, Chyna-dishes, Sandaraca, Turpentine, Styrax Liquida, and Caranna dried into a hard consistence...." (Dantzick Memoirs, Vol. I, page 180). To Dr. Gilbert's list of electrics Robert Boyle added the resinous cake which remained after evaporating one-fourth part of good oil of turpentine; the dry mass which remains after distilling a mixture of petroleum and strong spirits of nitre, glass of antimony, glass of lead, caput mortuum of amber, white sapphire, white amethyst, diaphanous ore of lead, carnelian, and a green stone supposed to be a sapphire (art. "Electricity," Ency. Brit.).

false, disgracefully inaccurate.[1] Now in order clearly to understand by experience how such attraction takes place, and what those substances may be that so attract other bodies (and in the case of many of these electrical substances, though the bodies influenced by them lean toward them, yet because of the feebleness of the attraction they are not drawn clean up to them, but are easily made to rise), make yourself a rotating-needle (electroscope—*versorium*) of any sort of metal,[2] three or four fingers long, pretty light, and poised on a sharp point after the manner of a magnetic pointer. Bring near to

one end of it a piece of amber or a gem, lightly rubbed, polished and shining: at once the instrument revolves. Several objects are seen to attract not only natural objects, but things artificially prepared, or manufactured, or formed by mixture. Nor is this a rare property possessed by one object or two (as is commonly supposed), but evidently belongs to a multitude of objects, both simple and compound, e.g., sealing-wax and other unctuous mixtures. But why this inclination and what

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[1] When amber has been rubbed, many "particles of matter, like so many fine threads, too small to be seen, come out of it, and dart themselves into the air, where meeting with small bodies, they get into the pores of them, and then return back into the amber; at the same time the air continually repelling these small threads, and forcing them to contract themselves into less and less compass, presses likewise in the same manner upon the light bodies into the pores of which these small threads have thrust themselves; so that in returning back to the amber they carry small straws, in whose pores they are engaged along with them" (Rohault's "System of Nat. Phil.", London 1728, page 187; *Rohaulti Physica*, London 1718, Par. III, Cap. VIII, page 408).

[2] See note 5, page xxxi.

these forces,—on which points a few writers have given a very small amount of information, while the common run of philosophers give us nothing,—these questions must be considered fully. Galen recognizes in all three kinds of attractions in nature: first, the attraction exercised by those bodies which attract by an elemental quality—heat, to wit; secondly, by those which attract by the in-rush into a vacuum; thirdly, by those which attract through a property pertaining to their entire mass: and these three kinds are enumerated by Avicenna and others. This division cannot by any means content us, nor does it define the causes (*causas*) of amber, jet, diamond, and other like substances, which owe to the same virtue the forces they possess; nor of loadstone or of other magnetic bodies, which possess a force altogether different from that of those other bodies, both in its efficiency and in the sources whence it is derived. We must, therefore, find other causes of movements, or must with these stray about as it were in darkness, never at all reaching our goal. Now amber does not * attract by heat, for when heated at a fire and brought near to straws, whether it is merely warm, or whether it is hot, even burning hot, or even brought to the flaming point, it has no attraction. Cardan (and Pictorius too) is of opinion that the attraction of amber is much like that seen in the cupping-glass: yet the attractional force of the cupping-glass does not really come from igneous force; but he had already said that a dry body is eager to drink up one that is moist and juicy, and therefore such bodies are drawn to it. These two explications are inconsistent, and they are without ground in reason also. For were amber to move toward its sustenance, or other bodies to turn to amber, as to their food, the one, being swallowed up, would disappear, while the other would increase in size. And then why seek in amber the attractive force of fire? If fire attracts, why do not many other bodies heated by the fire, the sun, or by friction attract also? Nor can attraction, because of air displaced, occur in open air, though this is the cause Lucretius assigns for magnetic movements; nor in the cupping-glass can heat or fire feeding on the air attract: the air in the cupping-glass rarefied to flame, when again it becomes dense and is compressed into small space, causes the skin and flesh to rise, because nature avoids a vacuum. In open air, heated objects cannot attract, not even metals or stones brought to a very high temperature by fire. For an iron rod at white heat, a flame, a candle, a flaming torch, or a * red-hot coal when brought near to straws or to a revolving pointer (*versorium*) does not attract; and yet plainly all these cause the air to come to them in a current, for they consume air as a lamp consumes oil. But of heat, and how very different is the view held by the whole crowd of the philosophers, as to its attractive power in natural bodies and materia medica, from the fact as seen in nature, we will treat elsewhere when we come to explain what heat and cold really are. They are very general properties or close appurtenances of substances, but are not called true causes; and if I may use the expression, they utter certain words, but in fact they show nothing specifically. Nor does the supposed attractive force of amber arise from any peculiar property of its substance or from any special relation between it and other bodies; for in many other substances, if we but search with any diligence, we see the same effect, and, by them, all other bodies, of whatever properties possessed, are attracted. And likeness is not the cause of amber's attracting, for all things that we see on the globe, whether similar or dissimilar, are attracted by amber and such like; hence no strong analogy is to be drawn either from likeness or from identity of substance. Besides, like does not attract like—a stone does not attract a stone, flesh flesh: there is no attraction outside of the class of magnetic and electric bodies. Fracastorio thinks that all bodies that mutually attract are alike, or of the same species, and that, either in their action or in their proper *subjectum:* "now the proper *subjectum,*" says he, "is that from which is emitted that emanational something which attracts, and, in mixed substances, this is not perceptible on account of deformation, whereby they are one thing *actu*, another *potentiâ*. Hence, perhaps, hairs and twigs are drawn to amber and diamond not because they are hairs, but because there is imprisoned within them either air or some other principle that is first attracted and that has reference and analogy to that which of itself attracts; and herein amber and diamond are as one, in virtue of a principle common to both." So much for Fracastorio. But had he in experiment noted that all bodies are attracted by electrics save those which are afire or flaming, or extremely rarefied, he never would have entertained such views. Men of acute intelligence, without actual knowledge of facts, and in the absence of experiment, easily slip and err. In greater error are they who hold amber, diamond, etc., and the objects attracted by them, to be like one another, but not the same, near to one another in kind, and that therefore like moves toward like, and is by it perfected. But that is reckless speculation; for all bodies are drawn to all electrics, save bodies aflame or too rarefied, as the air which is the universal effluvium of the globe. Plants draw moisture, and thus our crops thrive and grow; but from this analogy Hippocrates in his book *De Natura Hominis*, I., illogically infers that morbid humor is purged by the specific virtue of a drug. Of the action of purges we will treat elsewhere. Wrongly, too, attraction is postulated to exist in other effects; e.g., when a stoppered bottle of water being covered with a heap of wheat, its liquid is drawn out; for in fact the liquid is reduced to vapor by the spirit of the fermenting wheat, and the wheat takes in that vapor. Nor do elephants' tusks suck up moisture, but transform it into vapor and absorb it. And thus very many bodies are said to attract, whereas the ground of their action is to be sought elsewhere. A large polished lump of amber attracts; * a smaller piece, or a piece of impure amber, seems not to attract without friction. But very many electric bodies (as precious stones, etc.) do not attract at all unless they are first rubbed; while sundry other bodies, and among them some * gems, have no power of attraction, and cannot be made to attract, even by friction; such bodies [anelectrics—non-electrics] are emerald, agate, carnelian,[1] pearls, jasper, chalcedony, alabaster, porphyry, coral, the marbles, lapis lydius (touchstone, basanite), flint, bloodstone, emery or corundum (*mugris*), bone, ivory; the hardest woods, as ebony; some other woods, as cedar, juniper, cypress; metals, as silver, gold, copper, iron. The loadstone, though it is susceptible of a very high polish, has not the electric attraction. On the other hand, many bodies (already mentioned) that can be polished attract when rubbed. All this we shall understand when we have more closely studied the prime origin of bodies. As is plain to all, the earth's mass or rather the earth's framework and its crust consist of a twofold matter, a matter, to wit, that is fluid and humid, and a matter that is firm and dry. From this twofold matter, or from the simple concretion of one of these matters, come all the bodies around us, which consist in major proportion now of terrene matter, anon of watery. Those

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[1] *Sarda* was the name of *carnelian*, so called because it was first found near Sardis. The *sardonyx* was also another name for *carnelian* (Dr. Th. Thomson's "Chemistry," 1830, Vol. I, page 100).

that derive their growth mainly from humors, whether watery humor or one more dense; or that are fashioned from these humors by simple concretion, or that were concreted out of them long ages ago; if they possess sufficient firmness, and after being polished are rubbed, and shine after friction,—such substances attract all bodies presented to them in the air unless the said bodies be too heavy. For amber and jet are concretions of water; so too are all shining gems, as rock-crystal, which is a product of limpid water, not always of such water at an extremely low temperature, as some have thought but sometimes at a more moderate degree of cold, the nature of the ground fashioning them, and the humor or juices being prisoned in definite cavities, just as fluorites are generated in mines. So clear glass is reduced from sand and other substances that have their origin in humid juices. But these substances contain a quantity of impurities of metals, or metals themselves, stones, rocks, wood, earth, or are largely mixed with earth; therefore they do not attract. Rock crystal, mica, glass, and other electric bodies do not attract if they be burned or highly heated, for their primordial humor is destroyed by the heat, is altered, and discharged as vapor. Hence all bodies that derive their origin principally from humors, and that are firmly concreted, and that retain the appearance and property of fluid in a firm, solid mass, attract all substances, whether humid or dry. Such as are parts of the true substance of the earth or differ but little from that, appear to attract also, but in a very different way, and, so to speak, magnetically: of them we are to treat later. But those that consist of mixed water and earth, and that result from equal degradation of both elements—in which the magnetic force of the earth is degraded and lies in abeyance, while the aqueous humor, spoilt by combination with a quantity of earth, does not form a concretion by itself, but mingles with the earthy matter —such bodies are powerless to attract to themselves aught that they are not in actual contact with, or to repel the same. For this reason it is that neither metals, marbles, flints, woods, grasses, flesh, nor various other substances can attract or solicit a body, whether magnetically or electrically (for it pleases us to call electric force that force which has its origin * in humors). But bodies consisting mostly of humor and not firmly compacted by nature wherefore they do not stand friction, but either fall to pieces or grow soft, or are sticky, as pitch, soft rosin, camphor, galbanum, ammoniacum, storax, asa, gum benjamin, asphaltum (especially in a warm atmosphere), do not attract corpuscles. For without friction few bodies give out their true natural electric *emanation* and effluvium. Turpentine resin in the liquid state does not at-* tract, because it cannot be rubbed; but when it hardens to a mastic it does attract.

And now, at last, we have to see why corpuscles are drawn toward substances that derive their origin from water, and by what manner of force, by what hands, so to speak, such substances lay hold of matters nigh them.

In all bodies everywhere are presented two causes or principles whereby the bodies are produced, to wit, matter (*materia*) and form (*forma*). Electrical movements come from the *materia*, but magnetic from the prime *forma;* and these two differ widely from each other and become unlike,—the one ennobled by many virtues, and prepotent; the other lowly, of less potency, and confined in certain prisons, as it were; wherefore its force has to be awakened by friction till the substance attains a moderate heat, and gives out an effluvium, and its surface is made to shine. Moist air blown upon it from * the mouth or a current of humid air from the atmosphere chokes its powers; and if a sheet of paper or a linen cloth be interposed there is no movement. But loadstone, neither rubbed nor heated, and even though it be drenched with liquid, and whether in air or water, attracts magnetic bodies, and that, though solidest bodies or boards, or thick slabs of stone or plates of metal, stand between. A loadstone attracts only magnetic bodies; electrics attract everything. A loadstone lifts great weights; a strong one weighing two ounces lifts half an ounce or one ounce. Electrics attract only light weights; e.g., a piece of amber three ounces in weight lifts only one-fourth of a barleycorn's weight.

But this attraction of amber and of electric bodies must be investigated further; and since it is an acquired state (*affectio*), the question arises why amber is rubbed, and what state is brought about by rubbing; also, what causes are evoked that seize all sorts of substances. By friction it is made moderately hot and also smooth; and these conditions must in most cases concur; but a large polished piece of amber or of jet attracts even without friction, though not strongly; yet if it be carefully brought nigh to a flame or a red coal and warmed to the same degree as by friction, it does not attract corpuscles, because it becomes involved in dark fumes from the body of the hot or flaming mass, which emits a hot exhalation; and the vapor from that other body is driven upon it—something quite alien to the nature of the amber. Besides, the exhalation produced in the amber by an alien heat is feeble, for the amber must not have any heat save that produced by friction: its own heat, so to speak,—not heat contributed by other bodies. For as the igneous heat emitted by any flaming matter is useless to procure for electrics their virtue, so, too, heat from the sun's rays does not excite an electric by the right dissolution of its matter,—rather dissipates and consumes it (albeit a body that undergoes friction and then is exposed to the solar rays retains its powers longer than it does in shade, because that in shade effluvia are condensed more and more quickly); further, the sun's heat, heightened by means of a burning-glass, imparts no power to amber, for it dissipates and spoils all the electric effluvia. Again, flaming sulphur and burning sealing-wax do not attract, for heat produced by friction dissolves bodies into effluvia, and these are consumed by flame. It is impossible for solid electrics to be resolved into their effluvia otherwise than by attrition, save a few that, because of their native strength, emit effluvia continually. They are to be rubbed with bodies that do not foul the surface, and that cause them to shine, e.g., strong silk, and coarse woollen cloth, scrupulously clean, and the dry palm of the hand. Amber may be rubbed with amber, with diamond, with glass, etc. Thus are electrics made ready for action.

And now what is it that produces the movement? The body itself circumscribed by its contour? Or is it something imperceptible for us flowing out of the substance into the ambient air? (This appears to have been in some sense the opinion of Plutarch, who, in the *Quæstiones Platonicæ*, says that there is in amber something flame-like, or having the nature of the breath, and that this, when the paths are cleared by friction of the surface, is emitted and attracts bodies.) And if it is an effluvium, does the effluvium set the air in current, and is the current then followed by the bodies? or is it the bodies themselves directly that are drawn up? But if the amber attracts the body itself, then supposing its surface is clean and free from adhesions, what need is there of friction? Nor does the force come from the lustre proceeding from the rubbed and polished electric; for the vincentina, the diamond, and pure glass attract when they are rough, but not so strongly nor so readily; because then they are not so easily cleansed of extraneous moisture settled on the surface, nor are they subjected all over to such an equal degree of friction as to be resolved into effluvia. Nor does the sun, with its shining and its rays, which are of vast importance in nature, attract bodies thus; and yet the common run of philosophizers think that liquids are attracted by the sun, whereas only the denser humors are resolved into rarer, (and) into vapor and air; and thus, through the motion given to them by diffusion, they ascend to the upper regions, or, being attenuated exhalations, are lifted by the heavier air. Neither does it seem that the electric attraction is produced by the effluvia rarefying the air so that bodies, impelled by the denser air, are made to move toward the source of the rarefaction: if that were so, then hot bodies and flaming bodies would also attract other bodies; but no lightest straw, no rotating pointer is drawn toward a flame. If there is afflux and appulsion of air, how can a minute diamond of the size of a chick-pea pull to itself so much air as to sweep in a corpuscle of relatively considerable length, the air being pulled toward the diamond only from around a small part of one or other end? Besides, the attracted body must stand still or move more slowly before coming into contact, especially if the attracting body be a broad flat piece of amber, on account of the heaping up of air on the surface, and its rebounding after collision. And if the effluvia go out rare and return dense (as with vapors), then the body would begin to move toward the electric a little after the beginning of its application; yet, when rubbed electrics * are suddenly applied to a versorium, instantly the pointer turns, and the nearer it is to the electric the quicker is the attraction. But if rare effluvia rarefy the medium, and therefore the bodies pass from a denser into a rarer medium, then the bodies might be attracted sideways or downward, but not upward, or the attraction and holding of the bodies would be only for a moment. But jet and amber after one friction strongly and for a length of time solicit and attract bodies, sometimes for as long as five minutes, especially if the weather is fair. But if the mass of amber be large, and its surface polished, it attracts without friction. Flint, on being struck, gives off inflammable matter that turns to sparks and heat. Hence the denser fire-containing effluvia of flint are very different indeed from the electrical effluvia, which, by reason of their extreme tenuity, cannot take fire, nor are they fit matter of flame. They are not a breath, for, when given forth, they do not exert propelling force; they flow forth without any perceptible resistance, and reach bodies. They are exceedingly attenuated humors, much more rarefied than the ambient air; to produce them requires bodies generated of humor and consolidated to considerable hardness. Non-electric bodies are not resolvable into humid effluvia; and such effluvia mingle with the common and general effluvia of the earth, and are not peculiar. In addition to the attracting of bodies, electrics hold them for a considerable time. Hence it * is probable that amber exhales something peculiar that attracts the bodies themselves, and not the air. It plainly attracts the body itself in the case of a spherical drop of water standing on a dry surface; for a piece of amber held at suitable distance pulls toward itself the nearest particles and draws them * up into a cone; were they drawn by the air the whole drop would come toward the amber. And that amber does not attract the air is thus proved: take a very slender wax candle giving a very small clear flame; bring a broad flat piece of * amber or jet, carefully prepared and rubbed thoroughly, within a couple of fingers' distance from it; now an amber that will attract bodies from a considerable radius will cause no motion in the flame, though such motion would be inevitable if the air were moving, for the flame would follow the current of air. The amber attracts from as far as the effluvia are sent out; but as the body comes nearer the amber its motion is quickened, the forces pulling it being stronger, as is the case also in magnetic bodies, and in all natural motion; and the motion is not due to rarefaction of the air or to an action of the air impelling the body to take the vacated place; for in that case the body would be pulled but not held, since, at first, approaching bodies would even be repelled just as the air itself would be: yet in fact the air is not in the least repelled even at the instant that the rubbed amber is brought near after very rapid friction. An effluvium is exhaled by the amber and is sent forth by friction; pearls, carnelian, agate, jasper, chalcedony, coral, metals, and the like, when rubbed are inactive; but is there nought that is emitted from them also by heat and friction? There is indeed; but what is emitted from the denser bodies, and those with considerable admixture of earth matter, is thick and vaporous; and in fact in the case of very many of the electric bodies, if they be violently rubbed, there is but a faint attraction of bodies to them, or none at all; the best method is to use gentle but very rapid friction, for so the finest effluvia are elicited. The effluvia arise from a subtle solution of moisture, not from force applied violently and recklessly; this is true especially of bodies that are of oily substance consolidated, which, when the atmosphere is thin and the wind is from the north, or here in England from the east, produce their effects best and with most certainty; but in a south wind and a humid atmosphere the effect is very slight: so that effluvia that attract but feebly when the weather is clear, produce no motion at all when it is cloudy. And this as well because in thick weather light objects are harder to move, as also (and rather) because the effluvia are stifled, and the surface of the rubbed body is affected by the vaporous air, and the effluvia are stopped at their very origin ; hence it is that in amber, jet, and sulphur, because these bodies do not so readily collect the humid air on their surface, and are much more thoroughly resolved, this force is not so easily suppressed as in gems, rock-crystal, glass, and the like, which collect the condensed moist air on their surface. But the question may arise, why amber attracts water, though water existing on a surface annuls its action. That is because it is one thing to suppress the effluvium at its rise, another to destroy it after it is emitted. Thus a certain * gauzy texture of silk, commonly called *sarsnet*, when quickly laid over amber immediately after friction, hinders the body's * attraction ; but if it be interposed midway between the two bodies, it does not altogether annul the attraction. Moisture from steam, a breath from the mouth, water thrown on the amber, instantly check the effluvium. But olive-oil that is * light and pure does not prevent it, and even rubbing amber * with a warm finger dipped in the oil does not prevent attraction. But if after that friction the amber be drenched with alcohol, or brandy, it does not attract, as the spirit is heavier, denser, than the oil, and when added to the oil sinks below it. For olive-oil is light and rare, and does not oppose the passage of the lightest effluvia. A breath, then, proceeding from a body that is a concretion of moisture or aqueous fluid, reaches the body that is to be attracted, and as soon as it is reached it is united to the attracting electric ; and a body in touch with another body by the peculiar radiation of effluvia makes of the two one : united, the two come into most intimate harmony, and that is what is meant by attraction. This unity is, according to Pythagoras, the principle, through participation, in which a thing is said to be one. For as no action can be performed by matter save by contact, these electric bodies do not appear to touch, but of necessity something is given out from the one to the other to come into close contact therewith, and be a cause of incitation to it.

All bodies are united and, as it were, cemented together by moisture, and hence a wet body on touching another body attracts it if the other body be small; and wet bodies on the surface of water attract wet bodies. But the peculiar effluvia of electrics, being the subtilest matter of solute moisture, attract corpuscles.[1] Air, too (the earth's universal effluvium), unites parts that are separated, and the earth, by means of the air, brings back bodies to itself; else bodies would not so eagerly seek the earth from heights. The electric effluvia differ much from air, and as air is the earth's effluvium, so electric bodies have their own distinctive effluvia; and each peculiar effluvium has its own individual power of leading to union, its own movement to its origin, to its fount, and to the body that emits the effluvium. But bodies that give out a thick or a vaporous or an aerial effluvium when rubbed have no effect; for either such effluvia are diverse from humor (unifier of all things), or, being very like the common air, they become blended with the air and one with it: wherefore they have no effect in the air, and do not produce any movements different from those of that universal and common element. Bodies tend to come together and move about on the surface of water like the rod *C*, which dips a little into the water.

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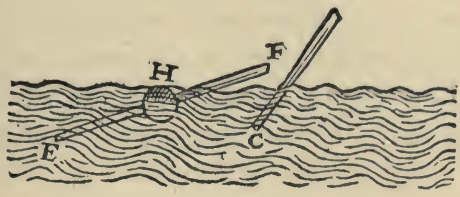
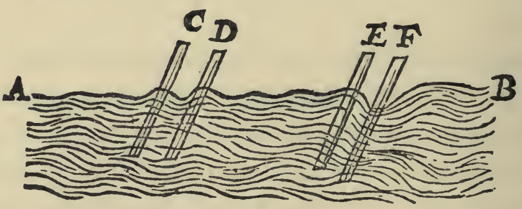
[1] Consult Robert Boyle's "Of the Strange Subtilty of Effluviums," 1673, pages 38–42, 52, 53; "Of the Great Efficacy of Effluviums," 1673, pages 18, 19, 32, 33; "Of the Determinate Nature of Effluviums," 1673, pages 21, 57; "An Essay about.... Gems," 1672, pages 108–112.

Evidently the rod *EF*, floated by the cork *H* and having only the wetted end *F* above the water's surface, will be attracted by the rod *C*, if *C* be wetted a little above the water's surface.



As a drop brought into contact with another drop is attracted, and the two forthwith unite, in the same way a wet object on the surface of water seeks union with another wet object when the surface of the water rises in both: at once, like drops or bubbles of water, they come together; but they are in much nigher neighborhood than in the case of electrics, and they unite by their wetted surfaces. But if the whole rod *C* be dry above the water, it no longer attracts but repels the rod *EF*. The same is seen in the case of bubbles on water: one is seen to approach another, all the more rapidly the nearer they are. Solids draw to solids through the medium of liquid; e.g., touch the end of a versorium with the end of a rod on which a drop of water stands: the instant the rotating pointer comes in contact with the circumference of the drop it adheres to it with a sudden motion. So do bodies concreted from liquids when melted a little in the air exercise attraction, their effluvia being the means of unition; for the water in humid bodies or in bodies drenched with superficial moisture on the top of water has the force of an effluvium. A clear atmosphere is a good medium for the electric effluvium developed from concreted humor. Wet bodies projecting out of the surface of water come together, if they be near, and unite.

for the water's surface rises around wet surfaces. A dry body does not move toward a wet, nor a wet toward a dry, but rather they seem to go away from each other; for if all of the body that is above the water is dry, the nearest water surface does not rise but falls away with subsidence of the surface around the dry object. So, too, a dry body does not run to the dry rim of a vessel containing water; but, on the contrary, a wet object does. In the figure, *AB* is the water surface;



C, *D*, two rods with their projecting ends wet. Evidently the surface of the water at *C* and *D* rises simultaneously with the rods; hence the rod *C*, because its water, standing above the general level, seeks equilibrium and union, moves with the water toward *D*. On the wet rod *E* the water rises also, but by the dry rod *F* the water is depressed, and as it strives to depress also the water rising on *E*, the higher water at *E* turns away from *F*, for it refuses to be depressed. All electric attractions are effected by means of moisture, and thus all things come together because of humor: fluid bodies and aqueous bodies come together on the surface of water, and concreted bodies, if reduced to vapor, come together in the air. And in the air the effluvium of electrics is very rare, that so it may more thoroughly permeate the atmosphere, and yet not give it impulsion by its own motion. For were this effluvium as dense as air, or the winds, or the fumes of burning saltpetre, or as the thick, foul effluvia emitted with much force from other bodies, or as the air from vaporized water rushing forth from a pipe (as in the instrument described by Hero of Alexandria in his book *Spiritualia*): in such case it would repel everything, and not attract. But those thinner effluvia lay hold of the bodies with which they unite, enfold them, as it were, in their arms, and bring them into union with the electrics; and the bodies are led to the electric source, the effluvia having greater force the nearer they are to that. But what is the effluvium from rock-crystal, glass, diamond—substances very hard and very highly compressed? For such effluvium there is no need of any notable or sensible outflow of substance: no need of abrading, or rubbing, or otherwise disfiguring the electric body: odoriferous substances give forth fragrance for many years, exhale continually, yet are not soon consumed. Cypress wood, as long as it remains sound—and it lasts a very long time—is fragrant, as many learned men testify from experience. Such an electric, after only a moment's friction, emits powers subtile and fine, far beyond all odors; but sometimes an odor also is emitted by amber, jet, sulphur, these bodies being more readily resolved. Hence it is that usually they attract after the gentlest friction, or even without friction; and they attract more powerfully and keep hold longer because their effluvia are stronger and more lasting. But diamond, glass, rock-crystal, and very many of the harder and more compacted gems are heated, and then rubbed for a good while at first, after which they, too, attract strongly: they cannot be resolved in any other way. Electrics attract all things save flame and objects aflame, and thinnest air. And as they do not draw to themselves flame, so they have no effect on a versorium if it have very near it on any side the flame of a lamp or of any burning substance; for it is plain *that the effluvia are consumed by flame and igneous heat. Therefore electrics do not attract either flame or bodies near flame ; for such effluvia have the virtue and analogy of rarefied humor, and they will produce their effect, bringing about unition and continuity, not through the external action of humors, or through heat, or through attenuation of heated bodies, but through the attenuation of the humid substance *into its own specific effluvia.[1] Yet they draw to themselves the smoke from an extinguished candle; and the lighter the smoke becomes as it ascends, the less strongly is it attracted, for substances that are too rare do not suffer attraction. At *last, when the smoke has nearly vanished, it is not attracted at all, as is plainly seen when the fact is observed toward the light. But when it has passed quite into the air it is not stirred by electrics, as has already been shown. For thin air itself is in no wise attracted, save by reason of its coming into a vacuum, as is seen in furnaces in which air is supplied by means of appliances for drawing it in. Therefore the effluvium called forth by a friction that does not clog the surface —an effluvium not altered by heat, but which is the natural product of the electric body—causes unition and cohesion, seizure of the other body, and its confluence to the electrical source, provided the body to be drawn is not unsuitable by reason either of the circumstances of the bodies or of its own weight. Hence corpuscles are carried to the electrical bodies themselves. The effluvia spread in all directions: they are specific and peculiar, and *sui generis*, different from the common air; generated from humor; called forth by calorific motion and rubbing, and attenuation; they are as it were

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[1] Nicolao Cabeo, *Philosophia Magnetica*, 1629, Lib. II, Cap. XXI, page 194.

material rods—hold and take up straws, chaff, twigs, till their force is spent or vanishes; and then these small bodies, being set free again, are attracted by the earth itself and fall to the ground. The difference (distinction) between electric and magnetic bodies is this: all magnetic bodies come together by their joint forces (mutual strength); electric bodies attract the electric only, and the body attracted undergoes no modification through its own native force, but is drawn freely under impulsion in the ratio of its matter (composition). Bodies are attracted to electrics in a right line toward the centre of electricity: a loadstone approaches another loadstone on a line perpendicular to the circumference only at the poles, elsewhere obliquely and transversely, and adheres at the same angles. The electric motion is the motion of coacervation of matter; the magnetic is that of arrangement and order. The matter of the earth's globe is brought together and held together by itself electrically. The earth's globe is directed and revolves magnetically; it both coheres and, to the end it may be solid, is in its interior fast joined.[1]

CHAPTER III.

OPINIONS OF OTHERS CONCERNING MAGNETIC COITION, WHICH THEY CALL ATTRACTION.

HAVING treated of electrics, we have now to set forth the causes of magnetic coition. Coition, we say, not attraction, for the term attraction has wrongfully crept into magnetic

[1] "In these obscure axioms we trace the recognition of *terrestrial electricity*,—the expression of a force,—which, like magnetism, appertains as such to matter. As yet we meet with no allusions to repulsion, or the difference between insulators and conductors" (Humboldt, "Cosmos," 1849, Vol. II, page 727).

philosophy, through the ignorance of the Ancients; for where attraction exists, there, force seems to be brought in and a tyrannical violence rules. Hence, if we have at any time spoken of magnetic attraction, what we meant was magnetic coition and primary confluence.[1] But here it will be not unprofitable first to set forth briefly the views of others, both among the ancients and the moderns. Orpheus, in his hymns, tells that iron is drawn by the loadstone as the bride to the embraces of her spouse. Epicurus holds that iron is drawn by the loadstone as straws by amber; and adds a reason: "Atoms," he says, "and indivisible bodies that flow from stone and from iron, agree together in their figures, so that they readily embrace mutually; hence, when they impinge on concretions both of iron and stone, they rebound into the middle space, connected together on the way, and carry the iron with them." This, surely, cannot be, for though solid and very dense bodies, or blocks of marble, stand between, they do not hinder the passage of this potency, though they can separate atoms from atoms; besides, on the hypothesis, the stone and iron would quickly be resolved into atoms, so profuse and incessant would be the atomic outflow. And as the mode of attraction is quite different in amber, there the Epicurean atoms cannot agree in their figures. Thales, as we are told by Aristotle, in Book I, *De Anima*, deemed the loadstone endowed with a sort of life, because it possesses the power of moving and attracting iron. Anaxagoras was of the same opinion. The opinion of Plato in the *Timæus*, about the effect of the Herculean stone, is baseless. He says: "With respect to all the motions of water, the fallings of thunder, and

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[1] "Coition, says Gilbert, is not made by any attractive faculty, either of the load-stone or of the iron, but by a Syndrome, or concordance of both of them" (Creech's translation of Lucretius, London 1714, Vol. II, page 720).

the wonderful circumstances observed in the attraction of amber, and the Herculean stone,—in all these, no real attraction takes place at all, but, as a vacuum can nowhere be found, the particles are mutually impelled by each other; hence, as they all individually, both in a separate and mingled state, have an attraction for their own proper seats, it is by the mutual intermingling of these affections, that such admirable effects present themselves to the view of the accurate investigator."[1] Galen knows not why Plato should have chosen rather the theory of circumpulsion than of attraction (on this point alone differing from Hippocrates), seeing that circumpulsion harmonizes in fact neither with reason nor with experiment. For neither is air nor anything else circumpelled, and even the bodies that are attracted are not borne to the attracting bo'^y in confused fashion or in a circle. The Epicurean poet Lucretius thus presents his master's theory:

Principiò, fluere è lapide hoc permulta necesse est
Semina sive æstum, qui discutit aëra plagis;
Inter qui lapidem, ferrumque est, cunque locatus,
Hoc ubi inanitur spatium, multisque vacefit
In medio locus : extemplò primordia ferri
In vacuum prolapsa cadunt coniuncta ; fit utque
Annulus ipse sequatur, eatque ita corpore toto, etc.[2]

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[1] In his note to the translation of the *Timæus* (Bohn, London 1849, Vol. II, page 394), Mr. Henry Davis adds: This is a very memorable passage, and clearly shows that Plato was not only well acquainted with the doctrine of attraction and repulsion, but was of opinion also that the law of repulsion depended on the congregation of similar elements throughout all nature. The whole matter, however, is largely treated by Plutarch in his Sixth Platonic Dissertation, Vol. II, page 1004, ed. Par.

[2] Mr C. F. Johnson renders the passage as follows ("Nature of Things," 1872, page 291):

First, from the stone innumerous atoms flow,
In streams that form an atmosphere around,
Displacing air between it and the stone.
Thus rarefied, the space, the particles
Of metal press, vacated place to fill,
And drag with them the mass to which they're joined;
For nothing is than steel more closely knit,

A similar explication is offered by Plutarch in the *Quæstiones Platonicæ*. He says that the loadstone emits heavy exhalations, whereby the contiguous air, being impelled, makes dense the air in front of it, and that air, driven round in a circle and returning to the part whence the air was displaced, forcibly carries the iron with it. The following theory of the powers of loadstone and amber is propounded by Joannes Costæus of Lodi: Costæus holds that "there is work on both sides, result on both sides, and therefore the motion is produced in part by the loadstone's attraction, in part by the iron's spontaneous movement; for, as we say that the vapors given out by the loadstone do by their own nature haste to attract the iron, so, too, do we say that the air impelled by the vapors, while seeking a place for itself, is turned back, and when turned back impels and transfers the iron, which is picked up, as it were, by it, and which, besides, is exerted on its own account. In this way there is found a certain composite movement, resulting from the attraction, the spontaneous motion, and the impulsion; which composite motion, however, is rightly to be referred to attraction, because the beginning of this motion is invariably from one term, and its end is there too; and that is precisely the distinguishing character of attraction." There is, it is true, mutual action, not mutual work; the loadstone does not thus attract, and there is no impulsion; neither is the principle of the motion found in vapors

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Nor more compacted in its elements:
Hence, little wonder, if, as said before,
The particles thus streaming to the void
Should drag with them along the chain entire!
And this they do; drag it to magnet stone,
Whereto it close adheres by secret bond.

T. LUCRETII CARI, *De Rerum Natura*, London 1824, Book VI, v. 1000–1006. See Thomas Creech's translation, London 1714, Vol. II, pages 726, 727; likewise Mr. H. A. J. Monro's Explanatory Notes, II, Cambridge and London, 1886, pages 386, 387.

and their return movements: that is Epicurus's theory, so oft repeated by others. Galen errs in his first book, *De Naturalibus Facultatibus*, cap. 14, when he expresses the opinion that whatever agents draw out the venom of serpents or arrows possess the same powers as the loadstone. As for this attraction (if attraction it may be called) of medicaments, we will treat of it in another place. Drugs against poisons and arrow-wounds have no relation, no resemblance, to the actions of magnetic bodies. Galen's followers, who teach that purgative medicines attract because of likeness of substance, say that bodies are attracted on account of resemblance, not of identity; therefore, say they, loadstone draws iron, but iron does not draw loadstone. But we say and prove that this takes place in all prime bodies, and in bodies that are allied and especially that are near akin to these, and this on account of identity: wherefore loadstone draws loadstone, and iron draws iron; all true earth substance draws its kind; and iron invigorated by the action of a loadstone within whose sphere of influence it is, draws iron more powerfully than it does loadstone. Cardan asks why no other metal is drawn by any stone; and his answer is, because no other metal is so cold as iron: as if, forsooth, cold were cause of attraction, or iron were much colder than lead, which neither follows the loadstone nor leans toward it. But this is sorry trifling, no better than old wives' gossip. Of the same sort is the belief that the loadstone is a living thing, and that iron is its victual. But how does loadstone feed on iron if the iron filings it is kept in neither are consumed nor become lighter in weight? Cornelius Gemma (*Cosmocrit*, X), declares that loadstone draws iron to itself by means of invisible rods; and to this opinion he tacks on a story of the sucking-fish and the catablepas. Guilelmus Puteanus deduces the power of the loadstone, not from a property of its whole substance unknown to any one and incapable of demonstration (as Galen held, and after him nearly all physicians), but from "its substantial form as from a prime motor and self-motor, and as from its own most potent nature and its natural temperament, as the instrument which the efficient form of its substance, or the second cause, which is without a medium, employs in its operations. So the loadstone attracts iron not without a physical cause, and for the sake of some good." But nothing like this is done in other bodies by any substantial form unless it be the primary one, and this Puteanus does not recognize. Naught but good is assuredly held out (*sed bonum sane*) to the loadstone, to be got from the appulsion of the iron (a sort of friendly association), yet the temperament of which he speaks is not to be found, cannot even be imagined as something that is to be the instrument of the form. For of what use can temperament be in magnetic movements that are calculable, definite, constant, comparable to the movements of the stars; at great distance, with thick, dense bodies interposed. In Baptista Porta's opinion, the loadstone seems to be a mixture of stone and iron, i.e., ferruginous stone, or stony iron. "The stone," he says,[1] "is not changed into iron so as to lose its own nature, nor is the iron so merged in the stone but that it retains its own essence; and while each strives to overcome each, from the struggle results attraction of the iron. In the mass (of the loadstone) there is more stone than iron; therefore the iron, lest it should be dependent on (subdued by) the stone, craves the strength and company of iron, to the end that what it cannot procure of itself it may obtain by the help of the other. . . . The loadstone does not attract stones because it

[1] "Natural Magick," 1658, Book VII, Chap. II.

has no need of them, there being stone enough in its mass; and if one loadstone attracts another that is not for the sake of the stone, but of the iron shut up in the stone." As though the iron in a loadstone were a distinct body and not one blended with another, like all other metals in their ores. And it is height of absurdity to speak of these substances, thus confounded together, as warring with each other and quarreling, and calling out from the battle for forces to come to their aid. Now, iron itself when touched with loadstone seizes iron with not less force than loadstone itself. These fights, seditions, conspiracies, in a stone, as though it were nursing quarrels as an occasion for calling in auxiliary forces, are the maunderings of a babbling hag, rather than the devices of an accomplished prestigiator. Others have thought that the cause is a sympathy. But even were fellow-feeling there, even so, fellow-feeling is not a cause; for no passion can rightly be said to be an efficient cause. Others again assign as the cause likeness of substance, and still others postulate rods (*radii*) imperceptible to the senses. These, in very many ways, make a sad misuse of a term first employed by mathematicians. In more scholarly fashion, Scaliger declares that iron moves to the loadstone as to its mother's womb, there to be perfected with recondite principles, as the earth tends to the centre. The godlike Thomas,[1] in Book 7 of his *Physica*, treating of the

[1] Thomas Aquinas, famous schoolman of the middle ages, also called the Angelic Doctor, and considered by many the greatest of Christian philosophers, was well worthy the profound respect and high admiration in which he was held by our author. His chief work, the *Summa Theologiæ*, to which he devoted the last nine years of his life, has been called the supreme monument of the thirteenth century. One of his biographers remarks that those wishing to thoroughly comprehend the peculiar character of metaphysical thought in the middle ages should study Aquinas, in whose writings it is seen with the greatest consistency. Aquinas died in 1274, and was canonized forty-nine years later by Pope John XXII.

causes of motion, says: "A thing can in another sense be said to pull, in that it moves (an object) toward itself, by altering it in any way, by which alteration it comes about that the body altered moves with respect to place; and in this way is the loadstone said to draw iron: for as a generant moves heavy things and light in so far as it gives them the form whereby they are moved to a place; so does the loadstone give to iron some quality through which it is moved to the loadstone." This view, one by no means ill-conceived, this most learned man, proceeds later briefly to corroborate, citing incredible accounts of the loadstone and of the power of garlic over the loadstone. Nor is what Cardinal de Cusa states to be disregarded. Says he: "Iron hath in the loadstone a certain principle of its efflux, and while the loadstone by its presence excites the heavy and ponderous iron, the iron is, by a wonderful longing, raised above the natural motion (whereby it ought to tend downward according to its weight), and moves upward, uniting in its principle. For were there not in iron some natural foretaste of the loadstone, it would no more move toward that than toward any other stone; and were there not in the loadstone a stronger inclination toward iron than toward copper, that attraction would not exist." Such, as propounded by different writers, are current opinions about the attraction of the loadstone, all of them full of doubt and uncertainty. As for the causes of magnetic movements, referred to in the schools of philosophers to the four elements and to prime qualities, these we leave for roaches and moths to prey upon.

CHAPTER IV.

OF THE STRENGTH OF A LOADSTONE AND ITS FORM: THE CAUSE OF COITION.

QUITTING the opinions of others about the attraction of the loadstone, we will now show the reason of its coition and the nature of its motion. There are two kinds of bodies that are seen to attract bodies by motions perceptible to our senses—electric bodies, and magnetic. Electrical bodies do this by means of natural effluvia from humor; magnetic bodies by formal efficiencies or rather by primary native strength (*vigor*). This form is unique and peculiar: it is not what the Peripatetics call *causa formalis* and *causa specifica in mixtis* and *secunda forma;* nor is it *causa propagatrix generantium corporum;* but it is the form of the prime and principal globes; and it is of the homogeneous and not altered parts thereof, the proper entity and existence which we may call the primary, radical, and astral form;[1] not Aristotle's prime form, but that unique form which keeps and orders its own globe. Such form is in each globe—the sun, the moon, the stars—one; in earth also 'tis one, and it is that true magnetic potency which we call the primary energy. Hence the magnetic nature is proper to the earth and is implanted in all its real parts according to a primal and admirable proportion. It is not derived from the heavens as a whole, neither is it generated thereby through sympathy, or influence, or other occult qualities: neither is it derived from any special star; for there is in the earth a magnetic strength or energy (*vigor*) of its own,

[1] Whewell, "Hist. of Ind. Sciences," 1859, Vol. II, Chap. II, page 220.

as sun and moon have each its own *forma;* and a little fragment of the moon arranges itself, in accordance with lunar laws (*lunatice*), so as to conform to the moon's contour and form, or a fragment of the sun to the contour and form of the sun, just as a loadstone does to the earth or to another loadstone, tending naturally toward it and soliciting it. Thus we have to treat of the earth, which is a magnetic body, a loadstone; then, too, of its true, native parts, which are magnetic, and of how they are affected by coition.

A body that is attracted by a magnetic body is not by it altered, but remains unimpaired and unchanged as it was before, neither has it now greater virtue. A loadstone draws magnetic bodies, and they from its energy eagerly draw forces not in their extremities only, but in their inmost parts. For an iron rod held in the hand is magnetized in the end where it is grasped, and the magnetic force travels to the other extremity, not along the surface only, but through the inside, through the middle. Electrical bodies have material, corporeal effluvia. Is any magnetic effluvium emitted, corporeal or incorporeal? Or is nothing at all that subsists emitted? But if the effluvium is a body, it must needs be light and spiritual so as to enter the iron. Is it such as is exhaled from lead when quicksilver, which is liquid and fluid, is by the mere odor and vapor of lead solidified, and remains as a strongly coherent metal? Gold, too, which is very solid and dense, is reduced to a powder by the thin vapor of lead. Can it be that as quicksilver can enter gold, so the magnetic odor can enter the substance of iron, changing it by its substantial property, though in the bodies themselves there is no change perceptible by our senses? For without such entering a body is not changed by another body, as the chemists, not without reason, do teach. But if these effects were produced by a material entrance, then were resistant, dense bodies interposed between such bodies; or were the magnetic bodies shut up in the middle of very thick, dense bodies, objects of iron would not be acted on by the loadstone. Nevertheless, these two do strive to come together and are changed. Therefore the magnetic forces have no such conception, no such origin, as this: nor are they due to those most minute particles of loadstone imagined by Baptista Porta concentrated as it were into hairs, and springing from friction of the loadstone, which parts fastening on to the iron give it the magnetic powers. For the electric effluvia, as they are hindered by the interposition of any dense body, so too are unable to attract through a flame, or if a flame be near by. But iron, which is hindered by no obstacle (from) deriving from the loadstone force and motion, passes through the midst of a flame to join the loadstone. Take a short piece of iron wire, and when you have* brought it near to a loadstone it will make its way through the flames to the stone; and a needle turns no less rapidly, no less eagerly, to the loadstone though a flame intervenes than if only air stands between. Hence a flame interposed does not prevent coition. But were the iron itself red-hot, it certainly would not be attracted. Apply a red-hot iron rod to a* magnetized needle and the needle stands still, not turning to the iron; but as soon as the temperature has fallen somewhat it at once turns to it. A piece of iron that has been magnetized, if placed in a hot fire until it becomes red-hot, and per-* mitted to remain for a little while, loses the magnetic power.[1]

[1] "For if a Load-stone be made red hot, it loseth the magnetical vigour it had before in itself, and acquires another from the Earth in its refrigeration; for that part which cooleth toward the Earth will acquire the respect of the North, and attract the Southern point or cuspis of the Needle" (Thomas Brown, *Pseudoloxia Epidemica*, 1658, page 65). Kenelm Digby, "The Nature of Bodies," 1645, Chapter XXI, pages 232–233.

Even loadstone itself loses its native and inborn powers of attracting, and all other magnetic properties, if left long in fire. And though some magnetic ores when roasted exhale a deep-blue or sulphurous and foul-smelling vapor, nevertheless such vapor is not the soul of the loadstone; neither is it the cause of the attraction of iron, as Porta supposes.[1] Nor do all loadstones when roasted or burned smell of sulphur or give out sulphur fumes: that property is something added, a sort of congenital evil which comes from the foul bed or matrix in which the loadstone is produced; nor does the material corporeal cause introduce into the iron anything of the same sort, for iron derives from loadstone the power of attracting and the property of verticity, though glass or gold or another sort of stone stand between, as later, when treating of the magnetic direction, we shall clearly prove. But fire destroys in the loadstone the magnetic qualities, not because it plucks out of it any particular attractional particles, but because the quick, penetrating force of the flame deforms it by breaking its matter up; just as in the human body the soul's primary powers are not burnt, though yet the burnt body remains without faculties. But though the iron remains after perfect ignition, and is not converted into either ash or slag; still, as Cardan not injudiciously remarks, red-hot iron is not iron, but something lying outside its own nature, until it returns to itself. For just as, by the cold of the ambient air, water is changed from its own nature into ice, so iron made white-hot by fire has a confused, disordered form, and therefore is not attracted by a loadstone, and even loses its power of attracting, however acquired; it also acquires a different verticity when, as though born anew, it is impregnated by a loadstone

[1] Porta's "Natural Magick," 1658, Book VII, Chapter II.

or the earth; in other words, when its form, not utterly destroyed, yet confused, is restored. I shall have more to say on this subject when treating of changed verticity (Book III, Chap. 10). Hence, Fracastorio finds no confirmation of his opinion that the iron is not altered; "for," says he, "if it were altered by the loadstone's form, the form of the iron would be spoiled." Yet this alteration is not generation, but restitution and re-formation of a confused form.

Hence that is not corporeal which emanates from the loadstone, or which enters the iron, or which is given forth again by the awakened iron; but one loadstone gives portion to another loadstone by its primary form. And a loadstone recalls the cognate substance, iron, to formate energy and gives it position: hence does it leap to the loadstone and eagerly conforms thereto (the forces of both harmoniously working to bring them together); for the coition is not indeterminate and confused, it is not a violent inclination of body to body, not a mad chance confluence. Here no violence is offered to bodies, there are no strifes or discords; but here we have, as the condition of the world holding together, a concerted action,—to wit, an accordance of the perfect, homogeneous parts of the world's globes with the whole, a mutual agreement of the chief forces therein for soundness, continuity, position, direction, and unity. In view of this so wonderful effect, this stupendous innate energy,—an energy (strength) not existing in other elements,—the opinion of Thales the Milesian is, in Scaliger's judgment, not utterly absurd, not a lunatic's fancy. Thales ascribed to the loadstone a soul, for it is incited, directed, and moved in a circle by a force that is entire in the whole and entire in each part, as later will appear, and because it seems most nearly to resemble a soul. For the power of self-movement seems to betoken a soul, and the supernal bodies, which we call celestial, as it were divine, are by some regarded as animated because that they move with wondrous regularity. If two loadstones be set over against each other in their floats on the surface of water, they do not come together forthwith, but first they wheel round, or the smaller obeys the larger and takes a sort of circular motion; at length, when they are in their natural position they come together. In iron that has not been excited by the loadstone, there is no need of these preliminaries; for iron, though made from the finest loadstone, has no verticity save such as it gets by chance and momentarily; and this is not stable nor fixed, for while it ran liquid in the furnace its parts were thrown into confusion. Such a body instantly receives from the presence of the loadstone verticity and natural conformity to it, being powerfully altered and converted, and absolutely metamorphosed into a perfect magnet: so, like an actual part of the loadstone, it flies to it. For there is naught that the best loadstone can do which cannot be done by iron excited by a loadstone—not magnetized at all, but only placed in the neighborhood of a loadstone. For as soon as it comes within the loadstone's sphere of influence, though it be at some distance from the loadstone itself, the iron changes instantly, and has its form renewed, which before was dormant and inert, but now is quick and active: all this will appear clearly when we come to present the proofs of magnetic direction (in Book III). Thus the magnetic coition is the act of the loadstone and of the iron, not of one of them alone: it is *ἐντέλεχεια,* not *ἔργον;* it is *συνεντελέχεια* and *conactus* (mutual action) rather than sympathy. There is, properly speaking, no magnetic antipathy; for the flight and turning away of the poles and the wheeling around of the whole is the act of each of the two toward unition, resulting from the συνεντελέχεια and *conactus*[1] of both. Thus the iron puts on anew its form; and because that is awakened, as also in order more surely to gain its form, it rushes headlong on the loadstone, and not with circlings and wheelings, as in the case of two loadstones. For as, long ages ago, nay at the very beginning of things, there were gendered in the loadstone and therein fixed verticity and the power of coördinating; and since the great mastering form of the earthly globe cannot be readily changed by another magnet, as iron is changed, therefore, the nature of each being constant, neither hath the momentary power of altering the verticity of the other, but the two do but come to agreement with each other. And magnetized iron, in case it is unable for whatever reason to cause the piece of iron in the natural state to turn, as does the pointer of a versorium, is itself seized at either end by a loadstone brought nigh it. For the loadstone, as it imparts so can it alter verticity, and it can in an instant bestow the formal energy in either end. Thus iron may be transformed variously, as that form is adventitious and has not yet abided long in the metal. In iron, because its body is fused when a magnetic or a ferruginous ore is smelted, the virtue of the primal form, which previously existed distinct, is now confused; but a sound loadstone, when brought near, sets up again the primal action: the form, now arranged and ordered again, joins forces with the loadstone, and, each with other, the two come to agreement, after the manner of the loadstone, in all their movements toward union; they enter into alliance, and whether joined by bodily contact or standing within their sphere of influence, are one and the same. For when iron is reduced in the furnace from its ore, or when steel is got from its ore,

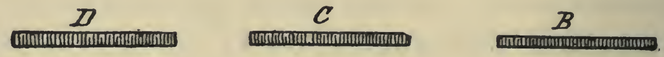
[1] *Conactus*, i.e., combined or mutual action. See Book V, Chapter XII.

which is loadstone, the metallic matter is melted and becomes fluid, and the iron and the steel run off, leaving their slag: this slag consists of matter spoilt by the intense heat of the fire, or of useless matter, or of dross, due to some imperfection or to some intermixture in the projecting surface of the earth. Thus the iron or steel is a purified material, wherein the metallic element, all disordered by the smelting (for the forces of that primal form are all confused and unsettled), is brought back again, as it were, to life, to normal form, and to completeness. Its matter is thus awakened, and tends to union, which is the bond of the universe and the necessary condition of the conservation of all things.

For this reason, and because of the purging of the ore and its change into a purer body, the loadstone gives to iron greater power of attracting than exists in itself. For if you put some iron-filings or a nail on a large magnet, a piece of iron joined to the magnet steals the filings and the nail, and holds them as long as it remains alongside the magnet: so, too, iron attracts iron more powerfully than does a loadstone, if the iron be afformed, and remain within the sphere of the form given out to it. Again, a piece of iron nicely adjusted to the pole of a loadstone holds a greater weight than the loadstone does. So, then, iron and steel are the better elements of their ores, purified by the action of fire, and the loadstone impregnates them again with their forms; wherefore to it do they come by spontaneous approach, so soon as they enter the circle of the magnetic forces, for by it are they first possessed, and made continuous, and united with perfect union. Once within that circle they have absolute continuity, and they are joined by reason of their accordance, albeit the bodies themselves be separated. For the iron is not, after the manner of electrics, possessed and pulled by substantial effluvia, but only by the immaterial act of the form or by its incorporeal going forth, which as in a continuous and homogeneous body doth act in the iron *subjectum*, and is received into it; nor has it need of wider paths.

Hence it is that, with the densest bodies interposed, the iron is put in motion throughout and is attracted, and that the iron, in presence of the loadstone thoroughly stirs and attracts the loadstone itself, and that with their mutual forces they make that rush toward union which commonly is called attraction. But these formal forces sally forth and in meeting unite; and the force conceived in the iron, that also forthwith has its efflux. But Julius Scaliger, who, in his 344th disquisition, cites other examples to prove this explanation to be absurd, is far astray. For the virtues of prime bodies are not comparable with those that are derivate and mixed. Were he still among the living, he might now, in the chapter on Effused Magnetic Spherical Forms, discover what is the nature of effused forms.

But if iron be badly injured by rust it is but little or not at all affected by the loadstone, for when the metal is corroded and marred by external causes or by decay it is spoilt, as has been said of the loadstone, and loses its prime qualities that are conjoined to its form, or, the stone being impaired by age, these qualities are weak and feeble; neither can it be duly informed when once it has suffered decay. But a strong, fresh (*vegetus*) loadstone pulls all sound clean iron, and the iron (having conceived force) powerfully attracts other iron—as pieces of iron wire, iron nails; and not only these separately and directly, but one after another, one at the end of another, thus holding three, four, or five: thus forming as it were a chain, the successive nails sticking to one another and suspended from one another. But the loadstone would not attract the last piece in such a line if there were no nails in the mid-space. Thus a loadstone placed at *A* pulls the nail or bar *B*, and, in like manner, after *B* pulls *C*, and after *C*, *D*; but at the same distance does not pull aloft *D*: that is so for

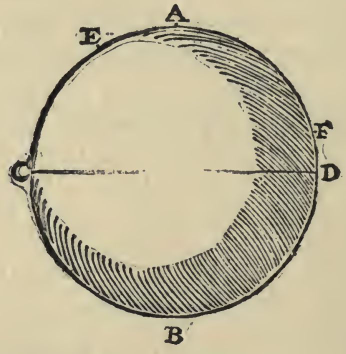


the reason that when the nails form an unbroken line the presence of the loadstone *A*, because of its proper forces, raises the magnetic form of the iron objects *B* and *C*, and makes them as it were its auxiliary forces, while *B* and *C*, like a continuous magnetic body, conduct on to *D* the force whereby it is seized or conformed, yet not so powerfully as *C* is seized by *B*. And these iron nails derive the force from the mere contact, and from the presence of the loadstone without contact, and they retain it in their bodies, as will be shown when we treat of Direction (Book III). For the iron does not assume these powers only while in presence of a loadstone, nor does it hold them of the stone only momentarily as [the distinguished orator "Euphrades"] Themistius [of Paphlagonia] supposes in his *Physica*, VIII. The best iron (steel) is solicited by the loadstone from a greater distance, a greater weight of it is lifted, it is more powerfully held, and it acquires greater force, than does common, cheaper iron, for it is made of the best ore or of loadstone, and is imbued with superior forces; but iron from impure ores is weaker, and is attracted more feebly. As for what Fracastorio writes, of having seen a bit of loadstone that on one side attracted loadstone but not iron, on another side attracted iron but not loadstone, and on another attracted both,—proof, according to him, that in one spot there was more loadstone, in another more iron, in the third the two were present equally; hence the difference in the attraction,—all this is utterly erroneous, and the result of mal-observation on the part of Fracastorio, who did not know how to present one loadstone to another properly. Loadstone attracts iron and loadstone if both be properly situated, and free to move and unrestrained. A light object is more readily moved from its position and place than a heavy one, for heavy objects make greater resistance, but a light object bestirs itself to meet a heavy one and is pulled by it.

CHAPTER V.

IN WHAT MANNER THE ENERGY INHERES IN THE LOADSTONE.

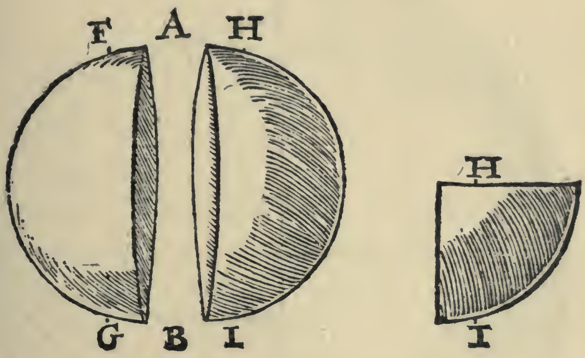
THAT the loadstone draws loadstone, iron, and other magnetic bodies was shown in Book I, as also by what forces the magnetic coition is regulated; we have now to inquire how this energy is ordered in magnetic bodies. Here we must bring in the analogy of a large loadstone. A magnetic body unites forcibly with a loadstone if the loadstone is powerful,—feebly if it be defective or if it has from any fault become im paired. Loadstone does not attract iron with equal force at every point; in other words, the magnetic body does not tend with the same force to every point of the loadstone; for the loadstone has points (i.e., true poles) at which its rare energy is most conspicuous. And the regions nearest the poles are the stronger, those remotest are the weaker; yet in all the energy is in some sense equal. In the figure of a terrella, *A*, *B*, are the poles, *CD* is the equinoctial line; the greatest attractive force is seen at *A* and *B*. At *C* and *D* there is no force that attracts to the body the ends of magnetic objects, for the forces tend toward each of the poles. But the directiv force at the equator is strong. *C* and *D* are at equal distance from both poles; hence a piece of iron on the line *CD*, bein



pulled in contrary directions, does not cling steadily, but i stays and adheres to the stone only when it falls to either sid of the line. At *E* the attractive force is greater that at *F*, fo *E* is nigher the pole. And this is not for the reason that ther is more energy resident at the pole, but because all the parts being united in the whole, direct their forces to the pole.

By the confluence of the forces from the plane of th equinoctial toward the pole the energy increases poleward * and absolute verticity is seen at the pole so long as the load stone remains whole; but let it be divided or broken up, anc in the separate parts the verticity will find other abiding places. For with change of mass always goes change of ver ticity. Hence, if the terrella be severed along the line *AB* sc as to make two stones, the poles in the severed parts will no be *AB*, but *FG* and *HI*. And though these two stones nov are so interrelated that *F* does not tend to *H*, nevertheless if before division, *A* was the north pole, *F* likewise is now north as is *H* also. For the verticity is not reversed, as Baptist

Porta erroneously affirms (Porta, VII, 4);[1] for though *F* and *H* are not so related as mutually to attract, yet the two turn to the same point of the horizon. If the hemisphere *HI* be cut in two quarter spheres, one pole will be at *H* and the other at *I*. The integral mass of the stone, as I have said,



gives to the vertex or pole a constant place; and any part of the stone, before it was hewed out of the rock might have been the pole or vertex: but of this we shall have more to say under Direction. For the present, the thing to be understood and to be borne steadily in mind is, that the poles are dominant in virtue of the force of the whole, for (the magnetic empire being divided in two by the equinoctial line) all the

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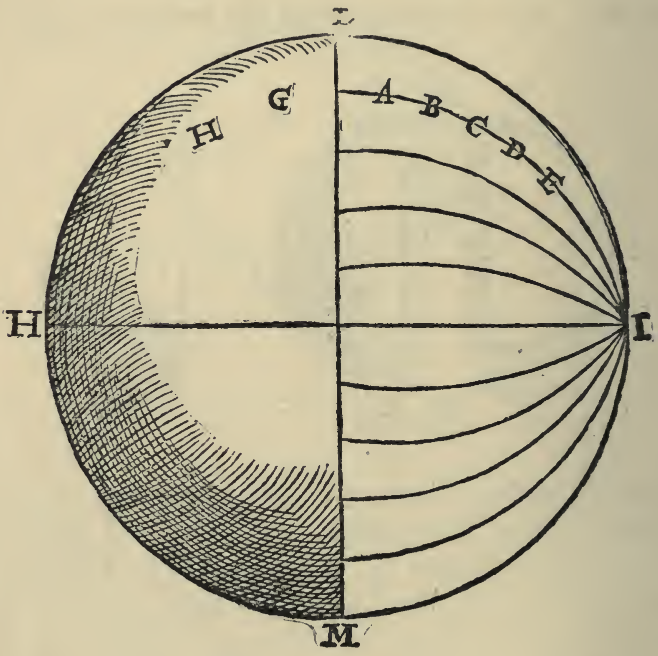
[1] John Baptist Porta, "Natural Magick," 1658, Book VII, Chapter IV, page 193: "But the two points we speak of are the end of the right line, running through the middle of the stone from North to south; if any man break the stone, and break this line, those ends of the division will presently be of another property and vertue, and will be enemies one to the other: which is great wonder: for these two points, when they were joined together, had the same force of turning to the pole, but, now being parted asunder, one will turn to the North, the other to the South, keeping the same posture and position they had in the Mine where they were bred: and the same happens in the least bits that are seen in the greatest load-stone."

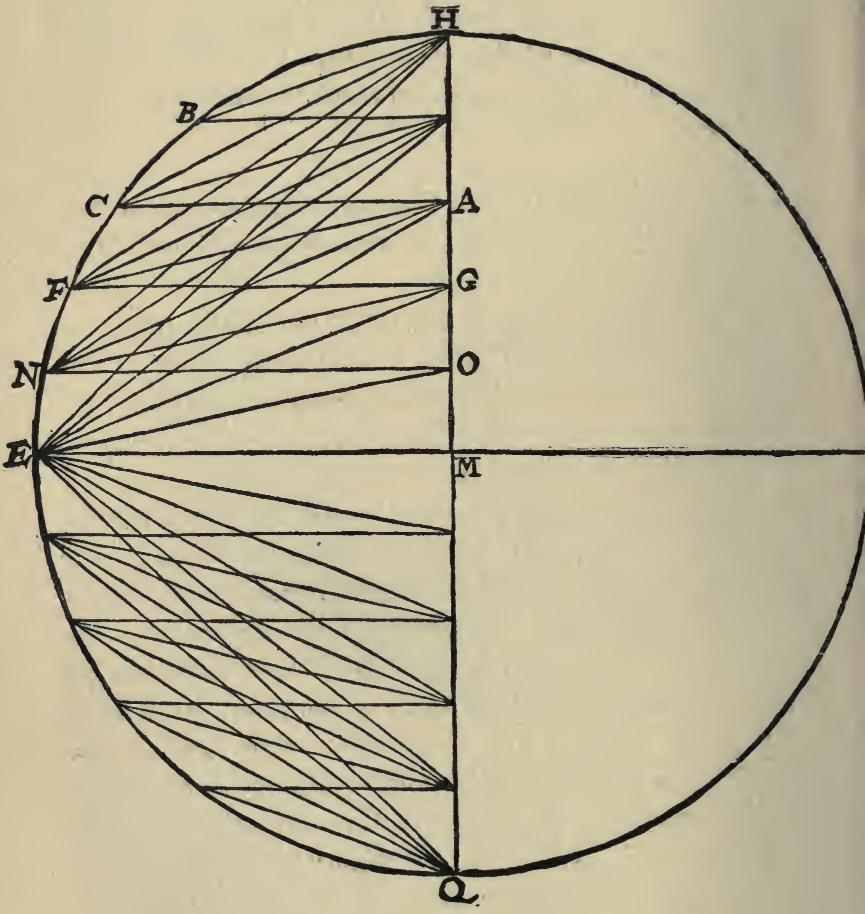
forces of the hemisphere tend north, and, conversely, all those of the other hemisphere tend south, so long as the parts are united, as appears from the following demonstration. For



the whole force tends separately to the two poles along an infinity of curves starting from every point of the equator that divides the sphere into two equal parts: from every point of the superficies from the equator to the north on one side and from the equator to the south on the other. Hence the verticity is, in each hemisphere, from the equinoctial circle to the pole. This force resides in the whole mass. From *A* the energy is transmitted to *B*, from *AB* to *C*, from *ABC* to *D* and from them to *E*, and likewise from *G* to *H*; and so on as long as the whole mass is one body. But if the piece *AB* be cut out, though it be near the equator, nevertheless the effect will be as great on the magnetic action as if *CD* or *DE*, equal quantities, had been taken away. For no part has any super-eminent value in the whole; whatever it be, that it is because of the parts adjoining, whereby an absolute and perfect whole is produced.

DIAGRAM OF THE MAGNETIC ENERGY DIFFUSED FROM THE PLANE OF THE EQUATOR TO THE PERIPHERY OF A TERRELLA OR OF THE EARTH.

Let *HEQ* be a terrella, *E* a pole, *M* the centre, *HMQ* the plane of the equinoctial circle. From every point of the equinoctial plane the energy reaches out to the periphery, but differently from each: for from *A* the formal energy goes toward *CFNE* and to every point betwixt *C* and *E* (the pole), and not toward *B*; neither from *G* toward *C*. The attractive force in the region *FGH* is not strengthened by the force residing in the region *GMFE*; but *FGH* increases the energy in the rising curve *FE*. Thus energy never proceeds from the lines parallel to the axis to points above those parallels, but always internally from the parallels to the pole. From every point of the plane of the equator the energy goes to the pole *E*; the point *F* derives its forces only from *GH*, and the point *N* from *OH*; but the pole *E* is strengthened by the whole plane *HO*. Therefore this mighty power has here its chief excellency; here is its throne, so to speak. But in the intervals at *F*, for example, there resides so much attractional energy as can be given by the section *HG* of the plane.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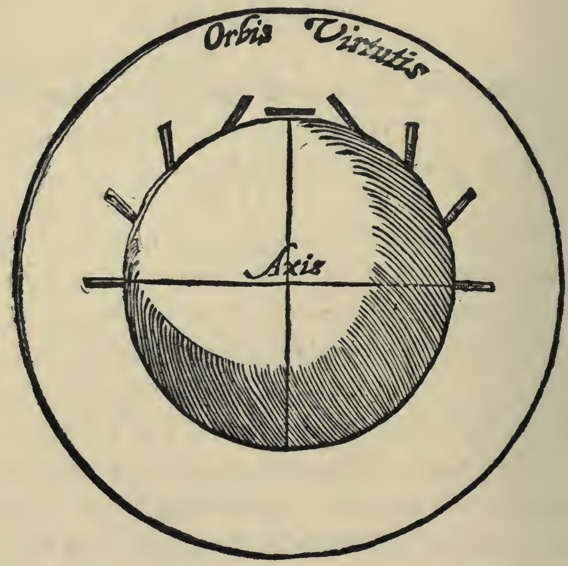
CHAPTER VI.

HOW MAGNETIZED IRON AND SMALLER LOADSTONES CONFORM TO THE TERRELLA AND TO THE EARTH ITSELF, AND ARE GOVERNED THEREBY.

COITION of bodies that are separate from one another, and that cohere naturally, takes place by another sort of movement, if they be free to move. The terrella sends its force abroad in all directions, according to its energy and its quality. But whenever iron or other magnetic body of suitable size happens within its sphere of influence it is attracted; yet the nearer it is to the loadstone the greater the force with which it is borne toward it. Such bodies tend to the loadstone not * as toward a centre nor towards its centre: that they do only at its poles, i.e., when that which is attracted and the pole of the loadstone, as well as its centre, are in a right line. But in the intervals between they tend to it in an oblique line, as seen in the figure below, wherein is shown how the force goes out to the magnetic associate bodies within the sphere. At the poles the line is a right one. The nearer the parts to the equinoctial circle the more obliquely do magnetic bodies attract, but the parts nearer the poles attract more directly; at the poles themselves attraction is in a right line. All loadstones alike, whether spherical or oblong, have the self-same mode of turning to the poles of the world; but it is easiest to experiment with oblong ones. For whatever the shape, verticity is present, and there are poles; but owing to imperfect and irregular shape, loadstones are often subject to drawbacks, and are interfered with in their movements. If the loadstone be oblong, with vertices at the extremities and not at the



sides, it attracts best at the vertex; for the parts convey to the poles a greater force in right lines than in oblique. Thus do the loadstone and the earth conform magnetic movements.

CHAPTER VII.

OF THE POTENCY OF THE MAGNETIC FORCE, AND OF ITS SPHERICAL EXTENSION.[1]

THE magnetic force is given out in all directions around the body; around the terrella it is given out spherically; around loadstones of other shapes unevenly and less regularly. But the sphere of influence does not persist, nor is the force that is diffused through the air permanent or essential; the loadstone simply excites magnetic bodies situate at convenient distance. And as light—so opticians tell us—arrives instantly in the same way, with far greater instantaneousness, the magnetic energy is present within the limits of its forces; and because its act is far more subtile than light, and it does not accord with non-magnetic bodies, it has no relations with air, water, or other non-magnetic body; neither does it act on magnetic bodies by means of forces that rush upon them with any motion whatever, but being present solicits bodies that are in amicable relations to itself. And as a light impinges on whatever confronts it, so does the loadstone impinge upon a magnetic body and excites it. And as light does not remain in the atmosphere above the vapors and effluvia nor is reflected back by those spaces, so the magnetic ray is caught neither in air nor in water. The forms of things are in an instant taken in by the eye or by glasses; so does the magnetic force seize magnetic bodies. In the absence of light

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[1] Sir Kenelm Digby, "A Treatise of Bodies," London 1645, Chap. XXI, pages 238, 239.

bodies and reflecting bodies, the forms of objects are neither apprehended nor reflected; so, too, in the absence of magnetic objects neither is the magnetic force imbibed nor is it again given back to the magnetic body. But herein does the magnetic energy surpass light,—that it is not hindered by any dense or opaque body, but goes out freely and diffuses its force every whither. In the case of the terrella and in a spherical loadstone the magnetic energy extends outside the body in a circle; yet in the case of an oblong loadstone it does not extend out in a circle, but into an area of form determined by the shape of the stone, as in the stone *A*, in the figure, the energy reaches to the limits *FCD*, everywhere equidistant from the stone *A*.

CHAPTER VIII.

OF THE GEOGRAPHY OF THE EARTH AND THE TERRELLA.

WE have next to speak of magnetic circles and magnetic limits, so that what follows later may be better understood. Astronomers, in order to account for and observe the movements of the planets and the revolution of the heavens, as also more accurately to describe the heavenly order of the fixed stars, have drawn in the heavens certain circles and bounds, which geographers also imitate so as to map out the diversified superficies of the globe and to delineate the fairness of the several regions. In a different sense we accept those bounds and circles, for we have discovered many such, both in the terrella and in the earth; but these are determined by nature itself, and are not merely imaginary lines. Geographers make a division of the earth chiefly by defining the equator and the poles; and these bounds are set and defined by nature. Meridians, too, indicate tracks from pole to pole, passing through fixed points in the equator; along such lines the magnetic force proceeds and gives direction. But the tropics and the arctic circles, as also the parallels of latitude, are not natural bounds described on the earth; yet all these parallel circles indicate that a certain conformity between themselves exists among regions of the earth situate in the same latitude or diametrically opposite to them. All these are of service to mathematicians in constructing globes and maps. Thus such circles are of use in the terrella, but they need not be drawn as geographers draw them—on the surface, for the loadstone may be perfectly even and uniform all over. Nor are there any "upper" or "lower" parts, in the terrestrial globe, as there are also none in the terrella, save perhaps that one may choose to call these parts "upper" which are at the periphery and those "lower" which are nigher the centre.

CHAPTER IX.

OF THE EQUINOCTIAL CIRCLE OF EARTH AND TERRELLA.

THE equinoctial circle imagined by astronomers, which is equidistant from both poles and divides the earth in the middle, measures the movements of their *primum mobile* or tenth sphere,[1] and is called the zone of the *primum mobile;* it is called "equinoctial" because when the sun is in this circle—which must happen twice a year—the days are of equal length with the nights. This circle is designated also *æquidialis;* hence the Greeks give it the name ἰσημερινὸς (which means the same, "equal day"). And it is also well called "equator," for it divides the whole globe of the earth from pole to pole in two equal parts. To the terrella also is justly assigned an equator whereby its power is distributed between two parts. By the plane of this equator, as it passes through the centre, the whole terrella is divided into two parts equal in mass and in verticity, and imbued with equal energy, as though a wall stood betwixt the two verticities.

CHAPTER X.

THE EARTH'S MAGNETIC MERIDIANS.

GEOGRAPHERS have devised meridians for the purpose of distinguishing the longitude and latitude of regions. But the

[1] For *primum mobile*, see Book VI, Chapter III.

magnetic meridians are numberless, and, even as the earth's meridians, they pass through fixed and opposite points in the equator and through the poles. On them also is magnetic latitude measured. By means of them we understand declinations; and along them there is a fixed direction toward the poles, except when the magnetic body for any cause varies, and is jostled out of the right course. The meridian commonly called magnetic is not properly magnetic, neither is it a meridian, but is supposed to pass through the limits of variation in the horizon. Variation is in fact a faulty deviation from the meridian in various places it is not fixed or constant in any meridian.[1]

CHAPTER XI.

PARALLELS.

In parallel circles the same energy and equal potency is seen throughout, when different magnetic bodies are placed on one and the same parallel, either of the earth or of the terrella. For the bodies are at equal distances from the poles and have equal changes of declination, and are attracted and held and come together under the action of like forces; just as regions of the earth on the same parallel, though they may differ in longitude, are said to have still the same quantity of daylight and the same climate.

[1] Nicolao Cabeo, *Philosophia Magnetica*, 1629, Lib. III, Cap. VI, page 211.

CHAPTER XII.

THE MAGNETIC HORIZON.

An horizon is a great circle separating the things seen from those that are out of sight, as one half of the heavens is always plainly visible while another half is always hid. So it seems to us by reason of the great distance of the starry sphere; yet the difference is in the ratio of the earth's semi-diameter to the semi-diameter of the starry heavens—a difference not perceived by the senses. But we take the magnetic horizon to be a plane perfectly level throughout, tangent to the earth or to the terrella at the place of the region, with which plane the semi-diameter, whether of the earth or of the terrella, being extended, makes right angles on all sides. Such a plane is to be imagined for the earth, and for the terrella likewise, for the sake of magnetic proofs and demonstrations. For we are considering the bodies themselves, and not the general aspects of the world. Therefore, not with reference to sight—for that varies according to the elevation of regions—we assume in magnetic demonstrations a sensible horizon, not what is called by astronomers the rational horizon.

CHAPTER XIII.

OF THE MAGNETIC AXIS AND POLES.

A line drawn through the centre of the earth (or of the terrella) to the poles is called the axis. The poles are so called by the Greeks (*πόλοι, ἀπὸ τον πολεῖν—poloi* from *polein*, to revolve), and by the Latins *cardines* (hinges, pivots) and *vertices* (centres of a whirling motion); and these names were given to signify that the world rotates and is ever whirling. We propose to show that the earth and the terrella are by the magnetic force made to revolve round these poles, whereof that one in the earth which points to Cynosura[1] is called the North, the Boreal, or the Arctic pole; the opposite one is called the South, Austral, or Antarctic pole. And neither in earth nor in terrella do the poles exist merely for the sake of rotation; they are furthermore reference points of direction and of position (*consistendi*),—on the one hand towards one's destination on the earth, and on the other hand as regards their angular distance (*tum versus destinatas mundi regiones*).

CHAPTER XIV.

WHY THE COITION IS STRONGER AT THE POLE THAN IN THE PARTS BETWEEN EQUATOR AND POLE; AND THE RELATIVE POWER OF COITION IN DIFFERENT PARTS OF THE EARTH AND THE TERRELLA.

WE have already shown that the supreme attractional power is at the pole, while the weaker and more sluggish power is in the parts nigh the equator. And as in the declination it is seen that this ordering and rotating force increases as we advance from the equator to the poles, so too does the coition of magnetic bodies grow stronger by the same degrees

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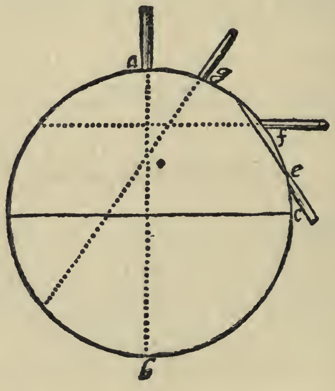
[1] Cynosura—Cynosure—the constellation of the Lesser Bear (*Ursa Minor*) containing the polar star.

and in the same proportion. For at points remote from the pole the loadstone does not pull magnetic bodies in a right line toward its centre, but they tend to it obliquely, and obliquely are attracted. For as a very small chord of a circle differs from the diameter, by so much do differ the attractional powers of different parts of the terrella. For inasmuch as the attraction is a coition to a body, and magnetic bodies come together owing to their natural tendency to turn to each other, in the diameter drawn from pole to pole a body impinges on the loadstone in a right line; but not so in other parts. Therefore the less it turns toward the body, the less and the more weak is the coition and the cohesion. Let *ab* be the poles. An



iron bar or the other magnetic body *c* is attracted at *e*; yet the end that is pulled does not tend toward the centre of the loadstone, but obliquely toward the pole, and a chord drawn from that end obliquely in the direction in which the body is attracted is a short one; the strength of the coition therefore is less, and so too the attracted object turns at a less angle to the terrella. But as from a body at *f* a longer chord proceeds, so the action there is stronger. At *g* the chord is still longer. At *a* (the pole) it is longest of all (for the diameter is the longest line), and thither do all the parts send their forces: there stands, as it were, the citadel, the judgment-seat, of the whole region,—not that the pole holds this eminence in its own right, but because it is the depository of forces contributed to it by all the other parts; it is like soldiers bringing reinforcement to their commander. Hence a rather oblong loadstone attracts better than a spherical one, if its length stretch from pole to pole, and yet the two may be from the same mine, and be of equal size and volume. The way is longer from one pole to the other in the oblong stone, and the force supplied by the other parts are not so scattered as in a spherical loadstone and the terrella; they are better massed and united, and thus united they are stronger and greater. But a flat or oblong loadstone is much less effective when the length is in the direction of the parallels, and the pole ends neither in a point nor in a circle or sphere, but lies flat on a plane surface so as to be held for something abject and of no account, for its unfit and unadaptable form.

CHAPTER XV.

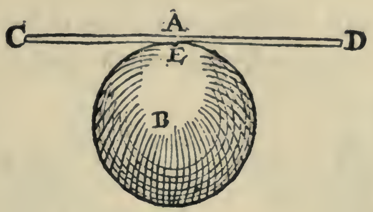
THE MAGNETIC FORCE IMPARTED TO IRON IS MORE APPARENT IN AN IRON ROD THAN IN AN IRON SPHERE OR CUBE, OR IRON OF ANY OTHER SHAPE.

It has been already said that an oblong loadstone lifts a greater weight of iron: so in a long piece of iron rubbed with a loadstone the magnetic force is stronger if the poles are at the ends; for the magnetic forces, which are sent to both ends from the poles, are concentrated at the narrow terminals, and not diffused. In square and other angular figures the force is scattered, nor does it proceed in right lines or along suitable arcs. The iron sphere, too, though it hath the figure of the earth, still has less attraction for magnetic bodies for the same reason; hence an excited iron spherule acts with less force on iron than does a magnetized bar of the same weight.

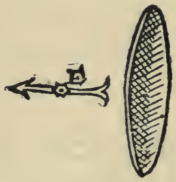
CHAPTER XVI.

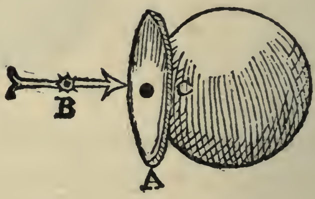
THAT MOTION IS PRODUCED BY THE MAGNETIC FORCE THROUGH SOLID BODIES INTERPOSED: OF THE INTERPOSITION OF A PLATE OF IRON.

An iron wire passed through a suitable piece of cork, or a needle poised on a point or in a mariner's compass, is set in motion when a loadstone is brought near it or is passed beneath it, though the water, the vessel, or compass-box stand between. No hindrance is offered by thick boards, or by walls of pottery or marble, or even of metals: there is naught so solid as to do away with this force or to check it, save a plate of iron. Whatever substances are interposed, however dense they be, as they do not annul the force nor obstruct its path, so do they in no wise hinder or lessen or retard. Nor is the whole of the force suppressed by a plate of iron, but in part diverted. For when the force enters the middle of an iron plate placed within the sphere of magnetic influence or directly over the pole of the loadstone, that force is distributed chiefly to the extremities, so that the rim of a circular plate of suitable size attracts pieces of iron wire at all points. The same is seen in a long iron rod rubbed with a loadstone in the mid-*

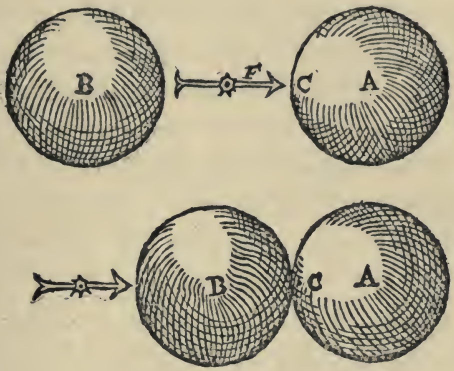


dle; it has the same verticity at both ends. In the figure, *CD* is a long rod magnetized in the middle by the north pole *E*; *C* is a south end or south pole, and *D* is another south end. But here note the singular fact, that a needle magnetized by that pole turns to that pole, though the round plate stands between, the plate not hindering, but the attraction being only* weaker; for the force is scattered to the extremities of the plate, and departs from the straight track, but yet the plate in its middle retains the same verticity with the pole when it is nigh it and alongside it: hence does the needle magnetized by the same pole tend to the centre of the plate. If the loadstone is a weak one, the needle hardly turns if an iron plate be interposed; for, being diffused out to the extremities of the plate, the loadstone's energy is less able to pass through the centre. But let the plate be magnetized in the middle by the pole, and* then let it be removed beyond the loadstone's sphere of influence, and you shall see the point of the same needle go in the contrary direction and quit the centre of the plate, which before it sought: for outside of the sphere of influence the plate has the contrary verticity, but near the loadstone it has the same; for near the loadstone the plate is as it were part of the loadstone and has the same pole. Let *A* be an iron plate near a pole; *B* a needle with point tending toward the centre of the plate, which plate has been magnetized by the pole *C* of a loadstone. Now if the same plate be placed outside the sphere of magnetic influence, the point of the needle will not turn to its centre, but only the crotch (the other end) of the





same needle. But an iron sphere interposed (if it be not too *large) attracts the point of the needle at the other side of the stone, for the verticity of that side is the same as that of the adjoining pole of the loadstone. And this turning of the needle's point (i.e., the end of it magnetized by contact with that pole) and of its cross (other end) at a considerable distance *takes place with an iron sphere interposed, whereas it would not take place at all were the space between vacant; for the magnetic force travels through bodies and is continued on by them. Let *A* be a terrella, *B* an iron sphere, *F* a needle between the two bodies, with its point magnetized by the pole *C*. In the second figure *A* is the terrella, *C* a pole, *B* an iron sphere: the needle tends toward *C*, the terrella's pole, through the iron sphere. The needle thus placed between terrella and sphere vibrates more forcibly toward the pole of the terrella, because the loadstone imparts instantaneous verticity to the opposite sphere. The earth's efficiency is the same, produced by the same cause. For if in a thick box made of gold (the densest of metals) or glass, or marble, you put a needle free to revolve, that needle, in spite of the box, will show that its forces are most closely allied to and unified with those of the earth; of its own accord and instantly, regardless of the box



that prisons it, it turns to its desiderated points of north and south. And it does the same though it be shut up in iron* vaults sufficiently roomy. Whatever bodies are produced here on the earth or are manufactured from nature's products by art, all consist of the matter of the globe: such bodies do not interfere with the prime potencies of nature derived from the primary form; nor can they withstand them, save by contrary forms. But no forms of mixed bodies are inimical to the innate primary form, though some of them oft do not accord among themselves. On the other hand, in all the bodies that have a material cause of attraction (e.g., amber, jet, sulphur) action is hindered by interposition of a body (as paper, leaves, glass, etc.), and the way is obstructed and blocked so that that which is exhaled cannot reach the light body that is to be attracted. But coition and movement of the earth and the loadstone, though corporeal hindrances be interposed, are shown also in the efficiencies of other chief bodies that possess the primary form. The moon, more than the rest of the heavenly bodies, is in accord with the inner parts of the earth because of her nearness and her likeness of form. The moon causes the movement of the waters and the tides of ocean ; makes the seashore to be covered and again exposed twice between the time she passes a given point of the heavens and reaches it again in the earth's daily rotation : this movement of the waters is produced and the seas rise and fall no less when the moon is below the horizon and in the nethermost heavens, than when she is high above the horizon. Thus the whole mass of the earth, when the moon is beneath the earth, does not prevent the action of the moon ; and thus in certain positions of the heavens, when the moon is beneath the horizon, the seas nearest to our countries are moved, and, being stirred by the lunar power (though not struck by rays nor illumined by light), they rise, approach with great impetus, and recede. Of the reason of this we will treat elsewhere : suffice it here just to have touched the threshold of the question. Hence, here on earth, naught can be held aloof from the magnetic control of the earth and the loadstone, and all magnetic bodies are brought into orderly array by the supreme terrene form, and loadstone and iron sympathize with loadstone though solid bodies stand between.[1]

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[1] In connection with the increased energy which magnets acquire by being armed, that is, fitted with a cap of polished iron at each pole, Dr. Whewell remarks, that it is only at a later period any notice was taken "of the distinction which exists between the magnetical properties of soft iron and of hard steel;—the latter being susceptible of being formed into *artificial magnets*, with permanent poles ; while soft iron is only *passively magnetic*, receiving a temporary polarity from the action of a magnet near it, but losing this property when the magnet is removed. About the middle of the last century various methods were devised of making artificial magnets, which exceeded in power all magnetic bodies previously known." ("Hist. of Ind. Sciences," 1859, Vol. II, page 220.)

CHAPTER XVII.

OF THE IRON HELMET (CAP) OF THE LOADSTONE, WHEREWITH IT IS ARMED AT THE POLE TO INCREASE ITS ENERGY; EFFICIENCY OF THE SAME.[1]

A CONCAVE hemisphere of thin iron, a finger's width in diameter, is applied to the convex polar superficies of a loadstone and properly fastened; or an iron acorn-shaped ball rising from the base into an obtuse cone, hollowed out a little and fitted to the surface of the stone, is made fast to the pole. The iron must be the best (steel), smooth, polished, and even. Fitted with this contrivance, a loadstone that before lifted only 4 ounces of iron will now lift 12 ounces. But the greatest force of the co-operating or rather unified matter is seen when two loadstones fitted with these projections are so joined * as mutually to attract and lift each other: thus may a weight of 20 ounces be lifted, though either stone unarmed would lift only 4 ounces. Iron is held faster by an armed loadstone than by one not armed, and hence it lifts greater weights, because iron clings more strongly to the armed stone: for, by the contiguous presence of the loadstone, the iron of the armature and the iron attracted are bound fast together; and when the armature has imbibed the magnetic energy by reason of the presence of the loadstone, and another piece of iron adjoining at the same time derives force from the presence of a loadstone, the two unite energetically. Hence when two powerful arma-

[1] Dr. J. Lamont's "Handbuch des Magnetismus," Leipzig 1867, page 53.

tures are in contact they cohere strongly. This is proved in Book III, Chap. IV, by iron rods cohering, as also where we mention the transformation of steel-filings into a concreted mass. For this reason iron situate near a loadstone takes away from it pieces of iron of suitable weight, provided only it be in contact with them; else, however near they may be, it does not match them. For masses of magnetic iron do not, within the field of a loadstone or near a loadstone, attract more strongly than the loadstone attracts any iron; but once they are in contact with each other they unite more strongly, and become as it were clamped together, though with the same forces at work the substance remains the same.[1]

CHAPTER XVIII.

AN ARMED LOADSTONE DOES NOT ENDOW WITH GREATER FORCE MAGNETIZED IRON THAN DOES AN UNARMED ONE.

TAKE two pieces of iron, one magnetized with an armed and the other with an unarmed loadstone, and apply to one of them a weight of iron proportioned to its powers: the other loadstone will lift the same weight, and no more. Two needles also turn with the same velocity and constancy toward the poles of the earth, though one needle may have been touched by an armed magnet and the other by one unarmed.

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[1] Sir Kenelm Digby, "The Nature of Bodies," 1645, Chap. XXII, page 243; Jacobi Rohaulti, *Physica*, Londini 1718, Par. III, Cap. VIII, p. 403, or the English translation by Dr. Clarke, London, 1728, Vol. II, page 181; Ath. Kircheri, *Magnes; sive de arte Magnetica*, 1643, Lib. I, Pars II, page 63; Nicolao Cabeo, *Philosophia Magnetica*, 1629, Lib. IV, Cap. XLII, page 407.

CHAPTER XIX.

THAT UNITION IS STRONGER WITH AN ARMED LOADSTONE; HEAVIER WEIGHTS ARE THUS LIFTED; THE COITION IS NOT STRONGER, BUT COMMONLY WEAKER.

THAT an armed loadstone lifts a greater weight is evident to all; but iron is drawn from the same distance, or rather from a greater distance, to the loadstone when the stone is without the iron helmet. This is to be tried with two pieces of iron of the same weight and form at * equal distance, or with one and the same needle, tested first with the armed then with the unarmed stone, at equal distances.

CHAPTER XX.

THAT AN ARMED MAGNET LIFTS ANOTHER, AND THAT ONE A THIRD: THIS HOLDS GOOD THOUGH THERE BE LESS ENERGY IN THE FIRST.

ARMED loadstones duly joined together cohere firmly and form one; and though the first be weak, the second nevertheless clings to it, not alone with the force of the first, but of the second, the stones thus helping each other: to the second a third will often cling, and with strong loadstones a fourth to the third.

CHAPTER XXI.

THAT WHEN PAPER OR OTHER MEDIUM IS INTERPOSED, AN ARMED LOADSTONE DOES NOT LIFT MORE THAN ONE UNARMED.

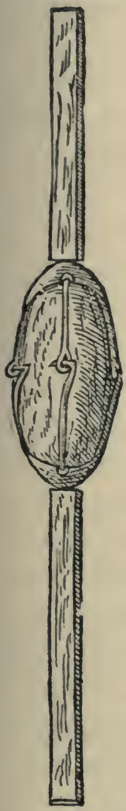
It has been shown above that an armed loadstone does not attract at a greater distance than an unarmed one, but that it lifts a greater quantity of iron, if it be in contact with the iron and continuous therewith. But put a leaf of paper between, and this intimate coherence is hindered, nor are objects of iron held together by the action of the loadstone.

CHAPTER XXII.

THAT AN ARMED LOADSTONE DOES NOT ATTRACT IRON MORE THAN AN UNARMED ONE; AND THAT THE ARMED STONE IS MORE STRONGLY UNITED TO THE IRON, IS SHOWN BY MEANS OF AN ARMED LOADSTONE AND A CYLINDER OF POLISHED IRON.

On a plane surface lay a cylinder too heavy for the unarmed loadstone to lift; then, with paper between, apply at the middle of the cylinder the pole of an armed loadstone: if the cylinder is pulled by the loadstone, it follows after it with rolling motion; but when there is no paper between, the cylinder, joined to the loadstone, is pulled by it, and does not roll at all. But if the same loadstone be unarmed, it pulls the rolling cylinder with the same velocity as does an armed loadstone with paper between, or wrapped in paper.

Armed loadstones of different weights, force, and shape, but * out of the same mine, show an equal degree of strength in adhering to or hanging from iron objects of suitable size and shape. The same is true of unarmed ones. A suitable piece of * iron applied to the under side of a loadstone that hangs from a magnetic body heightens the * energy of the loadstone, so that it clings with greater force. For a pendent loadstone clings faster to the body above, to which it is attached, when a piece of iron is applied and hangs from it, than when a piece of lead or other non-magnetic material is fastened to it.



A loadstone, whether armed or not, attached by its proper pole to the pole of another load- * stone, armed or not, makes that other lift a greater weight at its opposite end. The same thing is seen when iron is applied to the pole of a loadstone, viz., the opposite pole carries a greater weight of iron: thus, as in the figure, the loadstone with a bar of iron superposed carries the bar below, but cannot carry it if the upper piece be removed. Magnetic bodies in conjunction * form one magnetic body; hence, the mass increasing, the magnetic energy increases also.

An armed loadstone, as also an unarmed one, leaps more * quickly to a large mass of iron and combines with it more strongly than with a small mass.

CHAPTER XXIII.

THE MAGNETIC FORCE MAKES MOTION TOWARD UNION, AND WHEN UNITED CONNECTS FIRMLY.

MAGNETIZED objects cohere well and duly to one another according to their forces. Pieces of iron in the presence of a loadstone, though not in contact with it, come together, eagerly seek and seize one another, and when in conjunction are, as it were, glued together. Iron dust or iron reduced to a powder, packed in paper tubes, and placed on the meridian of a loadstone or merely brought near it, coalesces into one mass, and in an instant the many particles come together and combine; and the multitude of united grains acts on a piece of iron and attracts it, as though they formed but one continuous rod of iron, and take the north and south direction when laid on the loadstone. But if they be taken away from the stone to any distance, the particles, resolved again to their original condition, separate, and each stands alone: thus it is that the foundations of the earth are conjoined, connected, held together, magnetically. So let not Ptolemy of Alexandria, and his followers and our philosophers, maintain that the earth will go to pieces, neither let them be alarmed if the earth spins round in a circle.

Iron-filings when made hot are attracted by the loadstone not so strongly nor from as great a distance as if they were not heated. A loadstone subjected to any great heat loses some of its energy; for its humor is dissipated, and so its peculiar nature is marred. So, too, a mass of iron-filings, if roasted in a reverberatory furnace and changed to *Crocus Martis*, is not attracted by a loadstone;[1] but if it has not been very highly heated, not quite wasted, it clings to loadstone, though more feebly than iron that has not been put in fire. For *Crocus Martis* has nothing of the form of iron left; but metal that has been made hot takes heat from the fire, and in its vitiated substance the magnetic powers are less powerfully awakened by the loadstone, and iron that has quite lost its nature is not attracted by the loadstone.

CHAPTER XXIV.

THAT IRON WITHIN THE FIELD OF A LOADSTONE HANGS SUSPENDED IN AIR, IF ON ACCOUNT OF AN OBSTACLE IT CANNOT COME NEAR.

IRON within the magnetic field tends toward the points of the stone that have the most energy, if it be not hindered by

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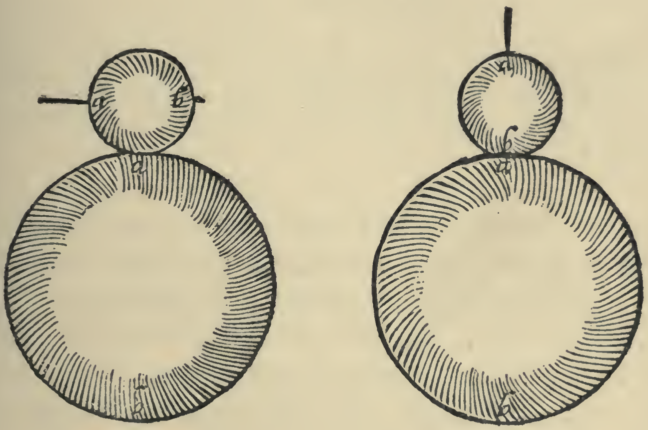
[1] Crocus Martis, or "Saffron of Mars," already mentioned, Book I, Chap. XV, was formed in ancient pharmacy by deflagrating iron filings with nitre and washing the residue. (Brande's "Manual of Chemistry," Vol. I, page 715.) Geber mentions oxide of copper under the name of *æs ustum*, the red oxide of iron under the name of *crocus* of iron. (Dr. Thomson, "Hist. of Chem.," Vol. I, page 130.) We read in Sir Thomas Brown's *Pseudoloxia Epidemica*, 1658, page 71: "It is likewise true what some have delivered of *Crocus Martis*, that is, steel corroded with vineger, sulphur, or otherwise, and after reverberated by fire. For the loadstone will not at all attract it, nor will it adhere, but lie therein like sand. This to be understood of *Crocus Martis* well reverberated, and into a violet colour; for common chalybs *præparatus*, or corroded and powdered steel, the loadstone attracts like ordinary filings of iron; and many times most of that which passeth for *Crocus Martis*. So that this way may serve as a test of its preparation; after which it becometh a very good medicine in fluxes. The like may be affirmed of flakes of iron that are rusty and begin to tend unto earth. For their cognation then expireth, and the loadstone will not regard them." Consult Lazarus Erckern's *Aula Subterranea*, Franckfurt 1672, page 294, or Sir J. Pettus' "Heta Minor," London 1683, although, according to Dr. Thomson, the translation is a very bad one.

force or by the matter of an intervening body; and this is so whether the iron tends downward to the loadstone, or seeks it from one side and obliquely, or whether it leaps up to it. But if on account of an obstacle it cannot reach the stone, it sticks to the obstacle and there remains, yet is held by a less constant bond, for, owing to the greater intervals and distances, the association (with the loadstone) is less amicable. Fracastorio, in his Chapter VIII, *De Sympathia*, says that a piece of iron will be suspended in air so that it cannot move either up or down if a loadstone be placed above it that has an attractive force on the iron equal to the force by which the iron tends downward: thus the iron will stand fixed in mid-air. That is ridiculous: for the nearer the loadstone the greater always is its force; and hence the iron that is lifted ever so little above the earth by the loadstone's force must needs be steadily drawn to it, and must cling to it. Baptista Porta suspends in air a piece of iron (with a loadstone fixed above), and holds back the iron by means of a thin thread fastened to it beneath, so that it shall not rise to the stone;—hardly a very brilliant idea. The piece * of iron is pulled in a perpendicular line by the loadstone, though the two are not in contact, but only near each other; but, as on account of the greater nearness, the iron mass is stirred by the force that was lifting it, straightway it speeds to the loadstone and clings to it. For the iron, the nearer it comes to the loadstone, the more is excited, and the stronger is the attraction.

CHAPTER XXV.

INTENSIFYING THE LOADSTONE'S FORCES.

ONE loadstone far surpasses another in energy, for one will snatch up almost its own weight of iron, while another is hardly able to move the smallest particle. All animals and plants that possess life have need of victual of some sort, to the end their powers may last and become firmer and stronger. But iron is not attracted by the loadstone, as Cardan and Alexander Aphrodiseus supposed, so that it may be nourished with morsels of it; neither does the loadstone gain strength from iron-filings as from a nutritious food. Baptista Porta, having his doubts about this view, and wishing to make an experiment, took a loadstone of determinate weight and buried it in iron-filings of a weight not unknown; and, after he had left it there many months, he found the stone heavier, the filings lighter. But the difference was so minute that Porta was uncertain as to the truth. This experiment of Porta's does not prove that the stone devours anything, nor does it show any process of nutrition, for minute quantities of filings are easily lost by handling. So, too, a very small quantity of the iron dust may adhere to some small part of the loadstone and not be noticed, thus adding somewhat to the weight of the stone; but that is a superficial accretion, and can be brushed off without much difficulty. Many think that when weak and sluggish the stone can bring itself back to a better condition, and that a very strong stone can endow a weaker one with the highest degree of force. Is it as when animals gain strength when they feed and are filled? Is a remedy found for the loadstone in addition or subtraction of something? Is there aught that can restore this primary form or give it anew? Surely nothing can do such a thing save what possesses magnetic properties. Magnetic bodies can restore soundness (when not totally lost) to magnetic bodies, and can give to some of them powers greater than they had originally; but to those that are by their nature in the highest degree perfect, it is not possible to give further strength. Hence the more infamous becomes all the charlatanry of Paracelsus, who declares that the loadstone's force and energy may be increased and transformed to tenfold what it is naturally. And the way of doing this is, so to speak, to half-candescify the loadstone, i.e., to make it very hot, yet so that it does not reach white heat, and then immediately to dip it in oil of vitriol made from the best Corynthian steel, letting it become saturated. "In this way," says Paracelsus, "you can give to a loadstone such strength that it will pull a nail out of a wall, and perform many other the like marvels impossible for a common loadstone." But a loadstone so dipped not only acquires no force, but suffers some loss it already hath. A loadstone rubbed and smoothed with steel is made better. When covered with filings of the best iron or pure steel, not rusty, it retains its properties. Sometimes, too, a good strong loadstone gains some strength when rubbed on its opposite pole with the pole of another loadstone: it takes in force. In such experiments it is well to observe the earth's pole, and to lay down in the direction required by the magnetic laws the stone that one wishes to make stronger: this point we will establish hereafter. A strong, large loadstone increases the power of another loadstone, as also the power of iron. If, on * the north pole of a loadstone, you place another loadstone, the north pole of the second becomes stronger, and a piece of iron clings like an arrow to the north pole *a*, and not at all to the south pole *b*. And the pole *a*, when it is in a right line above with the axis of both loadstones, they being joined according to the magnetic laws, raises the piece of iron to the perpendicular: this it cannot do if the larger loadstone be moved away, for its strength is insufficient. But as a ball of



iron on the pole of the terrella raises the piece of iron to the perpendicular, so, at the side, the iron is not directed toward the centre, but stands oblique and sticks everywhere; for in the iron ball the pole is ever the point of contact with the terrella's pole, and it is not constant, as it is in the smaller terrella. The parts of the earth, as of all magnetic bodies, are in accord and enjoy neighborhood with each other: there is in them all mutual love, undying good-will. The weaker loadstones are refreshed by the stronger ones, and the less vigorous bring no damage to the more vigorous. Yet a strong loadstone exerts more attraction in another strong one than in one that is feeble, for a vigorous stone contributes forceful action, and itself hastes, flies to the other, and solicits it vehemently; accordingly there is co-operation, and a clearer and stronger cohesion.

CHAPTER XXVI.

WHY THE LOVE OF IRON AND LOADSTONE APPEARS GREATER THAN THAT OF LOADSTONE AND LOADSTONE, OR IRON AND IRON WHEN NIGH A LOADSTONE AND WITHIN ITS FIELD.

ONE loadstone does not attract another on all its sides as it does iron, but only at one fixed point: hence the poles of the two must be properly arranged, else they do not duly and powerfully cohere. But this arranging is not easy nor the work of an instant: therefore one loadstone will seem to be refractory toward another, whereas they may be in perfect harmony. Iron, suddenly impressed by a loadstone, is not only attracted by it, but is renovated and its powers enhanced, whereby it pursues and solicits the loadstone with a force not less than its own, and also makes captive other iron objects. Suppose a little iron bar firmly adhering to a loadstone: if you bring near this piece of iron an iron rod, but without touching the loadstone, you shall see the iron instantly follow the rod, relinquishing the loadstone, leaning toward the rod, and, on contact, firmly adhering thereto; for iron in union and contact pulls more vigorously another piece of iron within the field of a loadstone than does the loadstone itself. The natural magnetic force, which in iron lies confined and asleep, is awakened by a loadstone, associates itself with it, and comes into sympathy with it in virtue of the primary form:[1] hence comes the perfect magnetized iron, which is as strong as the loadstone itself; for as the one imparts and arouses, so the other conceives, and, being awakened, endures, and by its very act gives back the force again. But in so much as iron is liker to iron than is loadstone, and in two pieces of iron within the field of a loadstone, the nighness of the latter enhances the powers of both: then, their forces being equal, likeness of substance becomes decisive, and iron gives itself up to iron, and the two pieces are united by their most like (identical) and homogeneous forces. This is effected not only by coition, but by a firmer union; and a steel cap or snout (*glans vel nasus*) properly adjusted to the pole of a loadstone lifts greater weights than can the stone by itself. When steel or iron is made from loadstone or from iron ore, the slag and impurities are separated from the substance by a better fusion: hence usually such iron contains the matter of the earth purged of foreign admixture and dross, and more homogenic and perfect (than before smelting), albeit deformed by fusion. And this matter, when acted on by a loadstone, conceives the magnetic virtue, and within the magnetic field is endowed with force surpassing that of an inferior loadstone, which is seldom without some admixture of impurities.

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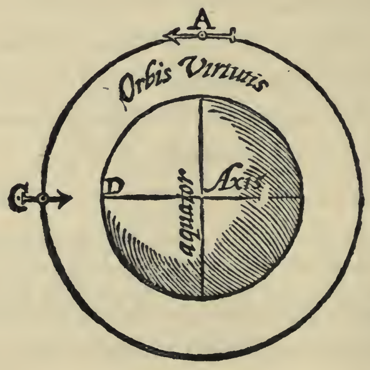
[1] "Let us imagine that *that* which impels the iron towards the loadstone, or the loadstone towards the iron, is a third body, or rather a certain matter which is in motion, and which is very subtle, because it cannot be perceived by our senses." (Jacobi Rohaulti, *Physica*, 1718, Par. III, Cap. VIII, page 391, or Dr. Clarke's translation, 1728, Vol. II, page 167.)

CHAPTER XXVII.

*THAT THE CENTRE OF THE MAGNETIC FORCES IN THE EARTH IS THE CENTRE OF THE EARTH; AND IN THE TERRELLA THE TERRELLA'S CENTRE.

THE rays of magnetic force are dispersed in a circle in all directions; and the centre of this sphere is not in the pole (as Baptista Porta deems, Chap. XXII), but in the centre of the stone and of the terrella. So, too, the earth's centre is the centre of the earth's magnetic movements, though magnetic bodies are not borne direct toward the centre in the magnetic movement save when they are attracted by the pole. For as the formal power of loadstone and earth promotes simply unity and conformity between things separate, it follows that everywhere at equal distance from the centre or from the convex circum-



ference, just as at one point it seems to attract in a right line, so at another it can control and rotate the needle, provided only the loadstone be not of unequal power. For if at the distance

C from pole *D* the stone is able to attract the needle, then at an equal distance *A* above its equator it can control and rotate the needle. Thus the centre and middle of the terrella is the centre of force, and thence to the circumference of its sphere of influence its magnetic virtues extend (for) equal distances in all directions.

CHAPTER XXVIII.

THAT A LOADSTONE DOES NOT ATTRACT TO A FIXED POINT OR POLE ONLY, BUT TO EVERY PART OF A TERRELLA, EXCEPT THE EQUINOCTIAL CIRCLE.

COITION is always strongest when pole touches pole, for at the poles the force is greatest by concert of the whole: hence one pole seizes the other with greatest force. Points at distances from the poles possess attractional power also, but somewhat weaker and sluggish in the ratio of the distance, so that finally in the equinoctial line they are utterly enervate and faint. The poles, too, do not attract as mathematical points, nor does magnetized iron unite at its poles only with the poles of a loadstone. On the contrary, the coition takes place all over the periphery, north and south, the force emanating from the whole mass. Magnetic bodies, however, are attracted feebly in the parts near the equator, but quickly in the parts near the poles. Wherefore not the poles alone, and not the parts alone that are near the poles, attract and solicit magnetic bodies; but magnetic bodies are controlled and rotated and unite with other magnetic bodies according as parts neighboring and adjoining lend their forces, which forces are ever of the same potency in the same parallel, except when otherwise distributed by causes producing variation.

CHAPTER XXIX.

OF DIFFERENCE OF FORCES DEPENDENT ON QUANTITY OR MASS.

LOADSTONES coming from the same mine, and not intermingled with neighboring metals or ores, have the same potency; yet the stone that is largest exhibits greatest force, as it carries the greatest weight and has a wider sphere of influence. A loadstone weighing an ounce does not lift an iron spike as does one that weighs a pound, nor does its control reach so far, nor does its force extend to such a distance. And if you take from a one-pound stone a part, somewhat of its power will be seen to leave also; for when a part is taken * away some of the energy is lost. But when such part is duly applied and united to the stone, though it be not cemented there nor perfectly fitted in by the mere apposition, the original strength is recovered, and the force returns. Sometimes, * however, the energy is increased by detachment of a part because of malformation of the stone, as when the force is diffused through awkward corners.

In stones of different sorts the ratio of power is different: one weighing a drachm may have more force than another one of 20 pounds. Many a loadstone is so weak that the force can scarcely be noticed, and such faint magnets are often surpassed by masses prepared of potter's earth. But we may ask: Supposing that a stone of a given kind and of definite goodness, and weighing a drachm, carries one drachm, whether one weighing an ounce will carry an ounce, a pound a pound, and * so on? So it is, for in proportion to size such loadstone has greater or less strength: so that a loadstone of proportionate size and weight, a drachm weight of which lifts a drachm weight of iron, will, when brought near a suitable great obelisk or enormous pyramid of iron, attract it and pull it to itself, and that with no greater effort of its nature and with no greater pains than when a drachm weight of loadstone seizes a drachm weight of iron. But in all such experiments the power of the loadstones should be equal, the form of the stones should be exactly proportioned: this is true not less of an armed than of a naked loadstone. As an experiment, take a loadstone weighing 8 oz., which when armed lifts 12 oz. of * iron; cut off of this stone a part which, when brought to the form of the whole stone as it was before, shall weigh only 2 oz.: such a stone, armed, lifts 3 oz. of iron. In this experiment it is requisite that the form of the 3-oz. piece of iron be the same as that of the 12-oz. piece; if the 12 oz. mass rose in form of a cone, the 3-oz. piece must assume a pyramidal form proportioned to the figure of the original mass.

CHAPTER XXX.

THE SHAPE AND THE MASS OF AN IRON OBJECT ARE IMPORTANT IN MAGNETIC COITIONS.

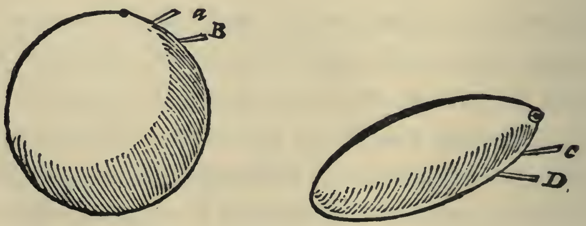
IT was shown before that the shape and mass of a loadstone are weighty factors in magnetic coitions: similarly, the shape and mass of the iron determine whether its force shall be great or little. Oblong, bacilliform pieces are both more quickly attracted and cling more firmly than spherical or square pieces, and this for the causes we have shown with regard to the loadstone. It is also worthy of note, that when a smaller iron object has at-

tached to it a weight of different material, so that the weight
* of the two shall equal that of another larger piece whose weight is proportioned to the power of the loadstone, it is not lifted by the loadstone like the larger object; for the smaller piece is not so powerfully attracted by the loadstone, because it gives back less force, and only magnetic matter conceives the magnetic energy: foreign matter appended to such a body cannot take in magnetic force.

CHAPTER XXXI.

OF OBLONG AND ROUND STONES.

IRON bodies are more forcibly attracted by an oblong stone than by a round one, provided only the pole of the stone is at the extreme end of its length. The reason is that in the oblong stone the magnetic body at the extremity is directed straight toward a body wherein the force proceeds in right lines and through a longer diameter. But the oblong stone has only little force on the side; for, plainly, the attraction at *a* and *B* is stronger in a round loadstone at equal distance
* from the pole, than in *c* and *D*.



CHAPTER XXXII.

SOME PROBLEMS AND MAGNETIC EXPERIMENTS ON THE COITION, AND REPULSION, AND REGULAR MOVEMENT, OF MAGNETIC BODIES.

LOADSTONES that are equal come together with equal * mutual incitation.

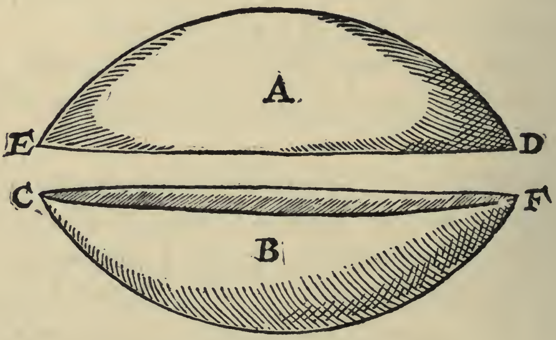
Magnetized iron bodies that are in all respects equal do * also come together with equal mutual incitation.

Iron bodies not magnetized, if they are equal, and not * hindered by their bulk, do also come together with equal movement.

Two loadstones placed on suitable floats apart on the surface of water, if they be suitably arranged within their magnetic field, attract each other. So, too, a proportionate piece of iron on one float hastes to a loadstone with the same speed with which the magnet itself, afloat, strives to reach the iron. For the two are impelled from their own places on either side to come together midway and coalesce. Two magnetized-iron * wires, floated in water by suitable corks, move forward to contact, and, with the proper end on, strike and are joined.

With magnetic bodies that are equal, coition is more vigor-* ous, and quicker than repulsion and separation. That magnetic bodies are more sluggish in repelling than in attracting, is seen in every magnetic experiment, as when loadstones are borne on suitable floats on water, or when magnetized iron wire or little bars are driven through cork and set afloat in water, as also in experiments with a needle. The reason is that, since the power of coition is one thing, the power of conformation and of ordering in place is another, therefore repulsion and aversation are the act of the force ordering in place; but the coming together is the result of mutual attraction to contact as well as of the force that orders in place; i.e., it is due to a twofold force.

The ordering force is often only the forerunner of coition, so that the bodies shall stand in due position before the onset: hence they turn in the direction of the points of coition, if they be hindered from attaining those points. If a loadstone be



cut in two equal parts along the meridian, the separated parts repel each other, if the poles be placed at a suitable even distance from each other; for they mutually repel with greater velocity than is the case when pole is wrongly opposed to pole. Thus the half *B* of a loadstone, placed near the other half *A*, repels *A* on its float, because *D* withdraws from *F* and *E* from *C*. But if *B* be again joined exactly with *A*, they come together and form one magnetic body; yet when they are only near each other they are mutually hostile. And if one half be turned about so as to bring *C* opposite to *D* and *F* to *E*, then *A* follows *B* within the field and becomes joined to it.

South parts of a stone retreat from south parts, and north parts from north. Nevertheless, if you bring the south end of a piece of iron near to the south part of the stone, the iron is seized and the two are held in friendly embrace ; as the verticity fixed in the iron is reversed and changed by the presence of the more powerful loadstone, which is more constant in its forces than the iron. For they come together in accordance with nature, if either by reversal or change there be produced true conformity and orderly coition as well as regular direction. Loadstones of identical shape, size, and strength attract each other with equal force, and when in wrong position repel with like energy.

Little rods of unmagnetized iron, though like and equal, *
yet act on one another often with different force ; for as there are different grounds for the acquisition of verticity and also of strength and vigor, so the particles that are most strongly excited by the loadstones themselves in turn act with most force.

Pieces of iron that have been magnetized at one same pole *
of a loadstone repel one another at the magnetized ends ; and their other extremities are also mutually hostile.

In rotating needles when the points are magnetized but *
not the crotches, the latter repel one another, but only feebly and in proportion to length.

In like rotating needles when the points are magnetized by *
the same pole of a loadstone the crotches attract with equal force.

In a long rotating needle the crotch is attracted feebly by *
the point of a short needle ; the crotch of a short one is attracted strongly by the point of a long one, because the crotch of a long needle has feeble verticity, but the point of a long needle has strong verticity.

* The point of a long needle repels the point of a short one more strongly than the point of a short needle repels that of a long one, if one of them be poised free on a sharp point and the other held in the hand; for though both have been equally magnetized by the same loadstone, still the longer one, by reason of its greater mass, has greater force at its point.

* In unmagnetized iron rods the south end of one attracts the north end of another, and the north end the south; the meridional parts, too, repel meridional parts, and north parts north parts.

If magnetic bodies be divided or in any way broken up, each several part hath a north end and a south end.

* A needle is stirred by a loadstone at as great a distance with an obstacle interposed as in air and in an open medium.

* Rods magnetized by friction with the pole of a loadstone draw toward that pole and follow it. Baptista Porta is therefore in error when he says (Chapter IV) that "if you bring a part nigh the part that gave it the force, it shudders, and repels and drives it away, and attracts the converse and opposite part."

The laws of rotation and attraction are the same as between loadstone and loadstone, loadstone and iron, and iron and iron.

When the parts of a magnetic body that has been broken up by force and cut into pieces are put together again and properly joined, they form one body and their joint force is one; nor have they separate poles.

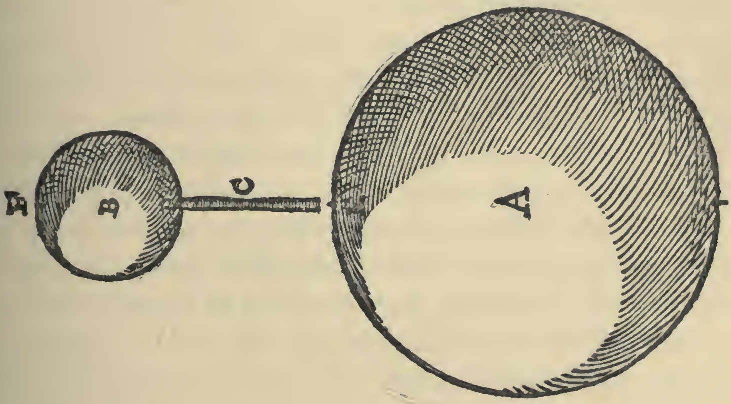
* The separated parts, if division has not been made on the parallels, assume new poles, north and south; if the division is along a parallel, they may retain one pole in the same place as before.

Iron rubbed and excited by a loadstone is seized at the fitting ends by a loadstone more powerfully than iron not magnetized.

If a small iron bar be set erect on the pole of a loadstone, * another bar-iron pin in touch with its upper end becomes firmly attached thereto, and if it be moved away pulls the standing bar from the terrella.

If, to the nether end of the erect bar you apply the end of * another bar, it does not cohere, nor do they unite.

As a rod of iron pulls iron away from the terrella, so does a small loadstone or a smaller terrella albeit of less force.



Here the iron bar *C* coalesces with the terrella *A*, and thus its force is enhanced and awakened magnetically both in the end in conjunction and also in the distal end by reason of its contact with the terrella; the distal end furthermore receives energy from the loadstone *B*, and the pole *D* of this magnet also gains force by reason of its favorable position and the nearness of the pole *E* of the terrella. Hence many causes coöperate to make the bar *C*, attached to the loadstone *B*.

cling more strongly to that than to the terrella *A*. The energy called forth in the bar, also the energy called forth in the loadstone *B*, and *B*'s native energy, all concur; therefore *D* is magnetically bound more strongly to *C* than *E* to *C*.

But if you turn the pole *F* to the iron *C*, then *C* does not cling to *F* as it did before to *D*; for, within the magnetic field, stones so arranged stand in an unnatural order: hence *F* does not get force from *E*.

Two loadstones, or two magnetized pieces of iron, duly cohering, fly apart on the coming of a stronger loadstone or a stronger magnetized mass of iron; for the newcomer, presenting the opposite pole, puts one to flight and overmasters it, and the mutual action of the two that before were conjoined ceases. So the forces of one of the bodies are reduced and fail; and were it possible, it would shake off its fellow, and, turning about, would go rolling over to the stronger. For this reason it is that magnetic bodies held pendent in air drop to the ground when the opposite pole of a loadstone is presented to them; and this not because there is any weakening or numbing of the forces of both of the bodies before conjoined, as Baptista Porta maintains, for pole cannot be hostile to both of the ends that cohere, but to one only: this end the newcomer, the stronger loadstone, drives away from itself by presenting its opposite pole, and thus one of the smaller bodies is compelled to give up its friendly association with the other.

CHAPTER XXXIII.

OF THE DIFFERENCE IN THE RATIO OF STRENGTH AND MOVEMENT OF COITION WITHIN THE SPHERE OF INFLUENCE.

If the greatest weight that is attracted to a loadstone at the nearest distance be divided into a given number of parts, and the radius of the sphere of magnetic attraction into the same number of parts, the parts of the weight will correspond to the intermediate parts of the radius.

The sphere of influence extends farther than the sphere of movement of any magnetic body, for a magnetic body is affected at the outermost edge though it may not move with local motion: that is done when the loadstone is brought nearer. A needle, even a very small one, turns round while remote from a loadstone, though, at the same distance and free to move and in no wise hindered, it does not come to the loadstone.

The velocity of the movement of a magnetic body to a loadstone is in proportion to the strength of the loadstone, or its mass, or its shape, or the nature of the medium, or the distance within the magnetic sphere of action.

A magnetic body approaches with greater velocity a powerful loadstone than a sluggish one, in the ratio of the respective energies of the two loadstones. A smaller mass of iron, as also one rather oblong in shape, is attracted with the greater velocity. The velocity of the movement of a magnetic body to a loadstone varies according to the medium, for bodies move with greater velocity in air than in water, and in a serene atmosphere than in thick and foggy weather.

In the ratio of distance, movement is quicker from anear than from afar. At the outermost edge of a terrella's field magnetic bodies move faintly and slowly. In the immediate neighborhood of the terrella the motor impetus is greatest.

* A loadstone that in the outermost verge of its field of force, at the distance of one foot, can hardly stir a rotating needle, will, when connected with a long iron rod, strongly attract and repel (accordingly as its different poles are presented) the needle at the distance of three feet, and this whether the loadstone is armed or unarmed. The iron rod should be of fitting quality, and of the thickness of the little finger.

For the energy of the loadstone awakens verticity in the iron and passes in and through iron to a far greater distance than it extends through air.

* The force also passes through a number of pieces of iron conjoined at their extremities, yet not so surely as through one continuous rod.

Steel-filings strewed on paper rise on end and present the appearance of stubby steel hairs when a loadstone is brought near above them ; when the loadstone is applied beneath, the hairlike crop rises also.

* Steel-filings, when the pole of a loadstone is brought near, coalesce into one body ; but when it would come to the loadstone, the body is broken up and rises to the steel in smaller masses that still hold together.

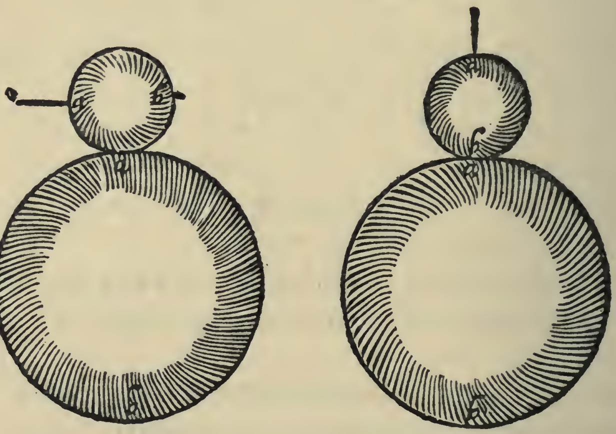
But if the loadstone be beneath the paper, the consolidated mass breaks up as before, and into very many parts, each of which consists of a multitude of grains ; and they remain united, like separate bodies ; and while the lowermost parts of these eagerly follow the pole of the loadstone beneath, so the separate masses stand like solid magnetic bodies. In like manner a bit of iron wire one barley-corn or two in length stands on end when a loadstone is applied either beneath or above.

CHAPTER XXXIV.

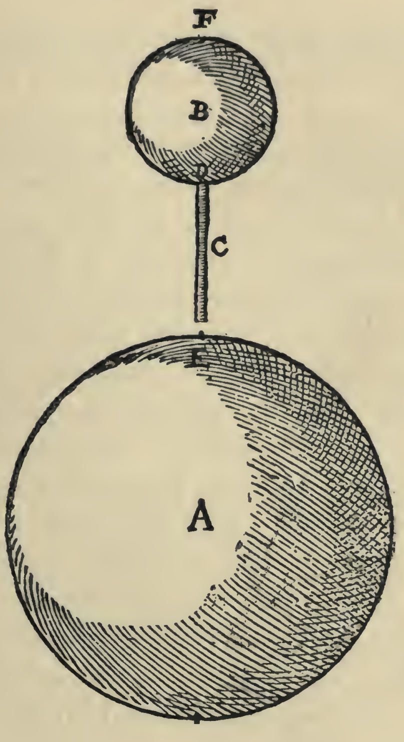
WHY A LOADSTONE IS OF DIFFERENT POWER IN ITS POLES AS WELL IN THE NORTH AS IN THE SOUTH REGIONS.

THE extraordinary magnetic energy of the earth is beautifully shown in the following neat experiment: Take a terrella of no ordinary power, or an oblong loadstone with equal cones forming its polar ends; but in any figure not exactly spherical it is easy to fall into mistakes, and the experiment is difficult. In northern latitudes raise the true north pole above the horizon straight toward the zenith. Plainly it holds erect on its north pole a larger bar of iron than could the south pole of the same terrella if turned in like manner toward the centre of the sky. The same demonstration is made with a small terrella set atop of a large one. *

Let *ab* be the earth or a large terrella, and *ab* a small terrella; a larger bar is raised erect by the north pole of the small terrella than the *b* pole of the same, if turned skyward, can raise to the erect position. And the *a* pole of the small terrella derives force from the greater, turning from zenith to the plane of the horizon or to the level. Now if, the smaller terrella having its poles directed as before, you apply a piece * of iron to its lower or south pole, that will attract and hold a greater weight than can the south pole if that be turned down. Which is thus shown: Let *A* be the earth or a terrella; *E* the



north pole or some point in high latitude; let *B* be a large terrella above the earth, or a small terrella above a larger one; *D* the south pole: it is plain that *D* (south pole) attracts a larger piece of iron, *C*, than can *E* (the north pole), if that pole be turned downward to the position *D*, looking toward the earth or the terrella in their northern regions. Magnetic bodies gain force from other magnetic bodies if they be arranged duly and according to their nature in neighborhood and within the sphere of influence; and hence, when a terrella is imposed on the earth or on another terrella in such way that the south pole looks toward the north pole, and north is turned away from north, the energy and forces of its poles are augmented. Hence the north pole of a terrella in such position lifts a heavier piece of iron than the south pole does if that be turned away. In like manner the south pole, gaining force from the earth or the larger terrella when it is duly placed as nature requires, attracts and holds heavier bars of iron. In the other portion of the terrestrial globe, toward the south, as



also in the southern parts of the terrella, the case is reversed, for, there, the south pole of the terrella is strongest when distal, as is the north pole of the terrella when it faces the earth or terrella. The farther a place is from the equinoctial line, whether of the earth or of a terrella, the greater is seen to be the accession of force; but nigh the equator the difference is slight; at the equator it is null; at the poles it is greatest.

CHAPTER XXXV.

OF A PERPETUAL-MOTION ENGINE ACTUATED BY THE ATTRACTION OF A LOADSTONE, MENTIONED BY AUTHORS.

CARDAN writes that out of iron and loadstone may be constructed a perpetual-motion engine—not that he saw such a machine ever; he merely offers the idea as an opinion, and quotes from the report of Antonius de Fantis, of Treviso; such a machine he describes in Book IX, *De Rerum Varietate*. But the contrivers of such machines have but little practice in magnetic experiments. For no magnetic attraction can be greater (whatever art, whatever form of instrument you employ) than the force of retention; and objects that are conjoined, and that are near, are held with greater force than objects solicited and set in motion are made to move; and as we have already shown, this motion is a coition of both, not an attraction of one. Such an engine Petrus Peregrinus, centuries ago, either devised or delineated after he had got the idea from others; and Joannes Taysner published this, illustrating it with wretched figures, and copying word for word the theory of it. May the gods damn all such sham, pilfered, distorted works, which do but muddle the minds of students![1]

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[1] See note 2, page 9, relative to Joannes Taisnier Hannonius.

With reference to the above-named passage, P. D. Timoteo Bertelli Barnabita, at Chap. VI, page 22, of his Memoir on P. Peregrinus, says that Gilbert has "appropriated other observations and experiments of Peregrinus," and has taken from him the idea of his *terrella* as well as the experiments on magnetic polarity. Farther on (page 28) Bertelli gives the following extract from Thévenot: "5° L'on voit encore que la pluspart des choses que l'on attribue à Gilbert et que luy ont donné la réputation de Père de la Philosophie de l'Ayman

CHAPTER XXXVI.

HOW A STRONG LOADSTONE MAY BE RECOGNIZED.

A STRONG loadstone sometimes lifts in air a mass of iron weighing as much as itself; a weak loadstone hardly attracts a bit of fine wire. Those, then, are the stronger loadstones which attract and hold the larger bodies, unless there is some defect of shape, or unless the pole of the stone is not properly applied. Besides, the stronger loadstone, when afloat, more readily turns its poles toward the poles of the earth or the points of variation on the horizon. But the stone that acts sluggishly, betrays some flaw in itself, shows that its force is exhausted. Loadstones are to be all prepared in the same way, shaped alike, and made of the same size; for when they are unlike and unequal, experiments are doubtful. All loadstones are tested for strength in the same way, viz., with a versorium (rotating needle) held at some distance; the stone that at the greatest distance is able to make the needle go round is the best and strongest. Baptista Porta also rightly determines the power of a loadstone by thus weighing in a

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estaient scües dès le treizième siècle." This, says he, is "doubtless an exaggeration. That Gilbert took from P. Peregrinus his *terrella* and many excellent scientific plans on magnetism, the ideas of others also, is probable, but it is indubitable that much was his own, and that, for his time, his work is a *véritable chef d'œuvre* of inductive and experimental method and the most finished treatise on magnetism which had up to that time appeared."

Consult, also, Bertelli, page 92; Gilbert, *De Magnete*, Book VI, Chap. IV; likewise, W. Wenckebach, "Sur Petrus Adsigerius . . .," Rome 1865, page 8, and the work therein quoted "Universal Lexicon," Leipzig 1741; also Nicolao Cabeo, *Phil. Magn.*, Ferrara 1629, page 23.

balance. A piece of loadstone is put in one scale and an equal weight of another substance in the other, so that the scales are balanced. Then some iron lying on a board is brought nigh, so that it shall cleave to the loadstone in the scale, and the two bodies cohere perfectly at their points of attraction; into the opposite scale sand is poured gradually till the scale in which is the loadstone separates from the iron. By weighing the sand the force of the loadstone is ascertained. So, too, we can make experiment and find the stronger stone by weighing sand, if we put in a pair of scales loadstones that balance each other. Such is an experiment given by Cardinal Cusanus in his *Statica*, and from him Porta would seem to have learned the one he cites. The stronger loadstones turn readily toward the poles or the points of variation; so, too, they propel their floats and cause them and other cumbrances, as so much wood, to wheel about. In an inclination or dip instrument the greater power of a loadstone is manifested and there greater power is requisite. Hence loadstones are stronger the more speedily they do their work, and the more rapidly they travel from side to side and return, and the sooner they come to a standstill. Feeble, exhausted loadstones travel more sluggishly, come to a rest more slowly, stick at the pole less decisively, and are easily displaced therefrom.

CHAPTER XXXVII.

USES OF THE LOADSTONE AS IT AFFECTS IRON.

By means of magnetic coition we test an iron ore. The ore is roasted in a furnace, is crushed, washed, dried, and so is freed from foreign humors. The loadstone being thrust among the particles collected from the bath attracts the iron dust, which being removed by a feather brush is caught in a crucible; again and again the loadstone is dipped in and the iron dust brushed into the crucible, till nothing remains that it will attract. Then the powdered iron is heated together with halinitro till it is melted and becomes a mass of iron. Now if the loadstone picks up the iron dust readily and easily, we deem the ore to be rich; if slowly, the ore is poor; if the loadstone seems quite to reject it, the ore is judged to have little or no iron. By the same method, iron particles may be separated from particles of any other metal. And many tricks are played by secretly attracting bits of iron to light bodies, or causing a concealed loadstone to attract the iron; to persons who know not the cause, the movements of the objects seem amazing. Any ingenious workman may exhibit a great number of such tricks for sport, with the air of one dealing in incantations and magic.

CHAPTER XXXVIII.

OF THE ATTRACTIONS OF OTHER BODIES.

PHILOSOPHIZERS of the vulgar sort and mere copyists oft repeat, from others' memoirs on natural philosophy, opinions and errors with regard to the attractional force of various bodies. They will say, for example, that diamond attracts iron and pulls it away from loadstone; that loadstones differ, some attracting gold, others silver, copper, lead—yea, flesh, water, fish. The flame of sulphur is said to seek iron and stones; so is white naphtha said to draw to itself fire. I have already said that inanimate natural bodies in no other wise attract or are attracted on this terrestrial globe, save either magnetically or electrically. It is therefore not true that there are loadstones that attract gold or other metals; for a magnetic body attracts only a magnetic body. Fracastorio tells of having seen a loadstone attracting silver. If that were true, then it must necessarily have been because some iron had been artificially mixed with the silver and lay hidden therein, or because nature had mixed iron with the silver (as she does sometimes, though very seldom); for iron is now and then mixed with silver by nature, but silver with iron very rarely or never. By false coiners and by avaricious princes, when money is coined, iron is mixed with silver; an instance of this we have in Anthony's denarius, if what Pliny declares be true. So Cardan (led into error, perhaps, by others) says there is a certain kind of loadstone which attracts silver; and he adds a very silly test of the thing: "If," says he, "a thin rod of silver be touched with this and then poised in equilibrium, when it comes to a standstill after being whirled, it will point to silver (especially a large quantity), though the same be buried in the ground; by this means anybody may easily unearth hidden treasures." He adds that "the stone must be of the best," and that he never saw such stone. Nor will he or anybody else ever see such a stone or such an experiment. Cardan cites an attraction, improperly so called, of flesh, which is altogether unlike magnetic attraction; his *magnes creagus* (or flesh-attracting loadstone, so named because it clings to the lips) must be cast out of the company of loadstones and of the whole family of attractional bodies. Lemnian earth, red ochre, and sundry minerals have this action, but it were absurd to say that they attract. Cardan imagines another loadstone, a third species as it were; if a needle be driven into this, it may be thrust into a person's body afterward without being felt. But what has attraction to do with numbing of sense, or what is there in common between stupefaction and the mind of a philosopher while he discourses of attraction? Many are the stones, both of natural origin and artificially compounded, that possess the power of dulling the senses. The flame of sulphur is by some said to attract because that it consumes certain metals by reason of its penetrating force. So does naphtha attract flame because it emits and exhales inflammable vapor, and hence is set aflame at some distance; even as the smudge of a candle that has just been extinguished catches fire again from another flame; for fire creeps to fire through an inflammable medium. Of the sucking-fish or remora (*Echeneis remora*), and how it stays ships, philosophers have discoursed variously. It is their custom oft to account with their reasonings for this and many other fables, before ascertaining that the thing is so in fact. Wherefore, approving and indorsing the absurdities of the ancients, they published the most blunderous theories and ridiculous theses—e.g., that there are rocks having the power of attraction and that there the remora dwells; and they postulate of the necessity of I know not what vacuum or how produced. Pliny and Julius Solinus tell of the stone *cathochites* and affirm that it attracts flesh and holds one's hand, as loadstone holds iron and amber holds chaff. But that is due solely to its viscosity and its natural glutinousness, for it adheres most readily to a warm hand. The *sagda*, or *sagdo*, is a gem of leek-green color mentioned by Pliny, Solinus, Albertus Magnus, and Euace, who themselves make up or from others copy the story that this stone has the peculiarity of attracting wood. And there are others who utter the nonsense that the wood attracted cannot be pulled off, but has to be cut away; while some tell of a stone of this kind that clings as firmly to ships' bottoms as do the barnacles gathered on a long voyage. But though a stone may cling to a surface, it does not therefore attract; and if it did attract, surely it would draw to itself chips and shavings electrically. A stone of this sort was seen by Encelius in the hands of a certain seaman; a weak stone, it was, hardly able to attract the smallest twigs; and its color was not a true leek-green. Diamond, carbuncle, rock-crystal, and other stones attract in that way. I say nothing of other fabulous stones, of *pantarbes* whereof Philostratus affirms that it attracts to itself other stones; of *amphitane*, said to attract also gold. Pliny, in telling of the discovery of glass, makes the loadstone attract glass as it does iron; for when in speaking of the mode of making glass he describes its nature, he adds this concerning the loadstone: "In time the skill of the workmen, clear sighted and resourceful, was no longer content with mixing in natron; loadstone began to be added because it is believed to attract to itself the liquid glass even as it attracts iron."[1] Georgius Agricola asserts that "A portion of loadstone is added to the ingredients of glass (sand and natron), because it is believed in our day as in early times that that force (the magnetic) attracts to itself the molten glass even as it attracts iron, that it purifies it when attracted, and changes it from green or orange-yellow to clear white; but afterward the fire consumes the loadstone." True it is indeed that loadstone of some kind (as the magnesia employed by glass-makers, which has no magnetic powers) is sometimes introduced into and mingled with the material of glass, yet not because that it attracts glass. But a red-hot loadstone does not attract iron at all, nor is iron at white heat attracted by loadstone; and the loadstone is even destroyed by very strong heat and loses its power of attraction. Nor is this work of purifying the function of loadstone alone in the glass furnace, but also of certain pyrites and of readily combustible iron ores; and these alone are used by such of our glass-makers as make clear, fine glass. These materials are mixed with sand, ashes, and natron (just as other materials are mixed with metals when they are smelted), so that, when the contents of the furnace become fluid glass, the well-known green and yellow color may be purged away by the penetrant heat. For no other matter reaches such degree of heat or endures fire for the requisite

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[1] The allusion to Pliny is made by J. B. Porta: *Natural Magick*, London 1658, Book VII, page 216; *Magiæ Naturalis*, Amstelodami 1664, Lib. VII, Cap. LVI, page 331. Sir Thomas Brown says (*Pseudoloxia Epidemica*, London 1658, Book II, page 76): "True it is that in the making of glass it hath been in ancient practice to cast in pieces of Loadstone: conceiving it carried away all ferreous and earthy parts from the pure and running portion of glass, which the Loadstone would not respect; and therefore if that attraction were not rather Electrical than Magnetical, it was a wonderous effect what *Helmont* delivereth concerning a glass wherein the Magistery of Loadstone was prepared; which after retained an attractive quality."

length of time that the material of the glass may become perfectly fluid, and just then is burnt up by the strong fire. But sometimes it happens that on account of the magnetic stone, or magnesia, or iron ore, or pyrites, the glass hath a dusky tinge, these substances being too resistant to fire and hence not being burnt up, or having been introduced in too great quantity. For this reason, glass-makers procure the right sort of stone and carefully attend to the proportion of ingredients in the mixture. Thus, then, Georgius Agricola and later writers are badly led astray by Pliny's stupid philosophy when they declare that loadstone is needed by glass-makers for its magnetic virtues and attractive force. And Scaliger (*De Subtil, ad Cardanum*) strays far from truth when, in treating of magnetic bodies, he speaks of diamond attracting iron; unless he means only that diamond electrically attracts iron as it does bits of wood, straws, and other small bodies of all kinds. Fallopius thinks that quicksilver attracts metals in virtue of an occult property, just as the loadstone does iron, or as amber attracts chaff. But there is no attraction properly so called when quicksilver enters into metals. For metals imbibe quicksilver as clay does water, but not unless the substances are in contact; for quicksilver does not draw to itself gold or lead from a distance, but remains fixed in its place.

CHAPTER XXXIX.

OF MUTUALLY REPELLANT BODIES.

AUTHORS who have treated of the forces of attracting bodies have discoursed of the powers of repellant bodies also; and in particular those who have classified objects in nature according to sympathy and antipathy. It would seem, therefore, that we must needs say something about the strife of bodies among themselves, lest widespread errors, accepted by all to the ruin of true philosophy, should extend farther. They tell us that as like things attract for conservation's sake, so unlike things and opposites repel and drive each other away, as is seen in the *antiperistasis* (counteraction) of many bodies; but it is most potent in plants and animals, which, as they attract things in affinity and of kin, so do put away things extreme and disadvantageous to themselves. But in other bodies the same reason does not exist for their coming together by mutual attraction when they are separated. Animals take food (as do all things that live), bring it into their inwards, absorb their nourishment by means of certain organs (the vital principle acting and operating). Only things set before them and adjoining them do they enjoy through a natural instinct, not things placed afar; herein there is no exercise of force, no movement on the part of those other things; and therefore animals neither attract bodies nor repel. Water does not repel oil, as some do think, for oil floats on water; nor does water repel mud, because when mixed with water it settles at last. This is a separation of bodies unlike or not perfectly mixed, because of their matter; but after they have been separated, they still remain in conjunction without any natural strife. Thus, in the bottom of a vessel, muddy sediment rests quiet, and oil remains on the top of water, nor is it ordered away. A drop of water remains whole on a dry surface, nor is it chased away by the dry. Wrongly, therefore, do they who discourse of these things impart an antipathy —*antipathia* (i.e., a power of repulsion through opposite passions); for neither is there in them any repellant force, and repulsion comes of action not of passion. But these people dearly love their Greek terms. The question for us is whether there is any body that drives another away to a distance without material impetus, as the loadstone attracts. Now a loadstone does repel another loadstone; for the pole of one is repelled by the pole of another that does not agree naturally with it; driving it, it makes it turn round so that they may come together perfectly according to nature. But if a weak loadstone floating freely in water cannot, on account of obstacles, readily turn about, then it is repelled and driven farther away by the other. All electrics attract objects of every kind; they never repel or propel. What is told of some plants (e.g., of the cucumber, which, when oil is placed beneath it, moves away) is a material change from neighborhood, not a hidden sympathy. But when they show you a candle's flame that touches a cold solid (as iron) turning to one side, and pretend that here is antipathy, they talk nonsense. The reason of this they will see clearer than light when we come to treat of heat and what it is. As for Fracastorio's belief that a loadstone may be found that shall repel iron, in virtue of some principle latent in it that is opposed to iron, it is without any foundation.

BOOK III.

CHAPTER I.

OF DIRECTION.

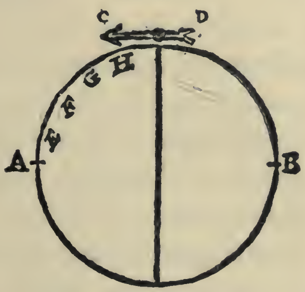
IN the ioregoing books it has been shown that a loadstone has its poles, iron also poles, and rotation, and fixed verticity, and finally that loadstone and iron direct their poles toward the poles of the earth. But now we have to set forth the causes of these things and their wonderful efficiencies known aforetime but not demonstrated. Of these rotations all the writers who went before us have given their opinions with such brevity and indefiniteness that, as it would seem, no one could be persuaded thereby, while the authors themselves could hardly be contented with them. By men of intelligence, all their petty reasonings—as being useless, questionable, and absurd, and based on no proofs or premises—are rejected with the result that magnetic science, neglected more and more and understood by none, has been exiled. The true south pole,* and not the north (as before our time all believed), of a loadstone placed on its float in water turns to the north; the south end of a piece of magnetized and of unmagnetized iron also moves to the north. An oblong piece of iron of three or four finger-breadths, properly stroked with a loadstone, quickly turns to north and south. Therefore artificers place such a bar, balanced on a point, in a compass-box or in a sun-dial; or they construct a versorium out of two curved pieces of iron that touch at their extremities so that the movement may be more constant; thus is constructed the mariner's compass, an instrument beneficial, salutary, and fortunate for seamen, showing the way to safety and to port. But it is to be understood at the threshold of their argument, before we proceed farther, that these directions of loadstone or of iron are not ever and always toward the world's true poles, that they do not always seek those fixed and definite points, nor rest on the line of the true meridian, but that at places, more or less far apart, they commonly vary either to the east or to the west; sometimes, too, in certain regions of land or sea, they point to the true poles. This discrepance is known as the variation of the needle and of the loadstone; and as it is produced by other causes and is, as it were, a sort of perturbation and depravation of the true direction, we propose to treat here only of the true direction of the compass and the magnetic needle, which would all over the earth be the same, toward the true poles and in the true meridian, were not hindrances and disturbing causes present to prevent: in the book next following we will treat of its variation and of the cause of perturbation.

They who aforetime wrote of the world and of natural philosophy, in particular those great elementarian philosophers and all their progeny and pupils down to our day; those, I mean, who taught that the earth is ever at rest, and is, as it were, a dead-weight planted in the centre of the universe at equal distance everywhere from the heavens, of simple uncomplex matter possessing only the qualities of dryness and cold—these philosophers were ever seeking the causes of things in the heavens, in the stars, the planets; in fire, air, water, and in the bodies of compounds; but never did they recognize that the terrestrial globe, besides dryness and cold, hath some principal, efficient, predominant potencies that give to it firmness, direction, and movement throughout its entire mass and down to its inmost depths; neither did they make inquiry whether such things were, and, for this reason, the common herd of philosophizers, in search of the causes of magnetic movements, called in causes remote and far away. Martinus Cortesius, who would be content with no cause whatever in the universal world, dreamt of an attractive magnetic point beyond the heavens, acting on iron. Petrus Peregrinus holds that direction has its rise at the celestial poles. Cardan was of the opinion that the rotation of iron is caused by the star in the tail of Ursa Major. The Frenchman Bessard thinks that the magnetic needle turns to the pole of the zodiac. Marsilius Ficinus will have it that the loadstone follows its Arctic pole, and that iron follows the loadstone, and chaff follows amber: as for amber, why, that, mayhaps, follows the Antarctic pole: emptiest of dreams! Others have come down to rocks and I know not what "magnetic mountains"! So has ever been the wont of mankind: homely things are vile; things from abroad and things afar are dear to them and the object of longing. As for us, we are habitants of this very earth, and study it as cause of this mighty effect. Earth, the mother of all, hath these causes shut up in her recesses: all magnetic movements are to be considered with respect to her law, position, constitution, verticity, poles, equator, horizon, meridians, centre, periphery, diameter, and to the form of her whole inward substance. So hath the earth been ordered by the Supreme Artificer and by nature, that it shall have parts unlike in position, terminal points of an entire and absolute body, and such points dignified by distinct functions, whereby it shall itself take a fixed direction. For like as a loadstone, when in a suitable vessel it is floated on water, or when it is suspended in air by a slender thread, does by its native verticity, according to the magnetic laws, conform its poles to the poles of the common mother,—so, were the earth to vary from her natural direction and from her position in the universe, or were her poles to be pulled toward the rising or the setting sun, or other points whatsoever in the visible firmament (were that possible), they would recur again by a magnetic movement to north and south, and halt at the same points where now they stand. But why the terrestrial globe should seem constantly to turn one of its poles toward those points and toward Cynosura [constellation of the Lesser Bear], or why her poles should vary from the poles of the ecliptic by 23 deg. 29 min., with some variation not yet sufficiently studied by astronomers,—that depends on the magnetic energy. The causes of the precession of the equinoxes and of the progression of the fixed stars, as well as of change in the declinations of the sun and the tropics, are traceable to magnetic forces: hence we have no further need of Thebit Bencora's "movement of trepidation," which is at wide variance with observations.[1] A rotating needle turns to conformity with the situa-

[1] Abú l'Hasan Thábet Ben Korrah, celebrated philosopher and geometrician, born in Mesopotamia A.D. 835–836, was appointed by Mo'tadhed Billah, sixteenth of the 'Abbaside Khalifs, one of his astrologers, and is the author of numerous treatises on mathematics and other scientific subjects, as well as of several works in Syriac, and many translations in Arabic, the bare mention of the titles of which take up nearly two folio pages of Casiri's Catalogue.

tion of the earth, and, though it be shaken oft, returns still to the same points. For in far northern climes, in latitude 70 to 80 deg. (whither in the milder season our seamen are wont to penetrate without injury from the cold), and in the middle regions, in the torrid zone under the equinoctial line, as also in all maritime regions and lands of the southern hemisphere, at the highest latitudes yet known, the magnetic needle ever finds its direction and ever tends in the same way (barring difference of variation) on this side of the equator where we dwell and in the other, the southern part, which, though less known, has been to some extent explored by our sailors: and the lily of the mariner's compass ever points north. Of this, we are assured by the most illustrious navigators and by many intelligent seamen. The same was pointed out to me and confirmed by our most illustrious Neptune, Francis Drake, and by Thomas Candish [Cavendish], that other world-explorer.

Our terrella teaches the same lesson. The proposition is demonstrated on a spherical loadstone. Let *A*, *B* be the poles; *CD*, an iron wire placed on the stone, always tends direct in



the meridian to the poles *A*, *B*, whether the centre of the wire be in the middle line or equator of the stone, or whether it be in any other region between equator and poles, as *H*, *G*, *F*, *E*.

So the point of a magnetized needle looks north on this side of the equator: on the other side the crotch is directed to the south; but the point or lily does not turn to the south below the equator, as somebody has thought. Some inexperienced persons, however, who, in distant regions below the equator, have at times seen the needle grow sluggish and less prompt, have deemed the distance from the Arctic pole or from the magnetic rocks to be the cause. But they are very much mistaken, for it has the same power and adjusts itself as quickly to the meridian as the point of variation in southern regions as in northern. Yet at times the movement appears to be slower, the point on which the compass needle is poised becoming in time, during a long voyage, rather blunt, or the magnetized needle itself having lost somewhat of its acquired force through age or from rusting. This, too, may be tested experimentally by poising the versorium of a sun-dial on a rather short-pointed needle rising perpendicularly out of the surface of the terrella. The magnetized needle turns to the poles of the terrella, and quits the earth's poles; for a general cause that is remote is overcome by a particular cause that is present and strong. Magnetized bodies incline of their own accord to the earth's position, and they conform to the terrella. Two loadstones of equal weight and force conform to the terrella in accordance with magnetic laws. Iron gets force from the loadstone and is made to conform to the magnetic movements. Therefore true direction is the movement of a magnetized body in the line of the earth's verticity toward the natural position and unition of both, their forms being in accord and supplying the forces. For we have, after many experiments in various ways, found that the disposing and ranging of the magnetized bodies depends on the differences of position, while the force that gives the motion is the one form common to both; also that in all magnetic bodies there is attraction and repulsion. For both the loadstone and the magnetized iron conform themselves, by rotation and by dip, to the common position of nature and the earth. And the earth's energy, with the force inhering in it as a whole, by pulling toward its poles and by repelling, arranges in order all magnetic bodies that are unattached and lying loose. For in all things do all magnetic bodies conform to the globe of earth in accordance with the same laws and in the same ways in which another loadstone or any magnetic body whatsoever conforms to the terrella.

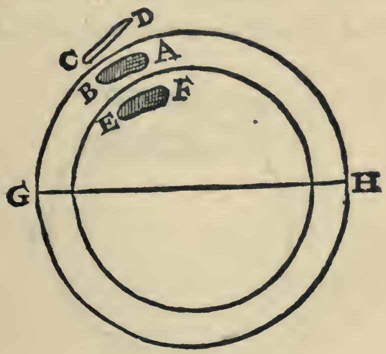
CHAPTER II.

DIRECTIVE (OR VERSORIAL) FORCE, WHICH WE CALL VERTICITY: WHAT IT IS; HOW IT RESIDES IN THE LOADSTONE; AND HOW IT IS ACQUIRED WHEN NOT NATURALLY PRODUCED.

THE directive force, which by us is also called verticity, is a force distributed by the innate energy from the equator in both directions to the poles. That energy, proceeding north and south to the poles, produces the movement of direction, and produces also constant and permanent station in the system of nature, and that not in the earth alone but in all magnetic bodies also. Loadstone occurs either in a special vein or in iron mines, for, being a homogenic earth-substance possessing and conceiving a primary form, it becomes converted into or concreted with a stony body which, in addition to the prime virtues of the form, derives from different beds and mines, as from different matrices, various dissimilitudes and differences, and very many secondary qualities and varieties of its substance. A loadstone mined in this *débris* of the earth's surface and of its projections, whether it be (as sometimes found in China) entire in itself, or whether it be part of a considerable vein, gets from the earth its form and imitates the nature of the whole. All the inner parts of the earth are in union and act in harmony, and produce direction to north and south. Yet the magnetic bodies that in the topmost parts of the earth attract one another are not true united parts of the whole, but are appendages and agnate parts that copy the nature of the whole; hence, when floating free on water, they take the direction they have in the terrestrial order of nature. * We once had chiselled and dug out of its vein a loadstone 20 pounds in weight, having first noted and marked its extremities; then, after it had been taken out of the earth, we placed it on a float in water so it could freely turn about; straightway that extremity of it which in the mine looked north turned to the north in water and after a while there abode; for the extremity that in the mine looks north is austral and is attracted by the north parts of earth, just as in the case of iron, which takes verticity from the earth. Of these points we will treat later under the head of "Change of Verticity."

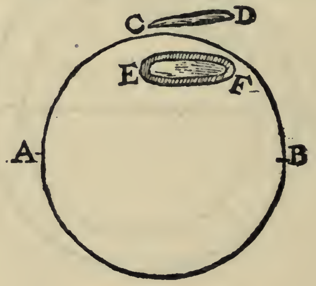
But different is the verticity of the inward parts of the earth that are perfectly united to it and that are not separated from the true substance of the earth by interposition of bodies, as are separated loadstones situated in the outer portion of the globe, where all is defective, spoilt, and irregular. Let *AB* be a loadstone mine, and between it and the uniform earthen globe suppose there are various earths and mixtures that in a manner separate the mine from the true globe of the earth.

It is therefore informated by the earth's forces just as *CD*, a mass of iron, is in air; hence the extremity *B* of the mine or of any part thereof moves toward the north pole *G*, just as does *C*, the extremity of the mass of iron, but not *A* nor *D*. But with the part *EF*, which comes into existence continuous with the whole and which is not separated from it by any



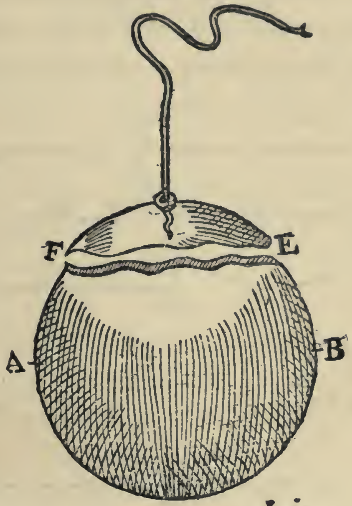
mixed earthy matter, the case is different. For if the part *EF*, being taken out, were to be floated, it is not *E* that would turn to the north pole, but *F*. Thus, in those bodies which acquire verticity in the air, *C* is the south extremity and is attracted by the north pole *G*. In those which come into existence in the detrital outermost part of the earth, *B* is south, and so goes to the north pole. But these parts which, deep below, are of even birth with the earth, have their verticity regulated differently. For here *F* turns to the north parts of the earth, being a south part; and *E* to the south parts of the earth, being a north part. So the end *C* of the magnetic body *CD*, situate near the earth, turns to the north pole; the end *B* of the agnate body *BA* to the north; the end *E* of the inborn body *EF* to the south pole—as is proved by the following demonstration and as is required by all magnetic laws.

Describe a terrella with poles *A*, *B*; from its mass separate the small part *EF*, and suspend that by a fine thread in a cavity or pit in the terrella. *E* then does not seek the pole *A* but the pole *B*, and *F* turns to *A*, behaving quite differently from the iron bar *CD*; for, there, *C*, touching a north part of the terrella, becomes magnetized and turns to *A*, not to *B*. But here it is to be remarked that if pole *A* of the terrella * were to be turned toward the southern part of the earth, still



the end *E* of the solitary part cut out of the terrella and not brought near the rest of the stone would turn to the south; but the end *C* of the iron bar would, if placed outside the magnetic field, turn to the north. Suppose that in the unbroken terrella the part *EF* gave the same direction as the whole; now break it off and suspend it by a thread, and *E* will turn to *B* and *F* to *A*. Thus parts that when joined with the whole have the same verticity with it, on being separated take the opposite; for opposite parts attract opposite parts, yet this is not a true opposition, but a supreme concordance and a true and genuine conformance of magnetic bodies in nature, if they be but divided and separated; for the parts thus divided must needs be carried away some distance above the whole, as later will appear. Magnetic bodies seek formal unity, and do not so much regard their own mass. Hence the part

FE is not attracted into its pit, but the moment it wanders* abroad and is away from it, is attracted by the opposite pole. But if the part *FE* be again placed in its pit or be brought



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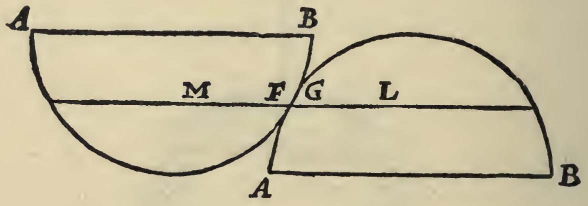
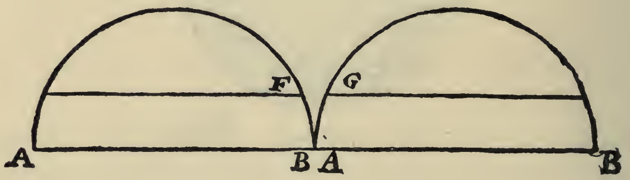
near without any media interposed, it acquires the original combination, and, being again a united portion of the whole, co-operates with the whole and readily clings in its pristine position, while *E* remains looking toward *A* and *F* toward *B*, and there they rest unchanging.

The case is the same when we divide a loadstone into two* equal parts from pole to pole. In the figure, a spherical stone is divided into two equal parts along the axis *AB*; hence, whether the surface *AB* be in one of the two parts supine (as in the first diagram), or prone in both (as in the second), the end* *A* tends to *B*. But it is also to be understood that the point *B* does not always tend sure to *A*, for, after the division, the verticity goes to other points, for example to *F*, *G*, as is shown in Chapter XIV of this Third Book. *LM*, too, is now the axis of the two halves, and *AB* is no longer the axis; for, once a magnetic body is divided, the several parts are integral and magnetic, and have vertices proportional to their mass, new poles arising at each end on division. But the axis and poles ever follow the track of a meridian, because the force





proceeds along the stone's meridian circles from the equinoctial to the poles invariably, in virtue of an innate energy that belongs to matter, owing to the long and secular position, and bearings toward the earth's poles, of a body possessing the fit properties; and such body is endowed with force from the earth for ages and ages continuously, and has from its first beginning stood firmly and constantly turned toward fixed and determinate points of the same.

CHAPTER III.

HOW IRON ACQUIRES VERTICITY FROM THE LOADSTONE, AND HOW THIS VERTICITY IS LOST OR ALTERED.

An oblong piece of iron, on being stroked with a loadstone, receives forces magnetic, not corporeal, nor inhering in or consisting with any body, as has been shown in the chapters on coition. Plainly, a body briskly rubbed on one end with a loadstone, and left for a long time in contact with the stone, receives no property of stone, gains nothing in weight; for if you weigh in the smallest and most accurate scales of a goldsmith a piece of iron before it is touched by the loadstone you will find that after the rubbing it has the same precise weight, neither less nor more. And if you wipe the magnetized iron * with cloths, or if you rub it with sand or with a whetstone, it loses naught at all of its acquired properties. For the force is diffused through the entirė body and through its inmost parts, and can in no wise be washed or wiped away. Test it, therefore, in fire, that fiercest tyrant of nature. Take a piece of iron the length of your hand and as thick as a goose-quill; pass it through a suitable round piece of cork and lay it on the surface of water, and note the end of the bar that looks north. Rub that end with the true smooth end of a loadstone; thus the magnetized iron is made to turn to the north. Take off the cork and put that magnetized end of the iron in the fire * till it just begins to glow; on becoming cool again it will retain the virtues of the loadstone and will show verticity, though not so promptly as before, either because the action of the fire was not kept up long enough to do away all its force, or be cause the whole of the iron was not made hot, for the property is diffused throughout the whole. Take off the cork again, drop the whole of the iron into the fire, and quicken the fire with bellows so that it becomes all alive, and let the glowing iron remain for a little while. After it has grown cool again (but in cooling it must not remain in one position) put iron and *cork once more in water, and you shall see that it has lost its acquired verticity. All this shows how difficult it is to do away with the polar property conferred by the loadstone. And were a small loadstone to remain for as long in the same fire, it too would lose its force. Iron, because it is not so easily destroyed or burnt as very many loadstones, retains its powers better, and after they are lost may get them back again from a loadstone; but a burnt loadstone cannot be restored.

Now this iron, stripped of its magnetic form, moves in a way different from any other iron, for it has lost the polar property; and though before contact with the loadstone it may have had a movement to the north, and after contact toward *the south, now it turns to no fixed and determinate point; but afterward, very slowly, after a long time, it turns unsteadily toward the poles, having received some measure of force from the earth. There is, I have said, a twofold cause of direction,—one native in the loadstone and in iron, and the other in the earth, derived from the energy that disposes things. For this reason it is that after iron has lost the faculty of distinguishing the poles and verticity, a tardy and feeble power of direction is acquired anew from the earth's verticity. From this we see how difficultly, and how only by the action of intense heat and by protracted firing of the iron till it becomes soft, the magnetic force impressed in it is done away. When this firing has suppressed the acquired polar power, and the same is now quite conquered and as yet has not been called to life again, the iron is left a wanderer, and quite incapable of direction.

But we have to inquire further how it is that iron remains possessed of verticity. It is clear that the presence of a loadstone strongly affects and alters the nature of the iron, also that it draws the iron to itself with wonderful promptness. Nor is it the part rubbed only, but the whole of the iron, that is affected by the friction (applied at one end only), and therefrom the iron acquires a permanent though unequal power, as is thus proved.

Rub with a loadstone a piece of iron wire on one end so as * to magnetize it and to make it turn to the north; then cut off part of it, and you shall see it move to the north as before, though weakly. For it is to be understood that the loadstone awakens in the whole mass of the iron a strong verticity (provided the iron rod be not too long), a pretty strong verticity in the shorter piece throughout its entire length, and, as long as the iron remains in contact with the loadstone, one somewhat stronger still. But when the iron is removed from contact it becomes much weaker, especially in the end not touched by the loadstone. And as a long rod, one end of which is thrust into a fire and made red, is very hot at that end, less hot in the parts adjoining and midway, and at the farther end may be held in the hand, that end being only warm,—so the magnetic force grows less from the excited end to the other; but it is there in an instant, and is not introduced in any interval of time nor successively, as when heat enters iron, for the moment the iron is touched by the loadstone it is excited throughout. For example, take an unmagnetized iron rod, * 4 or 5 inches long: the instant you simply touch with a loadstone either end, the opposite end straightway, in the twinkling of the eye, repels or attracts a needle, however quickly brought to it.[1]

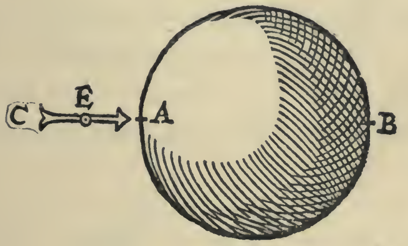
CHAPTER IV.

WHY MAGNETIZED IRON TAKES OPPOSITE VERTICITY; AND WHY IRON TOUCHED BY THE TRUE NORTH SIDE OF THE STONE MOVES TO THE EARTH'S NORTH, AND WHEN TOUCHED BY THE TRUE SOUTH SIDE TO THE EARTH'S SOUTH: IRON RUBBED WITH THE NORTH POINT OF THE STONE DOES NOT TURN TO THE SOUTH, NOR *vice versa*, AS ALL WRITERS ON THE LOADSTONE HAVE ERRONEOUSLY THOUGHT.

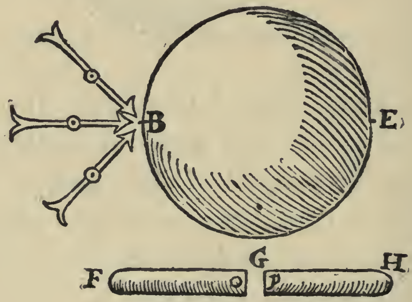
IT has already been shown that the north part of a loadstone does not attract the north part of another stone, but the south part, and that it repels the north end of another stone applied to its north end. That general loadstone, the terrestrial globe, does with its inborn force dispose magnetized iron, and the magnetic iron too does the same with its inborn force, producing movement and determining the direction. For whether we compare together and experiment on two loadstones, or a loadstone and piece of iron, or iron and iron, or earth and loadstone, or earth and iron conformated by the earth or deriving force from the energy of a loadstone, of necessity the forces and movements of each and all agree and harmonize in the same way.

[1] Dr. J. Lamont's "Handbuch des Magnetismus," Leipzig 1867, page 383.

But the question arises, Why does iron touched with loadstone take a direction of movement toward the earth's opposite pole and not toward that pole of earth toward which looked the pole of the loadstone with which it was magnetized? Iron and loadstone, we have said, are of the same primary nature: iron when joined to a loadstone becomes as it were one body with it, and not only is one extremity of the iron altered, but the rest of its parts are affected. Let *A* be the north pole of a loadstone to which is attached the tip of an iron pointer: the tip is now the south part of the iron, because it is con-

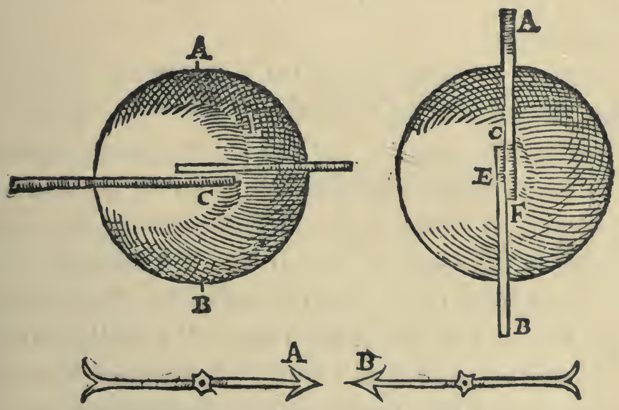


tiguous to the north part of the stone; the crotch of the pointer becomes north. For were this contiguous magnetic body separated from the pole of the terrella or the parts nigh the pole, the other extremity (or the end which when there was conjunction was in contact with the north part of the stone) is south, while the other end is north. So, too, if a magnetized needle be divided into any number of parts however minute, those separated parts will take the same direction which they had before division. Hence, as long as the point of the needle remains at *A*, the north pole, it is not austral, but is, as it were, part of a whole; but when it is taken away from the stone it is south, because on being rubbed it tended toward the north parts of the stone, and the crotch (the other end of the pointer) is north. The loadstone and the pointer constitute one body: *B* is the south pole of the whole mass; *C* (the crotch) is the north extremity of the whole. Even divide the needle in two at *E*, and *E* will be south as regards the crotch, *E* will also be north with reference to *B*. *A* is the true north pole of the stone, and is attracted by the south pole of the earth. The end of a piece of iron touched with the true north part of the stone is south, and turns to the north pole of the stone *A* if it be near; if it be at a distance from the stone, it turns to the earth's north. So whenever iron is magnetized it tends (if free and unrestrained) to the portion of the earth * opposite the part toward which inclines the loadstone at which it was rubbed. For verticity always enters the iron if only it be magnetized at either end. Hence all the needle points at *B* acquire the same verticity after being separated, but it is



the opposite verticity to that of the pole *B* of the stone; and all the crotches in the present figure have a verticity opposite to that of the pole *E*, and are made to move and are seized by *E* when they are in suitable position. The case is as in the oblong stone *FH*, cut in two at *G*, where *F* and *H*, whether the stone be whole or be broken, move to opposite poles of the earth, and *O* and *P* mutually attract, one being north, the other south. For if in the whole stone *H* was south and *F* north, then in the divided stone *P* will be north with respect to *H* and *O*, south with respect to *F*; so, too, *F* and *H* tend toward connection if they be turned round a little, and at length they come together. But if the division be made meridionally, i.e., along the line of the meridian and not on any parallel circle, then the two parts turn about and *A* pulls *B*, and the end *B*

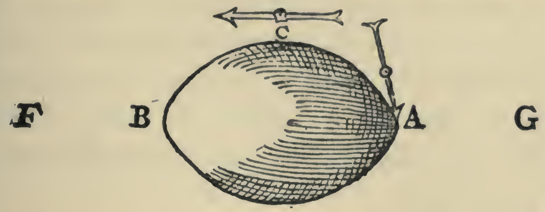
is attracted to *A*, until, being turned round, they form connection and are held together. For this reason, iron bars placed *
on parallels near the equator of a terrella whose poles are *AB*, do not combine and do not cohere firmly; but when placed



alongside on a meridian line, at once they become firmly joined, *
not only on the stone and near it, but at any distance within

the magnetic field of the controlling loadstone. Thus they are held fast together at *E*, but not at *C* of the other figure. For the opposite ends *C* and *F* of the bars, come together and cohere, as the ends *A* and *B* of the stone did. But the ends are opposite, because the bars proceed from opposite poles and parts of the terrella; and *C* is south as regards the north pole * *A*, and *F* is north as regards the south pole *B*. Similarly, too, they cohere if the rod *C* (not too long) be moved further toward *A*, and the rod *F* toward *B*, and they will be joined on the terrella just as *A* and *B* of the divided stone were joined. But * now if the magnetized needle point *A* be north, and if with this you touch and rub the point *B* of another needle that rotates freely but is not magnetized, *B* will be north and will turn to the south. But if with the north point *B* you touch still another new rotatory needle on its point, that point again will be south, and will turn to the north: a piece of iron not only takes from the loadstone, if it be a good loadstone, the forces needful for itself, but also, after receiving them, infuses them into another piece, and that into a third, always with due regard to magnetic law.

In all these our demonstrations it is ever to be borne in mind that the poles of the stone as of the iron, whether magnetized or not, are always in fact and in their nature opposite to the pole toward which they tend, and that they are thus named by us, as has been already said. For, everywhere, that is north which tends to the south of the earth or of a terrella, and that is south which turns to the north of the stone. Points that are * north are attracted by the south part of the earth, and hence when floated they tend to the south. A piece of iron rubbed with the north end of a loadstone becomes south at the other end and tends always (if it be within the field of a loadstone and near) to the north part of the loadstone, and to the north part of the earth if it be free to move and stand alone at a distance from the loadstone. The north pole *A* of a loadstone turns to the south of the earth, *G*; a needle magnetized on



its point by the part *A* follows *A*, because the point has been made south. But the needle *C*, placed at a distance from the loadstone, turns its point to the earth's north, *F*, for that point was made south by contact with the north part of the loadstone. Thus the ends magnetized by the north part of the stone become south, or are magnetized southerly, and tend to the earth's north; the ends rubbed with the south pole become north, or are magnetized northerly, and tend to the earth's south.

CHAPTER V.

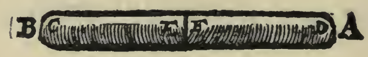
OF MAGNETIZING STONES OF DIFFERENT SHAPES.

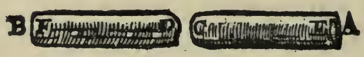
Of a magnetized piece of iron one extremity is north, the other south, and midway is the limit of verticity: such limit, in the globe of the terrella or in a globe of iron, is the equinoctial circle. But if an iron ring be rubbed at one part with a loadstone, then one of the poles is at the point of friction, and the other pole at the opposite side; the magnetic force divides the ring into two parts by a natural line of demarkation, which, though not in form, is in its power and effect equinoctial. But if a straight rod be bent into the form of a ring without welding and unition of the ends, and it be touched in the middle with a loadstone, the ends will be both of the same verticity. * Take a ring, whole and unbroken, rubbed with a loadstone at * one point; then cut it across at the opposite point and stretch it out straight: again both ends will be of the same verticity, —just like an iron rod magnetized in the middle, or a ring not cohering at the joint.

CHAPTER VI.

WHAT SEEMS TO BE A CONTRARY MOVEMENT OF MAGNETIC BODIES IS THE REGULAR TENDENCE TO UNION.

IN magnetic bodies nature ever tends to union—not merely to confluence and agglomeration, but to agreement, so that the force that causes rotation and bearing toward the poles may not be disordered, as is shown in various ways in the following example. Let *CD* be an unbroken magnetic body, with *C*





looking toward *B*, the earth's north, *B* and *D* toward *A*, the * earth's south. Now cut it in two in the middle, in the equator, and then E will tend to A and F to B. For, as in the whole, so in the divided stone, nature seeks to have these bodies united; hence the end E properly and eagerly comes together again with F, and the two combine, but E is never joined to D nor F to C, for, in that case, C would have to turn, in opposition, to nature, to A, the south, or D to B, the north—which were abnormal and incongruous. Separate the halves of the stone and turn D toward C: they come together nicely and combine. For D tends to the south, as before, and C to the north; E and F, which in the mine were connate parts, are now greatly at variance, for they do not come together on account of material affinity, but take movement and tendence from the form. Hence the ends, whether they be conjoined or separate, tend in the same way, in accordance with magnetic law, toward the earth's poles in the first figure of the stone, whether unbroken or divided as in the second figure; and FE of the second figure, when the two parts come together and form one body, is as perfect a magnetic mass as was CD when first produced in the mine; and FE, placed on a float, turn to the earth's poles, * and conform thereto in the same way as the unbroken stone.

This agreement of the magnetic form is seen in the shapes of plants. Let AB be a branch of ozier[1] or other tree that *

sprouts readily; and let A be the upper part of the branch and be the part rootward. Divide the branch at CD. Now,

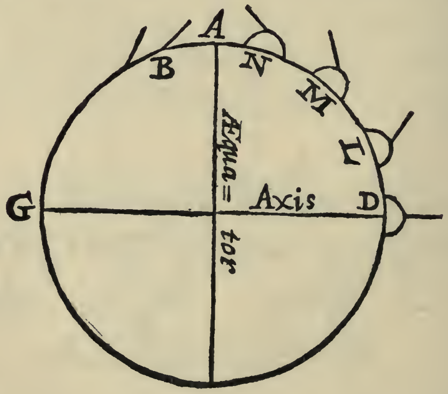
[1] Ozier, osier, a species of willow (*salix*).

the extremity *CD*, if skilfully grafted again on *D*, begins to grow, just as *B* and *A*, when united, become consolidated and germinate. But if *D* be grafted in *A*, or *C* on *B*, they are at variance and grow not at all, but one of them dies because of the preposterous and unsuitable apposition, the vegetative force, which tends in a fixed direction, being now forced into a contrary one.

CHAPTER VII.

A DETERMINATE VERTICITY AND A DIRECTIVE POWER MAKE MAGNETIC BODIES ACCORD, AND NOT AN ATTRACTIONAL OR A REPULSATIVE FORCE, NOR STRONG COITION ALONE OR UNITION.

IN the equinoctial circle *A* there is no coition of the ends of a piece of iron wire with the terrella; at the poles the

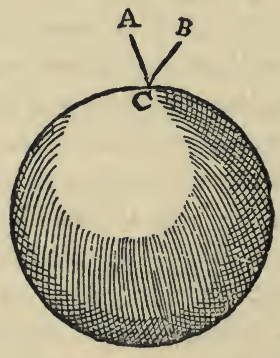


coition is very strong. The greater the distance from the equinoctial the stronger is the coition with the terrella itself, and with any part thereof, not with the pole only. But the pieces of iron are not made to stand because of any peculiar attracting force or any strong combined force, but because of the common energy that gives to them direction, conformity, and rotation. For in the region *B* not even the minutest bit* of iron that weighs almost nothing can be reared to the perpendicular by the strongest of loadstones, but adheres obliquely. And just as the terrella attracts variously, with unlike* force, magnetic bodies, so, too, an iron hump (or protuberance —*nasus*) attached to the stone has a different potency according to the latitude: thus the hump *L*, as being strongly adherent, will carry a greater weight than *M*, and *M* a heavier weight than *N*. But neither does the hump rear to perpendicular a bit of iron except at the poles, as is shown in the figure. The hump *L* will hold and lift from the ground two ounces of solid iron, yet it is unable to make a piece of iron wire weighing* two grains stand erect; but that would not be the case if verticity arose from strong attraction, or more properly coition, or from unition.

CHAPTER VIII.

OF DISAGREEMENTS BETWEEN PIECES OF IRON ON THE SAME POLE OF A LOADSTONE; HOW THEY MAY COME TOGETHER AND BE CONJOINED.

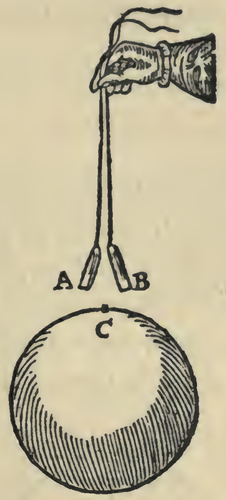
If two pieces of iron wire or two needles above the poles of a terrella adhere, when about to be raised to the perpendicular they repel each other at their upper ends and present* a furcate appearance; and if one end be forcibly pushed toward the other, that other retreats and bends back to avoid the association, as shown in the figure. *A* and *B*, small iron rods,



adhere to the pole obliquely because of their nearness to each other: either one alone would stand erect and perpendicular. The reason of the obliquity is that *A* and *B*, having the same verticity, retreat from each other and fly apart. For if *C* be the north pole of a terrella, then the ends *A* and *B* of the rods are also north, while the ends in contact with and held fast by the pole *C* are both south. But let the rods be rather long (say two finger-breadths), and let them be held together by force: then they cohere and stand together like friends, nor can they be separated save by force, for they are held fast to each other magnetically, and are no longer two distinct terminals but one only and one body, like a piece of wire bent double and made to stand erect.

But here we notice another curious fact, viz., that if the rods be rather short, not quite a finger's breadth in length, or as long as a barley-corn, they will not unite on any terms, nor will they stand up together at all, for in short pieces of wire the verticity at the ends farthest from the terrella is stronger and the magnetic strife more intense than in longer pieces.

Therefore they do not permit any association, any fellowship. Again, if two light pieces of wire, *A* and *B*, be suspended



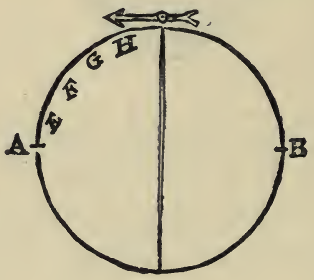
by a very slender thread of silk filaments not twisted but laid together,[1] and held at the distance of one barley-corn's* length from the loadstone, then the opposite ends, *A* and *B*, situate within the sphere of influence above the pole, go a little apart for the same reason, except when they are very near the pole *C* of the stone : in that position the stone attracts them to the one point.

[1] See Book I, Chapter XII.

CHAPTER IX.

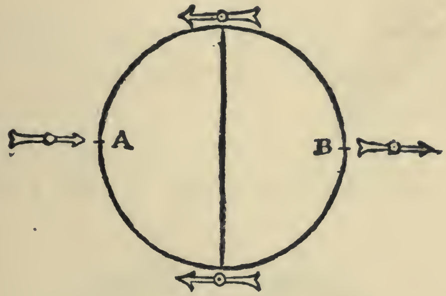
DIRECTIONAL FIGURES SHOWING THE VARIETIES OF ROTATION.

HAVING now sufficiently shown, according to magnetic laws and principles, the demonstrable cause of the motion toward determinate points, we have next to show the movements. On a spherical loadstone having the poles *A*, *B*, place a rotating needle whose point has been magnetized by the pole *A* : that point will be directed steadily toward *A* and attracted by *A*,



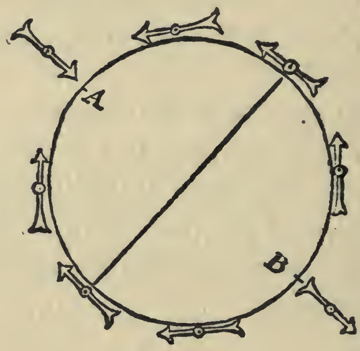
because, having been magnetized by *A*, it accords truly and combines with *A* ; and yet it is said to be opposite because when the needle is separated from the stone it moves to the opposite part of earth from that toward which the loadstone's pole *A* moves. For if *A* be the north pole of the terrella, the point of the needle is its south end, and its other end, the crotch, points to *B* : thus *B* is the loadstone's south pole, while the crotch of the needle is the needle's north end. So, too, the point is attracted by *EFGH* and by every part of a meridian from the equator to the pole, because of the power of directing; and when the needle is in those places on the meridian the point is directed toward *A*; for it is not the point *A* but the whole loadstone that makes the needle turn, as does the whole earth in the case of magnetic bodies turning to the earth.

The figure following shows the magnetic directions in the right sphere of a loadstone and in the right sphere of the earth, also the polar directions to the perpendicular of the poles. All the points of the versorium have been magnetized by pole *A*. All the points are directed toward *A* except the one that is repelled by *B*.



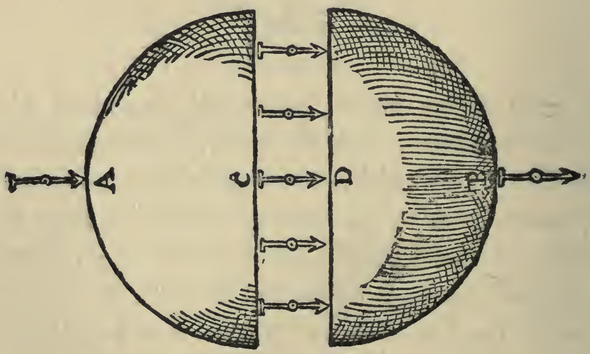
The next figure shows horizontal directions above the body of the loadstone. All the points that have been made south by rubbing with the north pole or some point around the north pole *A*, turn to the pole *A* and turn away from the south pole *B*, toward which all the crotches are directed.

I call the direction horizontal because it coincides with the plane of the horizon; for nautical and horological instruments are so constructed that the needle shall be suspended or supported in equilibrium on a sharp point, which prevents the dip of the needle, as we shall explain later. And in this way it best serves man's use, noting and distinguishing all the points of the horizon and all the winds. Otherwise in every oblique sphere (whether terrella or earth) the needle and all



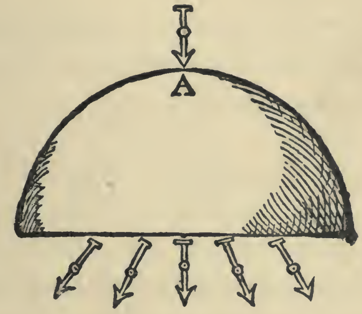
magnetized bodies would dip below the horizon, and, at the poles, the directions would be perpendicular, as appears from our account of the dip.

The next figure shows a spherical loadstone cut in two at the equator; all the points of the needles have been mag-



netized by pole *A*. The points are directed in the centre of the earth and between the two halves of the terrella, divided in the plane of the equator as shown in the diagram. The case would be the same if the division were made through the plane of a tropic and the separation and distance of the two parts were as above, with the division and separation of the loadstone through the plane of the equinoctial. For the points are repelled by *C*, attracted by *D*, and the needles are parallel, the poles or the verticity at both ends controlling them.

The next figure shows half of a terrella by itself, and its directions differing from the directions given by the two parts in the preceding figure, which were placed alongside. All



the points have been magnetized by *A* ; all the crotches below, except the middle one, tend not in a right line but obliquely, to the loadstone, for the pole is in the middle of the plane that before was the plane of the equinoctial. All points magnetized by parts of the loadstone away from the pole move to the pole (just as though they had been magnetized by the pole itself) and not to the place of friction, wherever that may be in the whole stone at any latitude betwixt pole and equator. And for this reason there are only two differences of regions—they are north and south as well in the terrella as in the great globe of earth ; and there is no east, no west place, no regions truly eastern or western, but, with respect to each other, east and west are simply terms signifying toward the east or west part of the heavens. Hence Ptolemy seems in the *Quadripartitum* to err in laying out eastern and western divisions, to which he improperly annexes the planets; he is followed by the rabble of philosophasters and astrologers.

CHAPTER X.

OF THE MUTATION OF VERTICITY AND MAGNETIC PROPERTIES, OR OF THE ALTERATION OF THE FORCE AWAKENED BY THE LOADSTONE.

IRON excited by the magnetic influx has a verticity that is pretty strong, yet not so stable but that the opposite parts may be altered by the friction not only of a stronger but of the same loadstone, and may lose all their first verticity and take on the opposite. Procure a piece of iron wire and with the self-same pole of a loadstone rub each end equally; pass the wire through a suitable cork float and put it in the water. Then one end of the wire will look toward a pole of the earth whereto that end of the loadstone does not look. But which *end of the wire? It will be just the one that was rubbed last. Now rub with the same pole the other end again, and straightway that end will turn in the opposite direction. Again rub the end that first pointed to the pole of the loadstone, and at once that, having, as it were, obtained its orders (*imperium nactus*), will go in the direction opposite to the one it took last. Thus you will be able to alter again and again the property of the iron, and the extremity of it that is last rubbed is master. And now merely hold for a while the north end of the stone near the north end of the wire that was last rubbed, not bringing the two into contact, but at the distance of one, two, or even three finger-breadths, if the* stone be a powerful one; again the iron will change its property and will turn to the opposite direction: so it will, too, though rather more feebly, if the loadstone be four finger-breadths away. The same results are had in all these experiments whether you employ the south or the north part of the stone. Verticity can also be acquired or altered with plates* of gold, silver, and glass between the loadstone and the end of the piece of iron or wire, provided the stone be rather powerful, though the plates of metal be touched neither by the stone nor by the iron. And these changes of verticity occur in cast-iron. But what is imparted or excited by one pole of the loadstone is expelled and annulled by the other, which confers new force. Nor is a stronger loadstone needed to make the iron put off the weaker and sluggish force and to put on a new. Neither is the iron "made drunken" (*inebriatur*) by equal forces of loadstone, so that it becomes "undecided and neutral," as Baptista Porta maintains. But by one same loadstone, and by loadstones endowed with equal power and strength, the force is altered, changed, incited, renewed, driven out. The loadstone itself, however, is not robbed, by friction with another bigger or stronger stone, of its property and verticity, nor is it turned, when on a float, to the opposite direction or to another pole different from that toward which, by its own nature and verticity, it tends. For forces that are innate and long implanted inhere more closely, nor* do they easily retire from their ancient seats; and what is the growth of a long period of time is not in an instant reduced to nothing unless that in which it inheres perishes. Nevertheless change comes about in a considerable interval of time, e.g., a year or two, sometimes in a few months—to wit, when a weaker loadstone remains applied, in a way contrary to the order of nature, to a stronger, i.e., with the north pole of one touching the north pole of the other, or the south of one touching the other's south. Under such conditions, in the lapse of time the weaker force declines.

CHAPTER XI.

OF FRICTION OF IRON WITH THE MID PARTS OF A LOADSTONE BETWEEN THE POLES, AND AT THE EQUINOCTIAL CIRCLE OF A TERRELLA.

TAKE a piece of iron wire not magnetized, three finger-widths long ('twill be better if its acquired verticity be rather weak or deformated by some process); touch and rub it with the equator of the terrella exactly on the equinoctial line along its whole tract and length, only one end, or both ends, or the whole of the iron, being brought into contact. The wire thus rubbed, run through a cork and float it in water. * It will go wandering about without any acquired verticity, and the verticity it had before will be disordered. But if by chance it should be borne in its wavering toward the poles, it will be feebly held still by the earth's poles, and finally will be endowed with verticity by the energy of the earth.

CHAPTER XII.

HOW VERTICITY EXISTS IN ALL SMELTED IRON NOT EXCITED BY THE LOADSTONE.

HITHERTO we have declared the natural and innate causes and the powers acquired through the loadstone; but now we are to investigate the causes of the magnetic virtue existing in manufactured iron not magnetized by the loadstone. The loadstone and iron present and exhibit to us wonderful subtile properties. It has already oft been shown that iron not excited by the loadstone turns to north and south; further, that it possesses verticity, i.e., distinct poles proper and peculiar to itself, even as the loadstone or iron rubbed with the loadstone. This seemed to us at first strange and incredible: the metal, iron, is smelted out of the ore in the furnace, flows out of the furnace, and hardens in a great mass; the mass is cut up in great workshops and drawn out into iron bars, and from these again the smith fashions all sorts of necessary implements and objects of iron. Thus the same mass is variously worked and transformed into many shapes. What, then, is it that preserves the verticity, or whence is it derived? First take a mass of iron as produced in the first iron-works. Get a smith to shape a mass weighing two or three ounces, on the anvil, into an iron bar one palm or nine inches long. Let the smith stand facing the north, with back to the south, so that as he * hammers the red-hot iron it may have a motion of extension northward; and so let him complete the task at one or two heatings of the iron (if needed); but ever while he hammers and lengthens it, have him keep the same point of the iron looking north, and lay the finished bar aside in the same direction. In this way fashion two, three, or more, yea one hundred or four hundred bars: it is plain that all the bars so hammered out toward the north and so laid down while cooling will rotate round their centres and when afloat (being

passed through suitable pieces of cork) will move about in water, and, when the end is duly reached, will point north. And as an iron bar takes verticity from the direction in which it lies while being stretched, or hammered, or pulled, so too * will iron wire when drawn out toward any point of the horizon between east and south or between south and west, or conversely. * Nevertheless, when the iron is directed and stretched rather to a point east or west, it takes almost no verticity, or a very faint verticity. This verticity is acquired chiefly through the lengthening. But when inferior iron ore, in which no magnetic properties are apparent, is put in the fire (its position with reference to the world's poles being noted) and there heated for eight or ten hours, then cooled away from the fire and in the same position with regard to the poles, it acquires verticity according to its position during heating and cooling.

Let a bar of iron be brought to a white heat in a strong fire, in which it lies meridionally, i.e., along the track of a meridian circle; then take it out of the fire and let it cool and return to the original temperature, lying the while in the same position as before: it will come about that, through the like extremities having been directed toward the same poles of the earth, it will acquire verticity; and that the extremity that looked north when the bar, before the firing, was floated in water by means of a cork, if now the same end during the firing and the cooling looked southward, will point to the south. If perchance the turning to the pole should at any time be weak and uncertain, put the bar in the fire again, take it out when it has reached white heat, cool it perfectly as it lies pointing in the direction of the pole from which you wish it to take verticity, and the verticity will be acquired. Let it be heated again, lying in the contrary direction, and while yet white-hot lay it down till it cools; for, from the position in cooling (the earth's verticity acting on it), verticity is infused into the iron and it turns toward points opposite to the former verticity. So the extremity that before looked north now turns to the south. For these reasons and in these ways does the north pole of the earth give to that extremity of the iron which is turned toward it south verticity; hence, too, that extremity is attracted by the north pole. And here it is to be observed that this happens with iron not only when it cools lying in the plane of the horizon, but also at any inclination thereto, even almost up to perpendicular to the centre of the earth. Thus heated iron more quickly gets energy (strength) and verticity from the earth in the very process of returning to soundness in its renascence, so to speak (wherein it is trans- * formated), than when it simply rests in position. This experiment is best made in winter and in a cold atmosphere, when the metal returns more surely to the natural temperature than in summer and in warm climates.[1]

Let us see also what position alone, without fire and heat, and what mere giving to the iron a direction toward the earth's poles may do. Iron bars that for a long time—twenty years * or more—have lain fixed in the north and south position, as bars are often fixed in buildings and in glass windows—such bars, in the lapse of time, acquire verticity, and whether suspended in air or floated by corks on water turn to the pole toward which they used to be directed, and magnetically attract and repel iron in equilibrium; for great is the effect of long-continued direction of a body toward the poles. This, though made clear by plain experiment, gets confirmation for what we find in a letter written in Italian and appended to a work by Master Philip Costa, of Mantua, also in Italian, *Of the Compounding of Antidotes*, which, translated, is as follows: "At Mantua, an apothecary showed to me a piece of iron completely turned to loadstone, so attracting other iron that it might be compared to a loadstone. But this piece of iron, after it had for a long time supported a terra-cotta ornament on the tower of the Church of San Agostino at Rimini, was at

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[1] See John Farrar's "Elem. of Elect. and Magn.," 1826, pages 201, 202.

last bent by the force of the winds and so remained for ten years. The friars, wishing to have it restored to its original shape, gave it to a blacksmith, and in the smithy Master Giulio Cesare, prominent surgeon, discovered that it resembled loadstone and attracted iron. The effect was produced by long-continued lying in the direction of the poles.[1] It is well, therefore, to recall what has already been laid down with regard to alteration of verticity, viz., how that the poles of iron bars are changed when a loadstone simply presents its pole to them and faces them even from some distance. Surely in a like way does that great loadstone the earth affect iron and change verticity. For albeit the iron does not touch the earth's pole nor any magnetic portion of the earth, still the verticity is acquired and altered—not that the earth's pole, that identical point lying thirty-nine degrees of latitude, so great a number of miles, away from this City of London, changes the verticity, but that the entire deeper magnetic mass of the earth which rises between us and the pole, and over which

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[1] It is said by Humboldt (*Cosmos*, 1849, Vol. II, page 718, note) that this observation, the first of the kind, was made on the tower of the Church of the Augustines at Mantua (Mantova), and that Grimaldi and Gassendi were acquainted with similar instances (the cross of the Church of Saint Jean, at Aix, in Provence), all occurring in geographical latitudes where the inclination of the magnetic needle is very considerable. Some writers give Gassendi's observation as occurring during 1632. (See Rohaulti, *Physica*, 1718, Par. III, Cap. 8, p. 399; or Rohault's "System of Nat. Phil.," 1728, page 176.)

"As the iron cross of an hundred weight upon the Church of Saint John in Ariminum, or that Load-ston'd iron of Cæsar Moderatus, set down by Aldrovandus." (Sir Thomas Brown, *Pseudoloxia Epidemica*, 1658, page 66.)

Consult "Lettera dell' Eccel. Cavallara ....," Mantova 1586, for a detailed account of this discovery, made January 6 of the last-named year. The iron rod supported a brick ornament in the form of an acorn, and stood on a pyramid at the summit of the belfry of the Church of St. John the Baptist at Rimini, belonging to the monks of St. Augustine. See Cabeo, *Philos. Magn.*, page 62; "Ulysses Aldrovandi, Patr. Bonon....Barthol. Ambros ....," Lib. I, Cap. VI, p. 134.

stands the iron—that this, with the energy residing within the field of the magnetic force, the matter of the entire orb conspiring, produces verticity in bodies. For everywhere within the sphere of the magnetic force does the earth's magnetic effluence reign, everywhere does it alter bodies. But those bodies that are most like to it and most closely allied, it rules and controls, as loadstone and iron. For this reason it is not altogether superstitious and silly in many of our affairs and businesses to note the positions and configurations of countries, the points of the horizon and the locations of the stars. For as when the babe is given forth to the light from the mother's womb and gains the power of respiration and certain animal functions, and as the planets and other heavenly bodies, according to their positions in the universe and according to their configuration with the horizon and the earth, do then impart to the new-comer special and peculiar qualities; so a piece of iron, while it is being wrought and lengthened, is affected by the general cause, the earth, to wit; and while it is coming back from the fiery state to its original temperature it becomes imbued with a special verticity according to its position. * Long bars have sometimes the same verticity at both ends, and hence they have a wavering and ill-regulated motion on account of their length and of the aforesaid manipulations, just as when an iron wire four feet long is rubbed at both ends with one same pole of a loadstone.

CHAPTER XIII.

WHY NO OTHER BODIES SAVE THE MAGNETIC ARE IMBUED WITH VERTICITY BY FRICTION WITH A LOADSTONE; AND WHY NO BODY NOT MAGNETIC CAN IMPART AND AWAKEN THAT FORCE.

WOOD floating on water never turns by its own forces toward the poles of the world save by chance: so neither threads of gold, silver, copper, zinc, lead, nor glass, when passed through cork and floated, have ever sure direction; and, therefore, when rubbed with a loadstone they show neither poles nor points of variation; for bodies that do not of their own accord turn toward the poles and are not obedient to the earth are in no wise governed by the loadstone's touch; neither has the energy of the loadstone entrance into their interior, nor are their forms excited magnetically; nor, if the energy did enter in, could it effect aught, for the reason that there are no primary qualities in such bodies, mixed as they are with a variety of efflorescent humors and degenerate from the primal property of the globe. On the other hand the properties of iron which are primal are awakened by approach of a loadstone: like brute animals and men when awakened out of sleep, the properties of iron now move and put forth their strength.

Here we must express wonder at a manifest error of Baptista Porta, who, though he properly refuses assent to the inveterate falsehood about a force the opposite of the magnetic, imparts a still falser opinion, to wit, that iron rubbed with diamond turns to the north. "If," he writes, "we rub an iron needle on diamond, and then put it in a boat or on a straw or suspend it properly with a thread, at once it turns to the north like iron rubbed on a loadstone, or perhaps a little more sluggishly. Nay—and this is worthy of remark—the opposite part, like the loadstone itself at its south end, repels iron, and when we experimented with a multitude of small iron rods in water, they all stood at equal distances apart and pointed north." Now this is contrary to our magnetic rules; and hence we made the experiment ourselves with seventy-five * diamonds in presence of many witnesses, employing a number of iron bars and pieces of wire, manipulating them with the greatest care while they floated in water, supported by corks; yet never was it granted me to see the effect mentioned by Porta. He was led astray by the verticity of the iron in the bars or wires got from the earth (as shown above); the iron of itself tended toward its determinate pole, and Porta, ignorant of this, supposed the thing was done by the diamond. But let searchers of the things of nature beware lest they be further deluded by their own faultily observed experiments, and lest, with errors and blunders, they throw into confusion the republic of letters. Diamond (*adamas*) is sometimes called siderite (*siderites*), not because it is ferruginous or that it attracts iron (*σίδηρος*, *sideros*), but on account of its glister, like that of shining iron; this brilliance is possessed by the finest diamonds. On account of this confusion of names many effects are credited to diamond that in fact belong to the loadstone siderite.[1]

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[1] See Book I, Chap. II.

CHAPTER XIV.

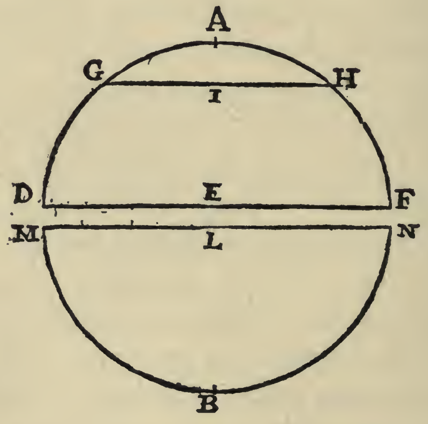
THE POSITION OF A LOADSTONE, NOW ABOVE, ANON BENEATH, A MAGNETIC BODY SUSPENDED IN EQUILIBRIUM, ALTERS NEITHER THE FORCE NOR THE VERTICITY OF THE MAGNETIC BODY.

THIS point we may not rightly pass by, because we must correct an error that has lately arisen out of a faulty observation of Baptista Porta; out of this erroneous judgment, Porta, by vain repetition, makes three chapters, viz., the eighth, the thirty-first, and the sixty-second. Now, if a loadstone or a piece of iron suspended in equilibrium or floating in water is attracted or controlled by another piece of iron or another loadstone held above it, the stone or the iron does not turn to the opposite direction when you apply the second iron or stone beneath; on the contrary, the ends of the floating loadstone or of the floating iron will ever turn to the same points of the stone, however the loadstone or the iron may be suspended in equilibrium or whether they be mounted on a point so that they may revolve freely. Porta was led into error by the uneven shape of some loadstone or by the fact that he did not manage the experiment aright. Thus he is badly mistaken, thinking it fair to infer that, as the loadstone has a north and a south pole, it has also an east and a west, a superior and an inferior, pole. So do many vain imaginations arise out of mistakes committed and accepted as true judgments.

CHAPTER XV.

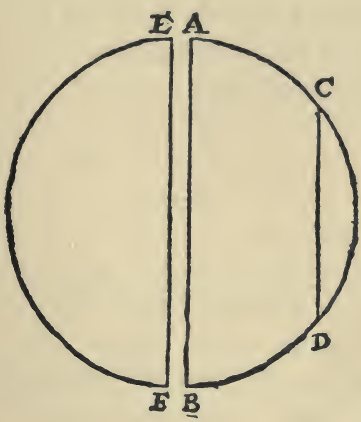
THE POLES, EQUATOR, CENTRE, ARE PERMANENT AND STABLE IN THE UNBROKEN LOADSTONE; WHEN IT IS REDUCED IN SIZE AND A PART TAKEN AWAY, THEY VARY AND OCCUPY OTHER POSITIONS.

LET *AB* be a terrella, *E* its centre, *DF* its diameter (and also its equinoctial circle). If you cut out a piece (for instance along the Arctic circle) *GH*, it is evident that the pole which before was at *A* now has its seat at *I*. But the centre and the



* equinoctial circle recede only toward *B*, so as always to be in the middle of the mass that remains between the plane of the Arctic circle *GIH* and the Antarctic pole *B*. Thus the segment of the terrella between the plane of the former equinoctial circle *DEF* (that is of the equinoctial circle which existed before

the part was cut away) and the newly acquired equator *MLN* will always be equal to one half of the part cut off, *GIHA*. But if the part be cut from the side *CD* then the poles and the* axis will not be in the line *AB* but in *EF*; and the axis is



changed in the same proportion as the equator in the previous figure. For these points of forces and of energy, or rather these terminals of forces that flow from the entire form, are moved forward by change of mass or of figure; as all these points result from the joint action of the whole and of all the parts united, and verticity or polarity is not a property innate in the part or in any fixed point, but a tendency of the force to such part. And as a terrella dug out of the earth has no longer the poles and the equator of the earth but special poles and equator of its own, so, too, if the terrella be cut in two again, these points and distinctions of its forms and powers migrate to other parts. But if the loadstone be in any way divided either on the parallels or on the meridians so that in consequence of the change of its shape either the poles or the equator migrate to other seats, then if the part that has been cut off be but set in its natural position and conjoined to the rest, though they be not cemented or otherwise fastened together, the terminal points go back again to the former places as though no part of the body had been cut away. When the body is whole the form remains whole; but when the mass of the body is reduced, a new whole results, and a new wholeness necessarily arises in each minutest piece of loadstone, even in magnetic gravel and fine sand.

CHAPTER XVI.

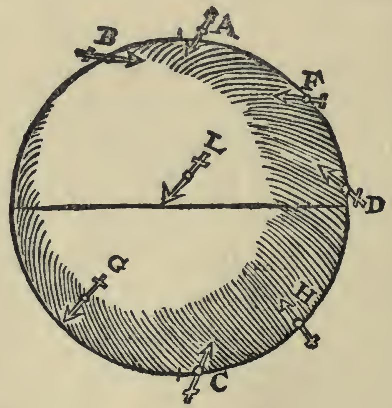
IF THE SOUTH PART OF A LOADSTONE HAVE A PART BROKEN OFF, SOMEWHAT OF POWER IS TAKEN AWAY FROM THE NORTH PART ALSO.

FOR though the south part of magnetic iron is attracted by the north part of the loadstone, still the south part of the stone does not reduce but increases the power of the north part. Hence if a loadstone be cut and divided at the Arctic circle, or at the tropic of Cancer, or at the equator, the south part does not so powerfully attract at its pole as before; for a new whole arises and the equator leaves its former place and advances poleward, because of the division of the stone. In the former state, inasmuch as the opposite part of the stone beyond the plane of the equator increases the mass, it also strengthens the verticity and the force and the movement toward unition.

CHAPTER XVII.

OF THE USE OF ROTARY NEEDLES AND THEIR ADVANTAGES; HOW THE DIRECTIVE IRON ROTARY NEEDLES OF SUN-DAILS AND THE NEEDLES OF THE MARINER'S COMPASS ARE TO BE RUBBED WITH LOADSTONE IN ORDER TO ACQUIRE STRONGER VERTICITY.

MAGNETIZED versoriums (or magnetized rotary needles) serve so many purposes in the life of man, that it will not be out of place to show the best process for rubbing and magnetically exciting them and the proper method of applying the process. With the aid of a small bar of iron magnetically prepared and suspended in equilibrium, rich iron ores and those containing most metal are recognized, and magnetic stones, clays, and earths, whether crude or prepared, are distinguished. A little iron bar—that soul of the mariner's compass, that wonderful director in sea-voyages, that finger of God, so to speak—points the way and has made known the whole circle of earth, unknown for so many ages. Spaniards (and Englishmen too) have again and again circumnavigated the whole globe on a vast circle by the help of the mariner's compass. They who travel on land or who remain at home have sun-dial horologes. The magnetic needle pursues and searches for veins of iron in mines: with its help mines are driven when cities are besieged; cannons and military engines are trained at night in the desired directions. The needle is of use for topography, for determining the areas and position of buildings, and in constructing underground aqueducts. On it depend the instruments invented for investigating its own dip and its own variation. When iron is to be quickened by the loadstone, let it be clean and neat, not disfigured by rust or dirt, and have it of the best steel. Let the stone be wiped dry so that there shall be no moisture, and scrape it gently with some well-polished iron tool. But beating it with a hammer is of no avail. And let the naked iron be applied to the naked stone and rubbed at it in such a way that they may come into closer contact—not in order that the corporeal matter of the stone may be joined to the stone and stick to it, but the two are slightly worn away by the friction, and (useless parts being ground off) are united closely: hence arises in the excited iron a grander force. In the figure, *A* shows the best mode of applying the versorium to the stone—its point touches the pole and is directed toward the pole—*B* is a passable mode, for though it is at a little distance from the pole it is directed



toward it; so, too, *C* is only a passable mode, the point being turned away from the pole; *D* is a worse mode on account of the greater distance from the pole; *F* is a bad mode because it lies on a parallel across the stone; the magnetic needle *L* that is rubbed on the equator is of no value and plainly is negative and forceless; the oblique indirect mode *G* and the oblique indirect averse *H* are both bad.

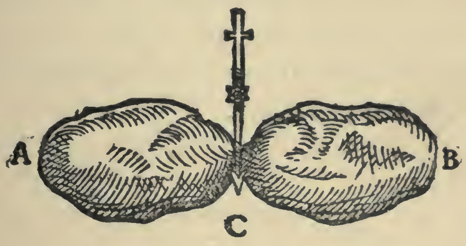
The purpose of all this is to show the different powers of a globular loadstone. But the artificers often use a stone rather tending toward the conical form, and, therefore, more powerful, its topmost projection being the pole, at which they rub the needles. Sometimes, also, the stone has at the top and above the very pole an artificial cap or snout of steel to give more strength; on this cap iron versoriums are rubbed, and thereafter they turn to that same pole as though they had been magnetized at that part without the cap.

The stone should be of good size and strong; the versorium, even if it be long, must be pretty thick, not too thin, with moderate-sized point, not too sharp, though the energy is not in the point itself but in the whole needle. Any powerful, large loadstone serves well for rubbing versoriums, though sometimes, owing to its powerfulness, it causes, when the needle is long, some dip and perturbation, so that the needle, that before friction stood in equilibrium in the plane of the horizon, now, after friction and excitation, dips with one end as low as the fulcrum on which it is supported permits. Hence in the case of a long versorium the end that is to be north should be, before friction, a little lighter than the other end, so that it may remain in exact equipoise after friction. But a versorium so prepared performs its function poorly at any considerable distance from the equinoctial circle. *

When the versorium has been magnetized, put it back in its box, and do not let it come in contact with other magnetic bodies, nor remain in close neighborhood with them, lest it become unsteady and sluggish through the action of opposite forces, whether potent or feeble. And if you rub the other end of the needle at the opposite pole of the stone, the needle will act with more steadiness, especially if it be rather long. Iron rubbed with loadstone keeps constant and strong, even for several centuries, the magnetic power awakened in it, if it be laid in the natural position, meridionally, not on a parallel, and is not spoilt by rust or any external ill coming from the ambient medium.

Porta seeks amiss a ratio between loadstone and iron: a small mass of iron, saith he, cannot hold a great measure of power, for it is wasted by the mighty energy of the loadstone. Clearly, the iron takes to the full its own virtue, though it weigh only one scruple and the mass of the loadstone more than 100 lbs. It is vain also to make the versorium rather flat at the end that is rubbed in order that it may become a better and stronger magnetic body, and that it may better seize and hold certain magnetic particles, but few of which can adhere to a sharp point; for it was Porta's belief that the energy is transmitted and retained by adhesion of particles of the loadstone, like hairs, whereas these particles are simply scrapings detached by the iron from the softer stone; besides, the magnetized iron points steadily north and south if, after friction, it be scoured with sand or emery or other material, and even though by long-continued friction its outer parts be ground down and worn away. In stroking the loadstone with a versorium each stroke should terminate at one end of the versorium, else, if the stroke is made toward the middle, a less degree of verticity, or none at all, or very little, is excited in the iron. For where the contact ends there is the pole and the point of verticity. To produce stronger verticity in iron by friction with a loadstone, it is necessary in northern latitudes to turn the loadstone's true north pole toward the zenith; on such pole that end of the versorium is to be rubbed which afterward will turn to the earth's north; the other end of the versorium must be rubbed on the south pole of the terrella turned toward the earth; so excited, it will incline to the south. In southern latitudes, below the equator, the case is different, and the cause of the difference is given in Book II, Chap. 34, where is shown (by means of a combination of earth and terrella) why the poles of a loadstone are, for diverse reasons, one stronger than the other.

If between the ends of two loadstones in conjunction and * equal in power, shape, and mass, you rub a versorium, it



acquires no property. *A*, *B* are two loadstones conjoined naturally at their opposite ends; *C*, the point of a versorium, * touched simultaneously by both, is not excited, if the loadstones be equal (though the loadstones are connected with it in the natural way); but if the loadstones be unequal, force is gained from the stronger.

In magnetizing a versorium with a loadstone begin at its middle and so draw it over the stone that one end quits the stone last; finally let the application be continued by a gentle stroking of the stone with the end of the needle for a while, say one or two minutes. The movement from middle to end must not, as is the wont, be repeated, for so the verticity is spoilt. Some delay is needed, for though the energy is infused and the iron is excited instantaneously, still the verticity is more steady and endures more surely in the iron when the versorium is left near the loadstone and abandoned at rest for a proper length of time; although an armed stone lifts a greater weight of iron than an unarmed, still a versorium is not more powerfully magnetized by the armed than by the unarmed stone. Take two pieces of iron wire, of equal length, cut off the same coil of wire, and let one be excited by the armed end, the other by the unarmed end: it will be found that they begin to move and make a perceptible inclination toward the loadstone at the same distances: this can be ascertained by measurement with a long rod. But objects powerfully excited turn quickly to the pole, those that are feebly excited turn slowly and only when brought nearer: the experiment is made in water with corks of equal size.

BOOK IV.

CHAPTER I.

OF VARIATION.

So far we have been treating of direction as if there were no such thing as variation; for we chose to have variation left out and disregarded in the foregoing natural history, just as if in a perfect and absolutely spherical terrestrial globe variation could not exist. But inasmuch as the magnetic direction of the earth, through some fault and flaw, does depart from the right track and the meridian, the occult and hidden cause of variance which has troubled and tormented, but to none effect, the minds of many has to be brought to light by us and demonstrated. They who hitherto have written of the magnetic movements have recognized no difference between direction and variation, but hold that there is one only movement of the magnetized needle. But the true direction is a movement of the magnetic body to the true meridian, and continuance therein, with the ends pointing to the respective poles. Yet very oft it happens, afloat and ashore, that a magnetic needle does not look toward the true pole, but is drawn to a point in the horizon nigh to the meridian, and that there is a deflection not only of the needle and magnetized iron in general and of the mariner's compass, but also of a terrella on its * float, of iron ore and ironstone, and of magnetic clays artificially treated; for they often look with their poles toward points different from the meridian. The variation, then, as observed with the aid of instruments or of the mariner's compass, is an arc of the horizon between the intersection of the horizon by the meridian and the term of the deflection on the horizon, or the range of deviation of the magnetized body. This arc varies and is different according to locality.[1] So the terminus of the variation is commonly assigned to a great circle —the circle of variation, as it is called—and a magnetic meridian passing through the zenith and the point of variation on the horizon.

In northern terrestrial latitudes this variation takes place either in the direction from north toward east, or from north toward west; in southern latitudes, in like manner, it is from south toward east, or south toward west. Hence in northern * latitudes we must heed the end of the needle that tends north, and in southern latitudes the end looking south: this naviga-

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[1] Gilbert defines variation to be the arc intersected between the point where the meridian of the place cuts the horizon and that point to which the magnetic needle looks; the length of this arc varying with the place of observation." ("Nature" for April 27, 1876, page 523.) The variation is now known by scientific writers as the declination. As expressed by Commander A. W. Greely, "declination is the variation of the magnetic meridian from the geographical meridian. It is measured by the angle between the two meridians, and is expressed in degrees of azimuth from zero either to the east or to the west of the true north. When the magnetic north is west of the true north it is west declination, and east when the reverse occurs."

tors and sciolists seldom understand, for on both sides of the equator they note only the north point terminal of the compass, or the one that looks north. As we have already said, every movement of loadstone and needle, every turn and dip, and their standing still, are effects of the magnetic bodies themselves and of the earth, mother of all, which is the fount and source and producer of all these forces and properties. Thus, then, the earth is the cause of this variation and tendence to a different point in the horizon; but we have to inquire further how and by what potencies it acts.

Here we must first reject the common opinion of modern writers concerning magnetic mountains or a certain magnetic rock or a distant phantom pole of the world controlling the movement of the compass or of the versorium. This opinion Fracastorio adopted and developed after it had been broached by others; but it does not agree with the experiments at all. For, if it were correct, in different places on land and sea the variation point would in geometrical ratio change to east or to west, and the versorium would always regard the magnetic pole; but experience teaches that there is no determinate pole, no fixed terminus of variation in the globe. For the arc of variation changes in different ways erratically, so that in different meridians and even in the same meridian, and when, according to the opinion of recent writers, the magnetized needle would deviate toward east, suddenly, on a trifling change of place, it goes from north toward west, as in the northern regions near Nova Zemlya (Nova Zembla).[1] In southern latitudes also, and at sea, far away from the equator and toward the Antarctic, and not in northern latitudes near those magnetic mountains, is variation frequent and great.

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[1] See Book IV, Chap. XVI.

But still more vain and silly are the imaginations of other writers—Cortesius, for example, who speaks of a motive force beyond the farthest heavens; Marsilius of Ficino, who finds the cause of variation in a star of Ursa; Petrus Peregrinus, who finds it in the pole of the world; Cardan, referring it to the rising of a star in the tail of Ursa; the Frenchman Bessard, to the pole of the zodiac; Livius Sanutus, to a certain magnetic meridian; Franciscus Maurolycus, to a magnetic island; Scaliger, to the heavens and to mountains; the Englishman Robert Norman, to the "respective point."[1]

Quitting, therefore, those opinions that are at odds with every-day experience, or that at least are by no means proven, let us look for the true cause of variation. The Great Loadstone, or the terrestrial globe, gives, as I have said, to iron a north and south direction; magnetized iron readily conforms itself to those points. But as the globe of earth is at its surface broken and uneven, marred by matters of diverse nature, and hath elevated and convex parts that rise to the height of some miles and that are uniform neither in matter nor in constitution but opposite and different, it comes about that this entire earth-energy turns magnetic bodies at its periphery toward stronger massive magnetic parts that are more powerful and that stand above the general level. Wherefore at the outmost superficies of the earth magnetic bodies are turned a little away from the true meridian. And since the earth's surface is diversified by elevations of land and depths of seas, great continental lands, ocean, and seas differing in every way,—while the force that produces all magnetic movements comes from the constant magnetic earth-substance, which is strongest in the most massive continent and not where the

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[1] See Book I, Chap. I; Book III, Chap. I; Book IV, Chap. VI.

surface is water or fluid or unsettled,—it follows that toward a massive body of land or continent rising to some height in any meridian (passing whether through islands or seas) there is a measurable magnetic leaning from the true pole toward east or west, i.e., toward the more powerful or higher and more elevated magnetic part of the earth's globe.[1] For as the earth's diameter is more than 1700 German miles, these continents may rise above the general superficies to a height equal to the depth of the ocean bed, or more than four miles, and yet the earth keep the spherical shape, albeit slightly uneven at the top. For this reason a magnetic body under the action of the whole earth is attracted toward a great elevated mass of land as toward a stronger body, so far as the perturbed verticity permits or abdicates its right. Yet the variation takes place not so much because of these elevated but less perfect parts of the earth and these continental lands, as because of the inequality of the magnetic globe and of the true earth-substance which projects farther in continents than beneath sea-depths. We have therefore to inquire how the demonstration of this new natural philosophy may be drawn from unquestionable experiments.

From the coast of Guinea to Cape Verde, the Canaries, and the frontier of the empire of Morocco, thence along the

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[1] Gilbert "refers the curvatures of the isogonic lines to the configuration of continents and the relative positions of sea basins, which possess a weaker magnetic force than the solid masses rising above the ocean." He considers "that the inflections of the lines of equal declination and inclination depend upon the distribution of mass, the configuration of continents, or the form and extent of the deep intervening oceanic basins. It is difficult to connect the periodic variations which characterize the three principal forms of magnetic phenomena (the isoclinal, isogonic, and isodynamic lines) with this rigid system of the distribution of force and mass, unless we represent to ourselves the attractive force of the material particles modified by similar periodic changes of temperature in the interior of the terrestrial planet." ("Cosmos," 1849, Vol. I, page 170; Vol. II, pages 717, 718.)

coasts of Spain, France, England, Holland, Germany, Denmark, Norway, the land on the right and to the east is all continent, vast regions forming one mass; on the left, immense seas and the mighty ocean extend far and wide: now we should expect that (as has in fact been observed by diligent investigators) magnetic bodies would deflect a little eastward from the true pole toward those more powerful and extraordinary elevations of the terrestrial globe. Very different is the case on the east coasts of North America, for, from the region of Florida through Virginia and Norumbega [1] to Cape Race and away to the north, the needle turns to the west. But in the mid spaces, so to speak, for example in the western Azores, it regards the true pole.[2] But it is not on account of that meridian or of the coincidence of the meridian with any magnetic pole, as the philosophastric crew suppose, that a magnetic body turns in like manner to the same regions of the world; neither does the variation take place along the entire * meridian, for on the same meridian near Brazil the case is very different, as later we will show.

Other things equal, variation is less along the equator, greater in high latitude, save quite nigh the very pole. * Hence it is greater off the coast of Norway and Holland than off Morocco or Guinea; greater, too, at Cape Race than in the

[1] Norumbega, "the lost city of New England," was called Arambec, or "Arambe" in 1523, "Aranbega" in 1529, "Norumbega" in 1539, and, subsequently, "Norumbdega," "Narembegue." Norumbega, in the Indian tongue, means *the place of a fine city*. Its site was indicated as on the bank of the Penobscot, the province of that name extending from the Kennebec River to the St. Croix River in that section of the country which afterwards became the State of Maine. (See "Magazine of Am. Hist." for 1877, pages 14, 321, and for 1886, page 291, "New England's lost city found"; also, "Antiquitates Americanæ," Roy. Soc. of Copenhagen; Lang's "Sagas of the Kings of Norway; Shea's "Catholic Church in Colonial Days;" Horsford, "Cabot's Landfall in 1497 and the site of Norumbega.")

[2] Humboldt, "Cosmos," London 1849, Vol. I, page 175, note.

ports of Norumbega or of Virginia. In the Guinea littoral, the magnetized needle inclines to the east one-third part of a point; in the Cape Verde Islands two thirds; in England, at the mouth of the Thames, one point: the higher the latitude the stronger the moving force, and the masses of land toward the pole exert most influence: all this is easily seen in a terrella. For just as, when the direction is true, magnetic bodies tend toward the pole (i.e., the greater force and the entire earth co-operating), so do they tend a little toward the more powerful elevated parts under the action of the whole and in virtue of the concurrent action of their iron.[1]

CHAPTER II.

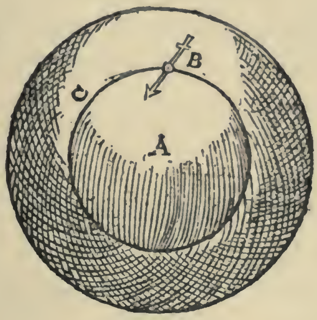
THAT VARIATION IS DUE TO INEQUALITY AMONG THE EARTH'S ELEVATIONS.

THIS very thing is clearly demonstrated on the terrella thus: take a spherical loadstone imperfect in any part or decayed (I once had such a stone crumbled away at a part of its surface and so having a depression comparable to the Atlantic sea or great ocean); lay on it bits of iron wire two barley-corns in length, as in the figure. *AB* is a terrella imperfect in parts and of unequal power on the circumference; the needles *E*, *F* do not vary but regard the pole straight, for they are placed in the middle of the sound and strong part of the terrella at a distance from the decayed part: the surface that is

[1] Ath. Kircheri, *Magnes; sive de arte magnetica*, 1643, Lib. II, Pars. V, page 410.

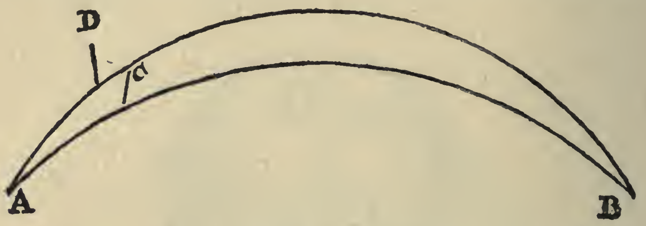
dotted and that is marked with cross-lines is weaker. Neither does the needle *O* vary because it is in the middle line of the decayed part, but turns to the pole just as off the western Azores. *H* and *L* vary, for they incline toward the sound

parts. And as this is shown on a terrella whose surface has sensible imperfections, so, too, in terrellas that are whole and perfect, for often one part of a stone is of greater strength on the outside than another, though no difference is plain to sense. With such a terrella variation is demonstrated and the * strong points are discovered in the following way: Here *A* is the pole, *B* the place of variation, *C* the more powerful region. The horizontal needle at *B* varies from the pole *C*-ward. So is the variation shown and the regions of greater force recognized. The more powerful surface is found also by means of a slender iron wire two barley-corns long: for though it will stand upright on the pole of the terrella and in other parts will lean toward the equator, still if on the same parallel circle it stands more nearly erect at one point than at another, the terrella's surface has more power where the needle is the more



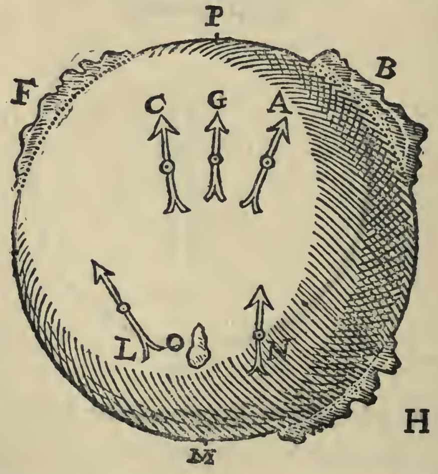
erect; and also when a piece of iron wire laid on the pole inclines more to one side than the other. For experiment take

a piece of iron wire three finger-widths long, resting on the pole *A* so that its middle lies over the pole. One of the ends turns toward *C* and will not rest in position toward *B*; yet, in a terrella that is flawless and even all over, it will be at rest on the pole no matter toward what point of the equator it be * directed. Or make another experiment: Suppose two meridians meeting at the poles *A*, *B* in equal arcs *DA* and *CA*; at

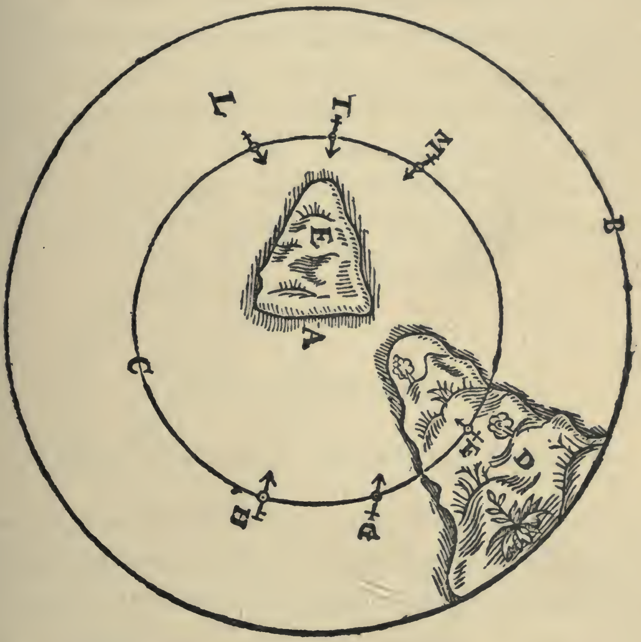


their extremities *D*, and *C*, let pieces of iron wire be reared: at *D* (which is the region of greater force) the wire will be reared more near perpendicular than at *C*, the region of less force. Thus can we discern the stronger and more powerful part of a loadstone, else not recognizable by the senses. In a terrella that is perfect, even, and alike in all its parts, there is at equal distances from the pole no variation.

Variation may be shown by means of a terrella having a



onsiderable part of its surface projecting a little above the rest: such terrella, though not decayed nor spoilt, attracts out of the true direction, its whole mass operating. The figure shows a terrella with uneven surface. The demonstration is made with small bars or short needles placed on the terrella: they turn from the terrella toward the projecting mass and the great eminences. In this way is verticity disturbed on the earth by the great continents which mostly rise above the beds of the seas and which at times cause the needle to devi-



ate from the straight track, i.e., from the true meridian. The tip of the versorium *A* does not point toward the pole *P* if there be a large projection *B* on the terrella; so, too, the point *C* varies from the pole because of the projection *F*. Midway between the two eminences, the needle *G* points to the true pole, because, being equidistant from both projections *B* and *F*, it deviates to neither but keeps the true meridian.

particularly when the energy of the projections is equal. But elsewhere, at *N*, the needle varies from the pole *M* toward the eminence *H*, nor is hindered nor stayed nor checked by the small eminence *D* on the terrella, which is like some island of the earth in the ocean. But *L* unhindered tends poleward.

In another mode may variation be shown, whether in a terrella or on the earth. Let *A* be the earth's pole; *B* its equator; *C* a parallel circle at latitude 30 degrees; *D* an eminence reaching poleward; *E* another eminence stretching from the pole equatorward. Evidently the versorium *F* in the middle line of *D* does not vary; but *G* deflects very much, *C* very little as being more remote from *D*. So, too, the needle *I*, placed directly toward *E*, does not deflect from the pole: but *L* and *M* turn from the pole toward the eminence *E*.

CHAPTER III.

VARIATION IS CONSTANT AT A GIVEN PLACE.[1]

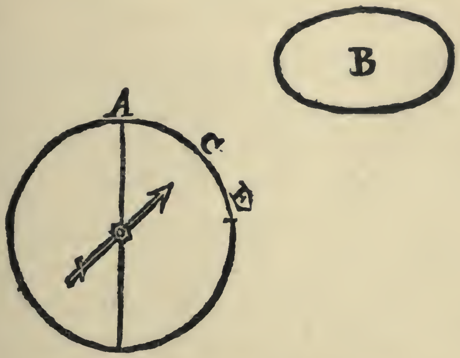
As the needle hath ever inclined toward east or toward west, so even now does the arc of variation continue to be the same in whatever place or region, be it sea or continent; so,

[1] Henry Gellibrand, English mathematician, professor of geometry at Gresham College, discovered, 1633–1635, the *secular variation of the declination.* In the words of Dr. Whewell ("Hist. of the Ind. Sciences," 1859, Vol. II, page 219): "Gellibrand discovered that the variation is not constant, as Gilbert imagined, but that in London it had diminished from eleven degrees east in 1580 to four degrees in 1633. Since that time the variation has become more and more westerly; it is now about twenty-five degrees west, and the needle is supposed to have begun to travel eastward again.

It may be added that the *diurnal variation* was subsequently found by George Graham, during the year 1722, whilst the *annual variation* was made known by Jean Jacques Dominique Cassini between 1782 and 1791.

too, will it be forevermore unchanging, save there should be a great break-up of a continent and annihilation of countries, as of the region Atlantis, whereof Plato and ancient writers tell.

The constancy of the variation and the regard of the versorium toward a fixed point of the horizon in each region is shown by laying a very small versorium on a terrella of uneven surface: the needle always diverges from the meridian over an equal arc. It is shown also by the inclination of the needle toward a second loadstone, though in truth this is done by a changed direction of all within the earth and the terrella. Lay upon a plane surface a versorium with its point looking



toward *A*, north; bring alongside the loadstone *B*, at such distance as to make the versorium turn to *C* and no further. Move the needle of the versorium as often as you will (yet without stirring either its case or the loadstone) and the needle will ever surely return to the point *C*. Thus if you so hold the stone as to make the needle turn to *E*, its point ever returns to *E* and not to any other point of the compass. Just so, by reason of the position of countries and the differing nature of the uppermost parts of the earth's globe (certain more magnetic projections of the terrestrial sphere prevailing), variation is ever fixed in a given place, but it differs and is unequal between one place and another, for the true and polar direction, having its birth in the entire globe of earth, is slightly diverted toward particular eminences of great magnetic force on the broken surface.

CHAPTER IV.

THE ARC OF VARIATION DOES NOT DIFFER ACCORDING TO DISTANCE BETWEEN PLACES.

ON the broad ocean, while a ship is borne by favoring wind along the same parallel, if the variation be reduced just one degree in a voyage of 100 miles, it does not follow that the next 100 miles will reduce it another degree. For the needle varies according to the position and conformation of the land and the magnetic force; also according to distance. For example, when a ship from the Scilly Islands bound for Newfoundland has proceeded so far that the compass points to the true magnetic pole, then, as she sails on, the borrholybic variation begins, but faintly and with small divergence. But after a while the arc increases in a higher ratio as equal distances are traversed, till the ship comes nigh the continent, when the variation is very great. Yet before she comes quite to land or enters port, while at some distance away, the arc is again lessened a little. But if the ship in her course departs much from that parallel, either to north or south, the needle will vary more or less according to the position of the land and the latitude of the region; for, other things equal, the higher the latitude the greater the variation.

CHAPTER V.

AN ISLAND IN OCEAN DOES NOT ALTER THE VARIATION; NEITHER DO MINES OF LOADSTONE.

ISLANDS, albeit they are more magnetic than the seas, still do not alter magnetic direction nor variation. For direction being a movement produced by the energy of the entire earth, and not due to the attractive force of any prominence but to the controlling power and verticity of the whole mass, therefore variation (which is a perturbation of the directive force), is a wandering from the true verticity and arises out of the great inequalities of the earth, by reason of which the earth itself, when very large and powerful magnetic bodies are present, has but little power of turning away magnetic bodies that revolve freely. As for the wonders that some do report about the island Elba: loadstones do there abound, but, nevertheless, the versorium (or the mariner's compass) makes no special inclination toward it when ships sail by in the Tyrrhenian Sea.[1] The reasons already given sufficiently account for this; but, furthermore, a reason may be found in the fact that the energy of minor loadstones reaches of itself but little beyond their own site; for variation is not produced by a pulling to, as they would make it who have thought out magnetic poles. Besides, mines of loadstone are only agnate, not innate, in the true earth-substance, and, therefore, the globe as a whole does not heed them; neither are magnetic bodies borne toward them, as is proved in the diagram of prominences.

[1] See note relative to Elba, Book I, Chap. VIII.

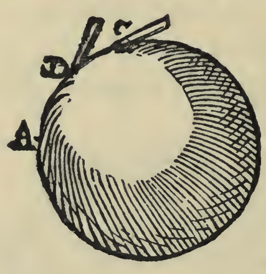
CHAPTER VI.

THAT VARIATION AND DIRECTION ARE PRODUCED BY THE CONTROLLING FORCE OF THE EARTH AND THE ROTATORY MAGNETIC NATURE, NOT BY AN ATTRACTION OR A COITION, OR BY OTHER OCCULT CAUSE.

INASMUCH as the loadstone is deemed by the philosophizers of the vulgar sort to seize and snatch objects away, as it were, and pretenders to science have, in fact, noticed no other properties save this much-lauded force of attraction, therefore they have supposed that the whole movement to north and south is produced by some natural force soliciting bodies. But the Englishman Robert Norman first strove to show that this is not done by attraction; he, therefore, originated the idea of the "respective point" looking, as it were, toward hidden principles, and held that toward this the magnetized needle ever turns, and not toward any attractional point; but he was greatly in error, albeit he exploded the ancient false opinion about attraction. Norman proves his theory as follows: Take a round vessel full of water; on the mid surface of the water float a small bit of iron wire supported by just so much cork as will keep it afloat while the water is in equilibrium; the wire must have been first magnetized so as to show plainly the variation point *D*. Let it remain in the water for a while. Clearly the wire with its cork does not move toward the rim *D* of the vessel, as it would do if attraction came to the iron from *D*, and the cork would move from its place. This assertion of the Englishman Robert Norman is demonstrable, and it does seem to do away with attraction, inasmuch as the iron remains in the still water both in the direction toward the very pole (if the direction be true) and in variation and irregular direction; and it revolves on its iron centre, and is not borne toward the vessel's rim. Yet the direction is not produced by attraction, but by a disposing and conversory power

existing in the earth as a whole, not in a pole or any attrahent part of the stone, neither in any mass projecting beyond the circle of the periphery, so that the variation should result because of the attraction of that mass. Besides, the directive force of the stone and of iron, and their natural power of revolving on their centre, produce the movement of direction and of collimation, in which is included also the motion of dip or inclination (*declinationis*). Nor does the earth's pole attract as though the force of the globe resided in the pole only: the magnetic force exists in the whole, but in the pole it is preeminent and surpassing. Therefore that the cork abides quietly in the midst, and that the magnetic needle does not move toward the rim of the vessel, is a fact in accord and agreement with the loadstone's nature, as is shown with the aid of a terrella. Here a little iron bar, placed on the stone at

C, clings there, nor is it pulled farther away by the pole *A* or by the parts near the pole. So, too, it continues at *D* and takes direction toward the pole *A*, but it sticks at *D*, and dips



also toward *D* in virtue of its power of rotation whereby it conforms itself to the terrella. On this point we shall treat further when we consider inclination or the dip of the compass.

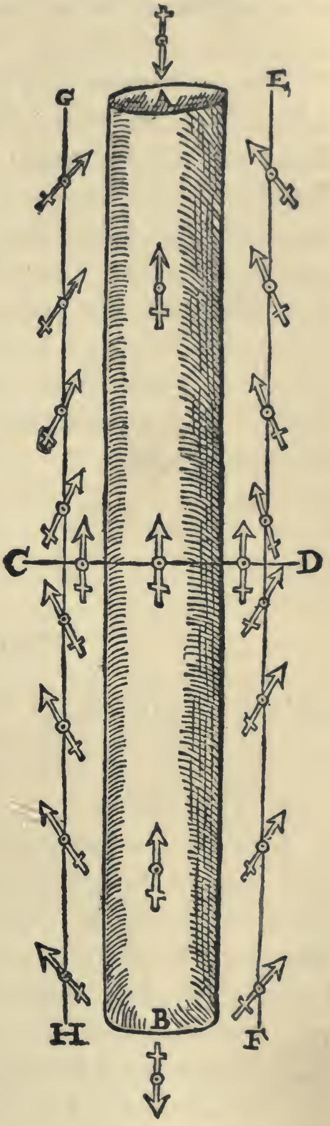
CHAPTER VII.

WHY THE VARIATION DUE TO THIS LATERAL CAUSE IS NOT GREATER THAN HITHERTO IT HAS BEEN OBSERVED TO BE, SELDOM APPEARING TO AMOUNT TO TWO POINTS OF THE COMPASS, EXCEPT NEAR THE POLE.

THE earth, by reason of lateral elevations of the more energic globe, causes iron and loadstone to diverge a few degrees from the true pole or true meridian. For example, here in England, at London, it varies 11⅓ degrees; in some other places the variation is somewhat greater, yet in no region does the end of the needle diverge very many degrees more from the meridian.[1] For as the needle always gets its direction

[1] Consult Cabeo, *Philos. Magn.*, Ferrara 1629, Lib. I, Cap. XVI.

from the true verticity of the earth, so the polar nature of a continent tends poleward, even as does that of the whole globe of earth; and though the mass of a continent may turn magnetic bodies away from the meridian, still the verticity of that same land (as of the whole earth also) controls and directs those bodies so that they shall not turn eastward in too large an arc. It were not easy to determine according to any general method how great the arc of variation is in every place, nor how many degrees and minutes it covers on the horizon, because it becomes greater or less according to divers causes. For we must take account of the force of true verticity of each place and of the elevated regions, also of the distances of those regions from the place under consideration and from the world's poles; and these distances are to be compared—a thing that cannot be done with precision. Still, by our method, the variation is ascertained in such way that no serious error is left to perturb the course of a sea-voyage. Were the



positions of masses of land uniform, if the land lay on a meridian line, and did not present a broken and indented contour, the variations near the land would be without complexity, as in the figure.

This is demonstrated with the aid of a long loadstone whose poles are at the ends *A*, *B*: the middle of the loadstone and the equinoctial is *CD*; and the lines *GH* and *EF* are meridians on which are arranged versoriums, the deviations of which are greater the greater their distance from the equator. But the inequalities of the seaboard parts of the habitable globe, the great promontories, the wide gulfs, the mountainous and the more elevated regions, and the more uneven and precipitous regions make the variations more difficult of determination, and in high latitudes less certain and more irregular.

CHAPTER VIII.

OF THE CONSTRUCTION OF THE COMMON MARINER'S COMPASS, AND OF THE DIFFERENT COMPASSES OF VARIOUS NATIONS.

In a round wooden box (bowl), having its top covered over with glass, a fly-card (versorium) rests on a pretty long pin fixed in the middle. The glass cover keeps out wind and draughts of air produced by outer causes. All that is within can be distinctly seen through the glass. The versorium (rotating part) is circular, made of light material, as pasteboard, to the under side of which is attached the magnetized iron or needle. On the upper side 32 spaces (points as they are called) are distributed to as many mathematical intervals in the horizon, or *winds*, which are distinguished by certain marks and by a lily (*fleur-de-lis*) indicating the north. The compass-box is suspended in equilibrium in the plane of the horizon, within a ring of brass, which is also pivoted (equilibrated) in another ring suspended in a roomy stand, a leaden weight being attached to the box so that it shall remain in the plane of the horizon though the ship may be tossed by the sea in all directions. There are either two magnetized-iron bars (with ends united) or one piece of a rather oval shape with the ends projecting: this style is the surer and quicker of the two in performing its function.[1] This is to be so fitted to the pasteboard disk (or card of the compass) that the centre of the disk shall be in the middle of the magnetized iron. But as variation begins in the horizon from the point where the meridian intersects it at right angles, therefore, on account of the variation, instrument-makers in different countries and cities inscribe the compass variously, and have different ways of attaching the magnetized iron to the card whereon are marked the bounds of the 32 spaces or points.

There are in general use in Europe four different constructions and forms of compass. First, the form adopted throughout the Mediterranean, and in Sicily, Genoa, and the Venetian republic. In all of these compasses the pieces of iron are so attached beneath to the rotating card that (where

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[1] This opinion of Gilbert's is not borne out by advanced knowledge of the laws of magnetization, which shows that the oval ring needle cannot be trusted to for keeping its magnetic axis securely in a constant direction under whatever disturbing influence it may be subjected to as does a thin rod or bar. The oval form was authoritatively condemned on this account by the British Admiralty Committee of 1837, who found the theoretical objection amply confirmed by experience. They actually found compasses of this pattern, which had been in use for some time at sea, presenting errors of as much as three degrees on account of the displacement of the magnetization in the substance of the needle. (Sir Wm. Thomson, "Good Words" for 1879, page 445.)

there is no variation) they turn to the true points of north and south. Hence the mark for north, designated by a lily, always indicates exactly the point of variation: for the point of the lily on the card, together with the ends of the pieces of magnetized iron beneath, come to a standstill at the point of variation. Another form of compass is that of Dantzic, employed in the Baltic Sea and in the Netherlands. Here the magnetized iron underneath diverges three fourths of one point eastward from the lily; for a voyage to Russia the divergence (recognized difference) is two thirds. But the compasses made at Seville, Lisbon, Rochelle, Bordeaux, Rouen, as well as throughout all England, have an interval of one half of a point.

Out of these differences have grown very serious errors in seafaring and in the science of navigation. For, after the directional positions of sea-coasts, of promontories, ports, islands, have been found by the aid of the compass, and the tides of the seas or the times of full sea have been determined from the moon's position above one or another point of the compass (as the phrase is), we have still to inquire in what country or according to what country's usage the compass was constructed by which the directions of said places and the times of the marine tides were observed and determined. For the mariner, who, using British compass, should follow the directions of the Mediterranean marine charts, must needs stray far from his true course; so, one who should use an Italian compass in the North Sea, the German Sea, or the Baltic, in connection with the marine charts commonly used in those parts, would oft stray from the right direction. These differences were introduced by reason of the unlike variations, that navigators might escape grave errors in those parts of the world. Yet Petrus Nonius seeks the meridian with a mariner's compass or versorium (the Spaniards call it a needle), taking no account of variation; and he brings forward many geometric proofs that rest on utterly vicious foundations: for he had small acquaintance or experience of things magnetic. In like manner Pedro de Medina, who does not accept variation,[1] has with many errors disgraced the art of navigation.

CHAPTER IX.

WHETHER TERRESTRIAL LONGITUDE CAN BE FOUND FROM VARIATION.

THAT were a welcome service to mariners and would advance geography very much. But Porta (Book VII, Chap. 38) is deluded by a vain hope and by a baseless theory. For he thinks that, in moving along a meridian, the needle observes order and proportion, so that the nearer it is to east the more it will deviate eastward, and, according as you advance west, the needle takes a westerly direction: all of which is false as false can be. Porta thinks he has found a true index of longitude; but he is mistaken. Taking, however, and assuming for true these premises, he constructs a large compass showing degrees and minutes for observing these proportional changes of the needle. But his principles are erroneous and illogically taken and very poorly studied; for a versorium does not vary more to the east because it is carried to the east; and though in the countries of western Europe and the seas

[1] Pedro de Medina, *Arte de Navegar*, Valladolid 1545 (Ronalds, page 341). Consult *L'arte del Navegar*, Dottor M. Pietro da Medina, Vinetia 1555, Libro Sesto, "Della Aguggia, over bossolo da navegar," pages cviii–cxvi.

adjoining the variation is to the east, and beyond the Azores it is changed a little toward the west, nevertheless variation is in divers ways ever uncertain, both because of latitude and longitude and because of approach to great masses of land, also because of the altitude of dominant terrestrial elevation; but it does not follow the rule of any meridian, as we have already shown. Livius Sanutus sorely tortures himself and his readers with like vanities. As for the opinion of the common run of philosophizers and mariners, that the meridian which passes through the Azores is the limit of variation, so that on the opposite side of that meridian a magnetic body will point to the poles exactly as at the Azores—an opinion held also by Joannes Baptista Benedictus and sundry other writers on the art of navigation—it is in no wise true. Stevinus (quoted by Hugo Grotius), in his *Portuum Inveniendarum Ratione*,[1] distinguishes variation according to meridians. "In the island Corvo,"[2] says he, "the magnetic pointer indicates the true north,[3] but the farther one advances thence toward the east the more will he see the needle 'easting'

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[1] Simon Stevinus, *Portuum Investigandorum Ratio,* Leyden 1599. This was printed in English, the same year, by the celebrated mathematician, Edward Wright, who afterwards attached it to the third edition of his "Certaine errors in navigation detected and corrected" (Engl. Cycl., "Biography," Vol. VI, page 834).

[2] Corvo, one of the Azores, the northernmost of the whole group, lying ten miles north of Flores.

[3] "The fact that the needle does not point at all places to the true north was early known, but the discovery that it changed its direction with a change of place is generally attributed to Columbus. This is incorrect, for the needle's departure from the geographic meridian (called its *variation* or *declination*) is marked down for different points of the sea, on the atlas of Andrea Bianco, which was made in the year 1436; but what Columbus really did discover was a line of no variation 2½° east of the island of Corvo on the 13th of September 1492" (A. M. Mayer, "The Earth a great Magnet," 1872, page 253).

See Thomas Brown, *Pseudoloxia Epidemica*, 1658, Book II, pages 68, 69.

(ανατολίζειν), till he comes to within one mile of Plymouth on the east, where the variation, reaching maximum, is 13 deg. 24 min. Then the anatolism (easting) begins to grow less as far as Helmshud, which place is not far from North Cape in Finmark: there the north is pointed to again. There are 60 degrees of longitude between Corvo and Helmshud, but the variation is greatest at Plymouth, whose longitude is 30 degrees." But though these statements are in part true, still along the entire meridian of the island of Corvo the compass does by no means point due north. Neither in the whole meridian of Plymouth at other places is the variation 13 deg. 24 min., nor in other parts of the meridian of Helmshud does the needle point to the true pole. For, on the meridian passing through Plymouth at lat. 60 deg., the north by east variation is greater; in lat. 40 deg. it is much less; in lat. 20 deg. it is very small indeed. On the meridian of Corvo, though the variation near the island is nil, yet in lat. 55 deg. the variation north by west is about ½; in lat. 20 deg. the variation is ¼ of a point toward the east. Hence the bounds of variation are not properly defined by great meridian circles, and far less are the ratios of increase or decrease toward a given region of the heavens investigated by that method. Therefore the rules of *clattumen* (declining) or *auxanomen* (increasing), anatolism (easting) or dysism (westing), cannot possibly be found by that device. The grounds of variation in the southern regions of the earth, which Stevinus thereafter searches into in the same way, are utterly vain and absurd; they have been put forth by some Portuguese mariners, but they do not agree with investigations: equally absurd are sundry observations wrongly accepted as correct. But the method of finding the port on long voyages to distant parts by means of accurate knowledge of the variation (a method invented by Stevinus and recorded by Grotius) is of great importance, if only fit instruments be at hand wherewith the deviation may positively be ascertained at sea.

CHAPTER X.

WHY IN VARIOUS PLACES NEAR THE POLE THE VARIATIONS ARE MUCH AMPLER THAN IN LOWER LATITUDES.

On the equator or near it, the variation of a needle is often trifling, not unusually it is null. In higher latitudes, as 60, 70, 80 degrees, the variations are not infrequently very great. The reason of this is found partly in the nature of the earth, partly in the position of the versorium. The earth causes magnetic bodies to rotate and directs them poleward strongly at the equator; at the poles there is no direction, but only fast coition of terminals that agree. Hence direction is weaker at the poles, because the versorium, by reason of its tendency to turn to the pole, dips greatly, and is but feebly directed; but the force of the lands and eminences is strong, with an energy proceeding from the entire earth, and, besides, the causes of variation are nearer: therefore the versorium deflects more to those eminences. It must be known also that the direction of a versorium poised on a needle toward the plane of the horizon is much stronger at the equator than anywhere else by reason of the lie of the versorium; and in proportion as latitude increases the direction is less strong, for at the equator the versorium is directed naturally toward the plane of the horizon, but in other places it is forced to be in equilibrium and remains in equilibrium because of an external force: by its nature it dips under the horizon as the latitude increases, as will be shown in the Book on Inclination or Dip. Wherefore direction becomes weaker and at the pole itself is null. For this reason a weak direction is easily overcome by powerful causes of variation, and near the pole the needle deflects more from the meridian. This is demonstrated with a terrella, on which is put an iron wire of two finger-breadths: the wire is quickly and strongly directed toward the poles on a meridian, but in the intervals between equator and pole it is directed weakly; herein we may see the great tendency to variation near the poles.

CHAPTER XI.

CARDAN'S ERROR IN SEEKING TO DETERMINE THE DISTANCE OF THE EARTH'S CENTRE FROM THE CENTRE OF THE WORLD BY MEANS OF THE LOADSTONE (IN HIS *De Proportionibus*, V).

HOW very easy it is to make mistakes and errors in the absence of trustworthy experiments, while investigating the hidden causes of things, is well shown by a gross blunder of Cardan, who thinks he has discovered the distances of the centres of the earth and the world through the variation of the magnetic needle over nine degrees; for he believed that the variation point in the horizon is everywhere distant eastward nine degrees from due north: on this basis he establishes a demonstrative ratio of the different centres.

CHAPTER XII.

OF FINDING THE AMOUNT OF THE VARIATION; WHAT THE QUANTITY IS OF THE ARC OF THE HORIZON FROM ITS ARCTIC OR ANTARCTIC INTERSECTION BY A MERIDIAN TO THE POINT TOWARD WHICH THE NEEDLE TURNS.

THE true meridian is the principal basis of the whole question; when that is surely known it is easy, with the mariner's compass (when you know its construction and how the iron bars are fixed in it), or with any large horizontal versorium, to show the arc of variation on the horizon. A variation compass of good size, after you have made two observations of the sun before and after noon, shows the variation by the shadow: the sun's altitude is observed with a *radius*[1] or with a large quadrant. On account of the greater size of the instrument, there is an easier and surer way of finding the variation on shore. Get a thick plank of suitable timber, two feet long, sixteen inches broad; on it describe several semicircles, as in the accompanying plate, but more numerous. In the centre erect perpendicularly a brass stilus; let there be also a rotatory pointer reaching from the centre to the outermost semicircle, and a magnetized versorium in a box with glass cover. Then

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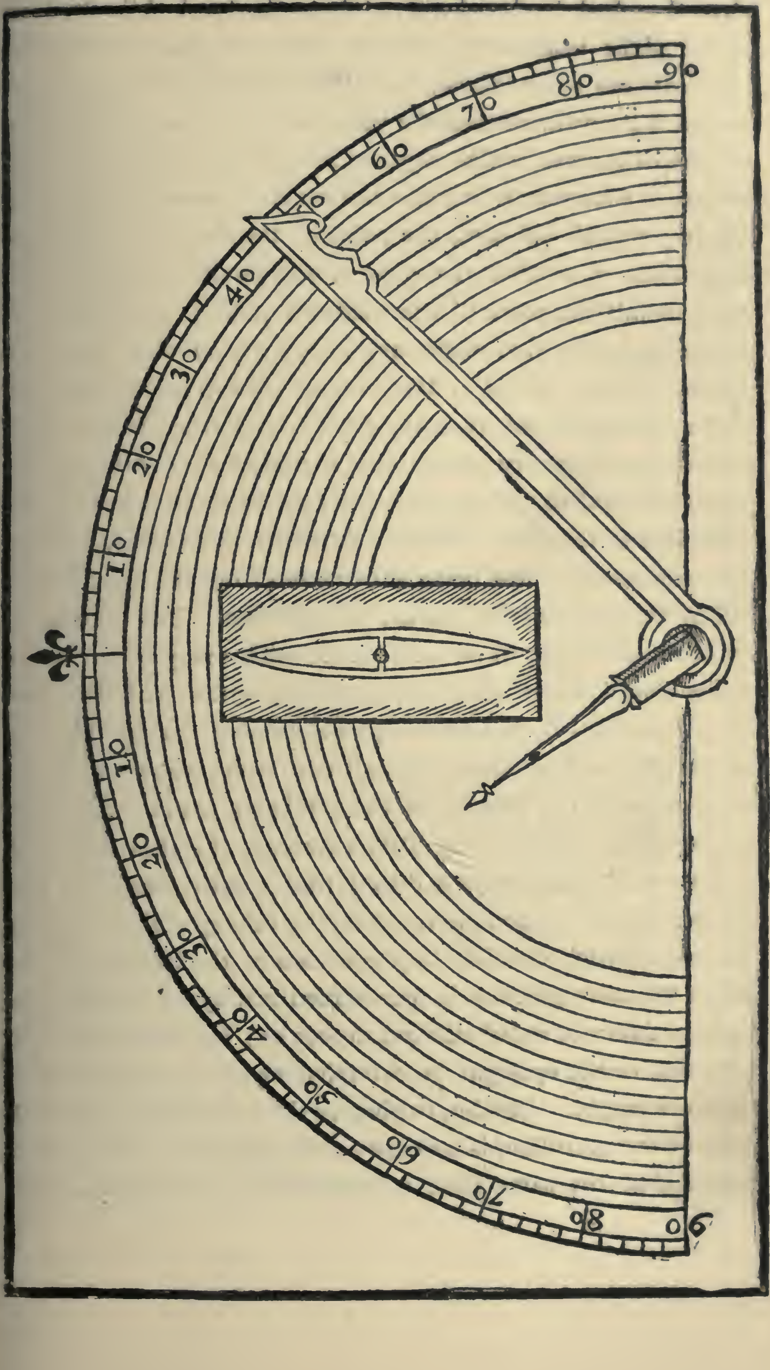
[1] *Radius—radius astronomicus*—measuring-rod, same as radiometer. An old instrument for measuring angles; the cross-staff; Jacob's-staff; a kind of astrolabe. (For *Radius* and *Quadrant*, etc., consult R. Ainsworth's "Latin Dict.;" the "Century Dict.," Volumes III, page 3213; V, pp. 4883, 4934–4935; J. E. Worcester, "Dict. of Eng. Lang.," 1881, Vol. I, page 786; Vol. II, page 1163; Noah Webster, "Int. Dict.," 1891, pp. 1171, 1399; Dr. John Ogilvie, "The Imp. Dict.," 1882, Vols. I, page 631; II, page 657; III, page 585; Johnson's "Dict. of Eng. Lang.," London 1876, Vol. II, pp. 5 and 676).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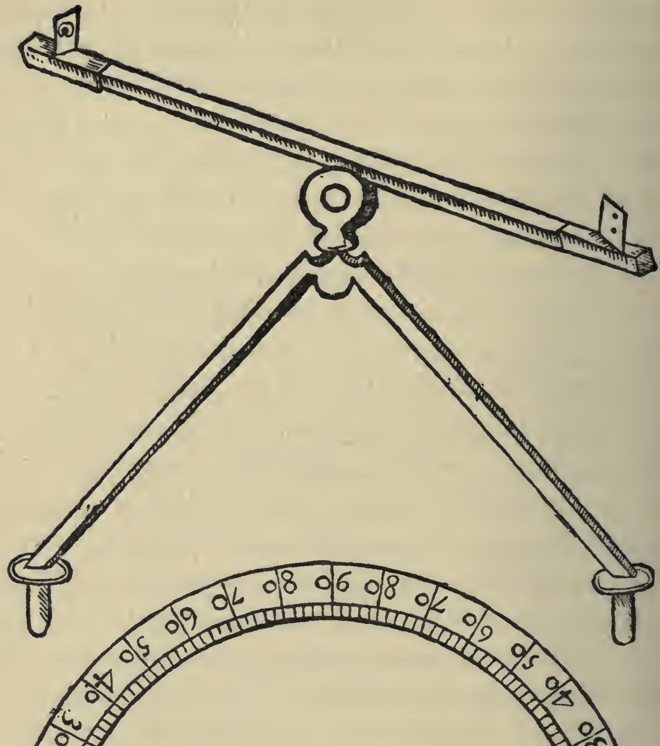
when the plank is placed accurately to the level of the horizon by the plane instrument with its perpendicular (*instrumento plano cum suo perpendiculo*), turn the extremity of the pointer toward the north, so that the versorium shall rest just on the midline of its case, which regards the point of variation in the horizon. Afterwards, at some convenient hour in the morning —8 or 9 o'clock—observe the point of the shadow cast by the stilus when it reaches the nearest semicircle, and mark with chalk or ink the place of the shadow's point; now bring the pointer round to that mark and note with another mark the number of the degree in the horizon shown by the pointer. In the afternoon, see when the extremity of the shadow again reaches the periphery of the same semicircle, and, bringing the pointer around to the tip of the shadow, find the degree at the other side of the lily. From the difference in degrees, you find the variation: the less being substracted from the greater, the half of the remainder is the arc of variation. The amount of variation is sought to be determined with many other instruments and in many other ways, in conjunction with the mariner's compass—by means of a globe, number, and by the ratio of triangles and of sines, the latitude being known and one observation of the altitude of the sun being made. But these methods and means are of little advantage, for it is useless to seek in roundabout ways and by intricate paths what you may find more quickly and more surely by taking a shorter road. The whole trick consists in proper use of the instruments by which the sun's position is ascertained readily and quickly (as the sun does not stand still but moves on), for either the hand trembles, or the eyesight is defective, or the instrument does not work aright. Besides, to observe the sun's altitude on both sides of the meridian, is as easy as to observe it on one side only and at the same time to ascertain the elevation of the pole. And he who can take one altitude with an instrument can take another, and if the one is doubtful, the whole work with globe, number, sines, and triangles is thrown away. Nevertheless, these exercises of mathematical minds are praiseworthy. It is easy for anyone who stands on the land, by means of accurate observations and with the use of fit instruments, to ascertain the variation, especially in a rather right sphere; but at sea, in view of the motion and the turning of the waters, experiments cannot be made with exactness as to degrees and minutes, and, in fact, with the instruments in common use, hardly within one third or one half of a point, particularly in high latitude: hence so many incorrect and faulty records of observations by navigators. As for us, we have contrived a method of finding the variation, by means of a convenient, handy instrument, from the rising of certain stars, the rising or setting of the sun, in northern regions, from the pole-star; for, at sea, when the ship is tossed by the waves, even the skilled observer determines the variation more surely with the aid of a simple instrument and one of no great precision. Such an instrument is constructed as follows:

After the pattern of a true and meridional mariner's compass (with a bare versorium or with a versorium fastened to a card circle), make an instrument at least one foot in diameter; divide its rim into four quarters, each subdivided into 90 degrees. Let the movable compass-box be balanced below (*subtus librata*) with a heavy weight of 16 pounds. On the edge of the suspended box at beginnings opposite quadrants, a semicircle rising in the middle to a point (*conum*) is to be erected (the feet of the semicircle at both sides being fastened in holes on the margin) so that the top of the *conum* shall be perpendicular to the plane of the compass; on its top a rule sixteen digits long is to be fastened at its middle over the central axis,


70 80 90 80 70

as it were (of the compass-box), like the beam of a balance, with such a joint that it may move. At the ends of the rule are small sights with holes through which we may observe the sun and stars. By means of the rising or the setting sun at the equinoxes, the variation can be taken very well and very readily with this instrument. When the sun is in other parts of the zodiac, the variation can also be determined when we have the altitude of the pole: that known, any one may find, with a globe, or maps, or with the instrument, the amplitude (of the sun or star) on the horizon and the distance from the true east as well of the sun as of the following fixed stars. Then, having counted the degrees and minutes of the ortive amplitude (time of rising) from the true east, we readily find the variation. Observe the foremost star of the three in Orion's belt when first it appears on the horizon; direct the instrument toward it, and observe the versorium, for as that star rises in the true east, generally one degree toward the south, we can see how far the versorium diverges from the meridian, allowance made for that one degree. You may also observe the Arctic pole-star when it is on the meridian or at greatest distance from the meridian (about 3 degrees: according to the observations of Tycho Brahe the pole-star is 2 deg. 55 min. from the pole), and with the aid of the instrument you may determine the variation scientifically, by adding or subtracting the *due prostaphæresis*[1] of the star's distance from the

[1] Prostaphæresis (*Gr.* previous subtraction). (1) The reduction to bring the apparent place of a planet or moving point to the mean place. (2) A method of computing by means of a table of natural trigonometrical functions without multiplying. It was invented by a pupil of Tycho Brahe, named Wittig, but was entirely superseded by logarithms ("The Century Dict.," 1890, Vol. IV, page 4790). It is more generally called *equation of the centre* (L. N. Bescherelle, "Nouv. Dict. Nat." 1887, Vol. III, page 1084). *Equation of the centre* is the difference between the place of a planet as supposed to move uniformly in a circle, and its place as moving in an ellipse (Noah Webster's

meridian (if it is not in the meridian). You will find when the pole-star is in the meridian, the sun's place and the hour of the night being known: even the practised observer will easily know that without much error, by the visible inclination of the asterism—as we do not care for a matter of a few minutes, as some do, who while striving to get at the minutes at sea often miss by a whole point. The experienced observer will allow somewhat for refraction in noting the rise of the sun or stars, so that his calculation may be more exact.

List of bright, brilliant stars not far from the equator, that can be observed in rising or in setting from the altitude of the pole and the declination of the stars, the ortive amplitude on the horizon being ascertained on a globe, or map, or the instrument whence the variation is determined by artful calculation.

		Right Ascension.		Declination.		
		deg.	min.	deg.	min.	
Aldebaran	Eye of Taurus	62	55	15	53	N.
Bellatrix	Left shoulder of Orion	72	24	4	5	N.
Betelgeuze	Right " " "	83	30	6	19	N.
Mintaka	Foremost star in belt of Orion	77	46	1	16	S.
Sirius	Canis Major	97	10	15	55	S.
Procyon	Canis Minor	109	41	5	55	N.
Alphard	Bright star in Hydra	137	10	5	3	S.
Pollux	South head of Gemini	110	21	28	30	N.
Castor	North " " "	107	4	32	10	N.
Regulus	Heart of Leo	146	8	13	47	N.
Denebola	Tail " "	171	38	16	30	N.
Spica	Spica Virginis	195	44	8	34	S.
Arcturus and Boötæ		29	13	21	54	N.
Altair	Heart of Aquila	291	56	7	35	N.

"Int. Dict." 1891, page 504). In ancient astronomy, it is usually the difference between the true and mean place of the centre of the epicycle (*Short*, Kepler, Par. 43); but in the case of the moon, generally the angle at the centre of the epicycle between the true and mean apogee (*Clavius; Ozanan*), though sometimes the first inequality (*Halma*, Almagest, Vol. VII). In modern astronomy, it is the excess of the true over the mean anomaly (*Gauss*, Theoria Motus, I. 7). See the "Century Dict.," 1890, Vol. II, page 1982; also, P. Larousse, "Grand Dict. Univ.," 1875, Volumes VII, page 771, and XIII, page 288; also Dr. John Ogilvie, "The Imp. Dict.," 1882, Vol. II, page 185.

An instrument for finding the ortive amplitude on the horizon. Describe the periphery of a circle and divide it into quarters by two diameters intersecting at right angles. One of the diameters indicates the equinoctial circle, the other the axis of the world. Divide the four quarters in the usual way, each into 90 degrees, and to every fifth or every tenth degree from each end of the two diameters in both directions assign numbers on the two margins (outside of this periphery) provided for the purpose. Then from each degree draw a right line parallel to the equator. Next make a rule, or alidade, of the same length as the diameter of the circle and divided into the same parts exactly as the diameter which represents the axis of the world. In the middle of this rule let a small projecting piece be left attached whereby the middle of the *linea fiducialis* [1] of the rule may be connected with the centre of the circle; and to each fifth or tenth part of the rule give a number, beginning in the middle and numbering right and left. The circle represents the plane of the meridian; its centre represents the very point of rising or setting, i.e., the intersection of horizon and equator. All these lines equidistant from the equator, represent parallels of the sun and stars; the *linea fiducialis* of the rule or alidade represents the horizon, and its parts degrees of the horizon, beginning at the point of rising or setting. Therefore, if to the given latitude of the place, as numbered at each end of the diameter that represents the

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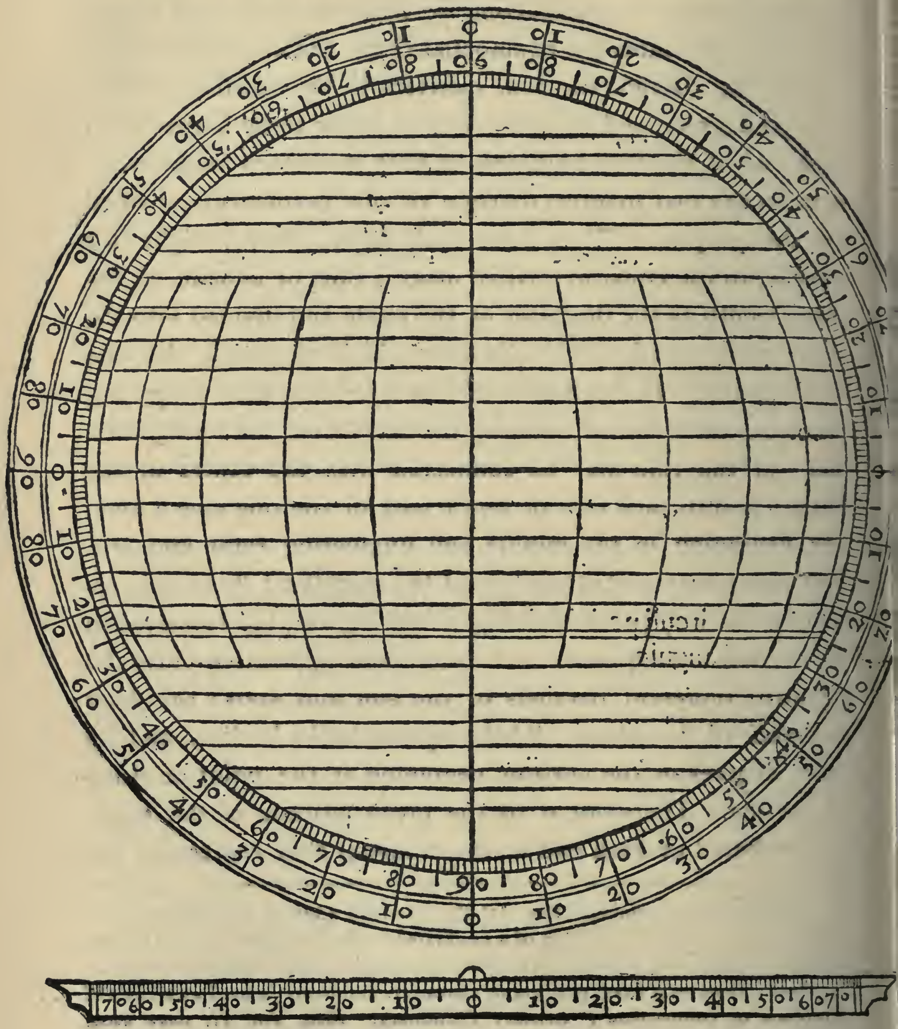
[1] *Linea fidicialis*—fiducial line: (1) The straight edge of the alidade of a plane table. (2) The initial line of a graduated circle or vernier. (3) Any line which is intended to be taken as a standard straight line. The term fiducial, in *physics*, denotes a fixed position or character, and hence is used as a basis of reference or comparison ("Century Dictionary," 1889, Vol. II, page 2202; and Vol. III, page 3463. See, likewise, Noah Webster's "International Dictionary," 1891, page 556; L. N. Bescherelle, "Nouv. Dict. Nat.," 1887, Vol. II, page 1576; Larousse, "Dict. Universel," 1872, Vol. VIII, page 336; M. P. E. Littré's "Dictionnaire," 1863, Vol. I, page 1665).

axis of the world, the *linea fiducialis* of the rule be applied; and if the given declination (less the complement of the lati-



tude of the station) of sun or any star from the equator be found on the rim of the instrument,—then a section of a parallel drawn from the point of this declination in the horizon, or in the *linea fiducialis*, will show the ortive amplitude of the given star or of the sun at the stated latitude of the place.

CHAPTER XIII.

OBSERVATIONS MADE BY SEAMEN COMMONLY VARY AND ARE UNTRUSTWORTHY, PARTLY THROUGH MISTAKES AND WANT OF KNOWLEDGE AND THE IMPERFECTNESS OF THE INSTRUMENTS, AND PARTLY BECAUSE THE SEA IS SELDOM SO CALM BUT SHADOWS OR LIGHTS MAY REST ON THE INSTRUMENTS.

FROM the time when first the variation of the needle was noticed, many alert navigators have in sundry ways striven to investigate the difference in the direction of the mariner's compass; but this has not been done with the exactness that was requisite, much to the disadvantage of the art of navigation. For, either, being unlearned, they knew of no sure method, or they used ill-constructed and unsuitable instruments, or they adopted some conjecture based merely on the false hypothesis of some prime meridian or magnetic pole; while many copy others' writings and pass off for their own the observations of earlier writers; and these early authors, however stupid the writings in which they entered their observations, are held in high respect just because of their antiquity; and their posterity hold it to be not safe to differ from them. Hence on long voyages, especially to the East Indies, the inexact records of variation of the compass kept by the Portuguese are prized ; but whoever reads what the Portuguese have written will quickly see that in very many respects they are mistaken, and that they did not rightly understand the construction and the use, in taking the variation of the compass of Portugal (in which the lily points one half point west from the magnetized needle). Hence while they exhibit the variation of the compass in different places, it is not certain whether they measure the deviation with a true meridional compass or with some other kind, in which the magnetized iron points away from the lily. The Portuguese (as is seen in their writings) employ the compass of Portugal, in which the magnetized iron is one half of a point to the east of the lily.

Even expert navigators find it very difficult to observe the variation at sea on account of the ship's motions and her tossing in every direction, though they may employ the best instruments yet devised and in use. Hence have arisen various opinions about magnetic deviation. For example, the Portuguese navigator Roderigues de Lazos takes it to be one half point off the island of St. Helena ; the Dutch, in their nautical journal, make it one point there ; Kendall, an expert English navigator, makes it only one sixth of a point, using a true meridional compass. Diego Alfonso finds no variation at a point a little southeast of Cape das Agulhas, and by the astrolabe shows that the compass stands in the true meridian ; but Roderigues declares that the compass points due north and south at Cape das Agulhas if it be of the Portuguese style, in which the variation is one half point to the southeast.[1] There

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[1] Cape Agulhas—Cape Aguilhas—Capo d'Aguhas—southernmost point of Africa. This name was given by the Portuguese on account of the magnetic derangement of their compass needles in its locality when Vasco de Gama sailed round it—*Aguilhas*, in Portuguese, signifying needles. (Walker, "Magn. of Ships," 1853, page 2.)

"And so likewise, because the Cape de las Agullas hath sea on both sides is the same degree of confusion, carelessness, and falsity in most of the other records.

CHAPTER XIV.

OF THE VARIATION UNDER THE EQUINOCTIAL LINE AND NEAR BY.

In northern regions the compass varies because of the northern eminences; in southern regions because of the southern eminences; on the equator, if the eminences on both sides were equal, there would be no variation. But because this seldom happens, therefore oftimes variation is observed under the equator; and even at some distance from the equator, three or four degrees, variation may be produced by austral eminences, if extensive and potent austral continents lie near on one side.

CHAPTER XV.

THE VARIATION OF THE MAGNETIZED NEEDLE IN THE GREAT SEA, ETHIOPIC AND AMERICAN, BELOW THE EQUATOR.

We have already spoken of the mode and reason of variation in the great Atlantic Sea; but below the equator, on the

near it, and other land remote, and as it were æquidistant from it, therefore at that point the needle conforms unto the true meridian, and is not distracted by the vicinity of Adjacencies. This is the general and great cause of variation" (Sir Thomas Brown, *Pseudoloxia Epidemica*, 1658, Book II, page 70). See the extract from unpublished letter of Mr. Archibald Smith to Lord Cardwell, dated February 13, 1866, relative to the loss of the iron steamer "Eastern Province" near Cape Agulhas, at page 387 of "Good Words" for 1879.

east coast of Brazil, the needle swerves toward the continent; with the end that looks south: thus, at that end, it declines from the true meridian, toward the west; this is noticed by navigators as a movement of the point of the needle, and so they think that the variation is to the east. But, over the whole route from the first eastern promontory of Brazil, past Cape Sao Agostino to Cape Frio and as far as the mouth of the Strait of Magelhan, the variation is always from south to west, the crotch of the needle tending to the Antartic pole. For it always turns with the proper end toward a continent. Yet the variation takes place not only on the coast itself, but at some distance from the land—over a space of 50 or 60 German miles or more.

But at a great distance from the land the arc begins to grow less, for the needle turns less toward distant prominences; and it is not made to diverge much by such prominences when present and on the spot, for it then shares with them. On the island of St. Helena (whose longitude is less than it is usually given in maps) the compass varies one or perhaps two degrees. The Portuguese, and others who have learnt of them, in sailing beyond the Cape of Good Hope to the Indies, in order to have favorable winds, shape their course toward the islands of Tristan de Acunha, and on the first half of the voyage find no considerable difference of variation; but near those islands the difference is greater than anywhere else in the entire voyage. For the great promontory of the southerly continent which lies to the southwest pulls and solicits that end of the versorium which points south (and at that end is the principal cause of the variation). But as the ship approaches the Cape of Good Hope the variation grows steadily less. In the prime meridian, at latitude 45 degrees, the needle points southeast by south; and so, too, he who sails along the coast from Manicongo to the tropic and a little beyond will find the needle tending from the south to the southeast, but not much. At Cape das Agulhas it still keeps a little of the variation it showed near the islands of Tristan de Acunha, but it is much diminished owing to the remoteness from the cause of the variation; and the south end of the needle does not yet point due south.

CHAPTER XVI.

OF THE VARIATION IN NOVA ZEMBLA.

THE variations are greatest in regions nigh to the poles, as has been proved, and there, too, the changes of variation are sudden, as Dutch observers noted some years ago, though their observations were not exact; yet the inexactitude can be excused, for, with the ordinary instruments, it is hard to get at the truth in such high latitudes—about 80 degrees. But now the variation of the compass gives the clear evidence of the existence of an open passage eastward through the North Sea—Arctic Ocean (*Mare Scythicum*), for, since the compass has so great an arc of variation to the west, it is evident that no continent stretches for any great distance along that whole route eastward. Therefore we can strive and explore more hopefully for a passage to the Moluccas by the northeast than by the northwest.

CHAPTER XVII.

VARIATION IN THE SOUTH SEA.

AFTER passing through the Strait of Magellan, the variation off the Peruvian coast is to the southeast; and a like deflection continues all along the coast of Peru to the equator. In higher latitude, up to 45 degrees, the variation is greater than near the equator; and, just as on the eastern coast of South America, the deflection was from south toward west, so now it is to the southeast. From the equator northward the variation is very small or null till you reach New Galicia; thence along the whole coast as far as Quivira the inclination is from the north to the east.

CHAPTER XVIII.

OF THE VARIATION IN THE MEDITERRANEAN SEA.

SICILIAN and Italian mariners declare that in the Sicilian sea and eastward to the meridian of Peloponnesus (as Francis Maurolycus relates) the needle grecizes, i.e., is diverted from the pole toward the wind called Græcus (Greek), or north wind; that on the coast of Peloponnesus it points to the true pole; but that when you proceed farther, then it mistralizes, inclining from the pole to the mistral or northwest wind: this is in accordance with our rule of the variation. For, as the

Mediterranean Sea stretches away from that meridian toward the west, so, on the side toward the east, there is open sea as far as Palestine, and toward the north and east is the whole archipelago, and hard by the Black Sea. From Peloponnesus to the north pole, that meridian passes through the largest and most elevated regions of all Europe: through Achaia, Macedonia, Hungary, Transylvania, Lithuania, Livonia, Novogoroda, Corelia and Biarmia.[1]

CHAPTER XIX.

THE VARIATION IN THE INTERIOR OF THE GREAT CONTINENTS.

GREAT seas usually have great variations; in some parts, however, there is no variation, but true direction poleward. On the continents, too, the needle often deflects from the meridian, as on the margin of the land and the confines, but the arc of variation is wont to be small: in the middle regions of great continents there is no variation. Hence in the heart of northern Europe and of Asia, in the interior of Africa, Peru, and of North or Mexican America, the versorium rests in the meridian.

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[1] Biarmia is the name given by Scandinavian writers to that section of N. E. Russia bordering upon the White Sea. See reference thereto in note, Book I, Chap. I, of present work.

CHAPTER XX.

THE VARIATION IN THE EASTERN OCEAN.

THE variation in the Eastern Ocean, all the way to Goa and the Moluccas, is noted by the Portuguese, but they are mistaken in very many points, for they follow the first observers who set down the variations for sundry places, ascertained by the use of unfit instruments, or by inaccurate observations, or by conjecture. Thus in the island of Brandö[1] they make the compass vary 22 degrees to the northwest. Now, in no region, in no place on earth that has not a higher latitude than that, is the variation so much as 22 degrees: in fact the deviation on that island is trifling. So, when they say that in Mozambique the compass varies to the northwest one point, they are in error even though the compass they use is that of Portugal; for, without a doubt, the needle varies in Mozambique to the southwest one quarter of a point or more. Again, they are all wrong in holding that beyond the equator, on the route toward Goa, the compass varies westward one point and one half; better had they said that in the first part of the route the compass of Portugal inclines one point, but that a true or meridional compass varies only one-half point. Yet to determine the amount of the variation in the Eastern Ocean according to our rules, we need a more exact and correct reconnoissance of the austral continent, which stretches farther from the south toward the equinoctial than it is described in current charts and globes.

[1] The island of Brandö lies in the Gulf of Bothnia, close by the east coast of Sweden.

CHAPTER XXI.

HOW THE DEVIATION OF THE NEEDLE IS GREATER OR LESS ACCORDING TO THE DISTANCES OF PLACES.

In the heart of great continents there is no variation; so, too, in the midst of great seas. On the edge of such lands and seas the variation is often large, but not as great as it is a little out at sea: thus off Cape Sao Agostino there is variation, but 50 miles away to the east there is a larger variation; still larger 80 miles away and 100 miles away. But from 100 miles distance the reduction of the deviation is slower as you approach the continent than from the distance of 80 miles, and from 80 miles than from 50; for the deviation is changed and reduced somewhat more quickly as you come toward the shore from anear then from afar. So, for mariners approaching Newfoundland, the change of the variation is quicker (i.e., a degree of variation is lost in a less arc of the route on a parallel) when they are not far from land than when they are 100 miles away; but when they journey inland the changes are more tardy at first than when they come farther into the interior.

The figure shows the ratio of the arcs on a parallel circle while a versorium is brought toward a continent that reaches to the pole; the ratio answers to the degrees of the variation. Let *A* be the pole, *B* the elevation of a great mass of land. At *C* there is no variation caused by *B*, which is too distant; at *D* the variation is greatest, because there the needle is attracted or is made by the whole earth to turn to the projecting land *B*; nor is the needle hindered, nor checked, nor led toward the pole by the verticity of this land, but, tending to the pole it is nevertheless deflected therefrom, because of the site o position and convenient distance of the overmastering eleva tions of land.

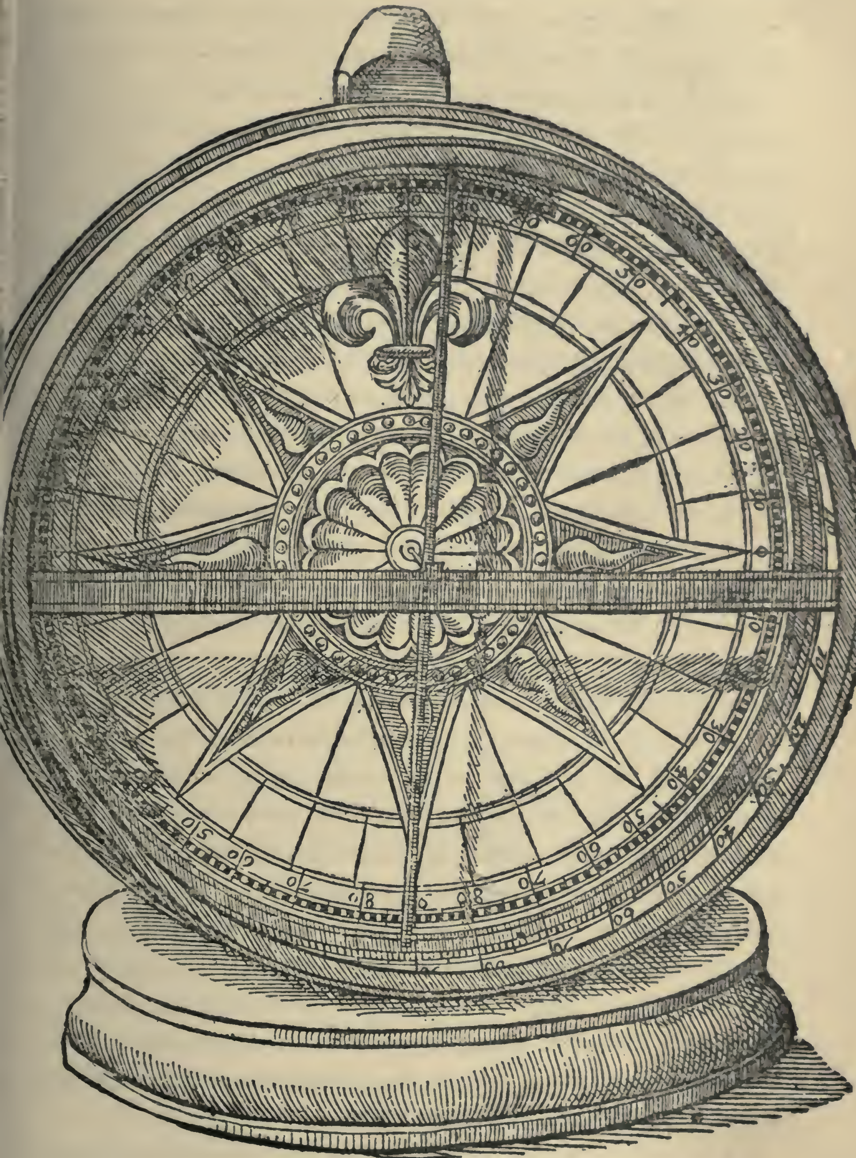
But, now, from *C* to *D* the variation grows, yet the versorium does not deviate so quickly in the first stages as it does when near *D*. But you sail more miles on the parallel circle *CD* as long as you are near *C*, to register one degree of variation, than you sail when near *D*; so, too, in travelling from *D* toward *E* you must make a greater number of miles when near *D* than when near *E*. Thus there are equal deviations for unequal distances sailed, both for rising and falling variation; yet it falls within a less space than it rises. There are, however, several other incidental cases that confuse this ratio.

BOOK V.

CHAPTER I.

OF THE DIP OF THE MAGNETIC NEEDLE.

WE come at last to that fine experiment, that wonderful movement of magnetic bodies as they dip beneath the horizon in virtue of their natural verticity; after we have mastered this, the wondrous combination, harmony, and concordant interaction of the earth and the loadstone (or magnetized iron), being made manifest by our theory, stand revealed. This motion we have so illustrated and demonstrated with many experiments, and purpose in what follows so to point out the causes and reasons, that no one endowed with reason and intelligence may justly contemn, or refute, or dispute our chief magnetic principles. Direction, as also variation, is demonstrated on the plane of the horizon whenever a magnetic needle poised in equilibrium comes to a rest in any fixed point of it. But inclination (dip) is seen to be the motion of the iron bar, first balanced on its axis and then excited by a loadstone, from that point in the horizon, one end or pole tending toward the earth's centre. And we have found that this inclination differs in the ratio of the latitude of each region. Now this movement is produced not by any motion away from the horizon toward the earth's centre, but by the turning of the whole of the magnetic body to the whole of the earth, as later we will show. Nor does the needle descend below the horizon in the ratio of the degrees of the elevation of the pole in the given region, and with an equal arc of the quadrant in any oblique sphere, as later will be seen. But how much the needle dips in every horizon can now first be ascertained by means of an instrument (which, however, is not very easily constructed), just as in sun-dials when the needle returns to points in the horizon, or as in the mariner's compass. Get a circular planed board with diameter at least six finger-lengths, which is to be fastened to one face of an upright square post and to rest on a wooden base. Divide the periphery of the instrument into four quadrants, and then each quadrant into ninety degrees. In the centre of the instrument drive a brass nail, and in the centre of its head bore a small hole well reamed and smoothed. Adjust to the instrument a circle or ring of brass about two finger-breadths wide, with a transverse plate or flat bar of the same metal fastened across the middle of the ring and serving for horizon. In the middle of this horizon bar bore another hole which shall be exactly opposite to the centre of the instrument, in which a hole was already bored. Next get a steel wire such as is used for compass needles, and at the exact middle of it and at right angles to it pass a very thin iron axis through it so that the middle of the axis and the middle of the needle shall exactly meet; let this inclination (dipping) needle, the ends of the axis having been inserted into the holes, be suspended so that it may move freely and evenly on itself in most exact equilibrium, and so accu-

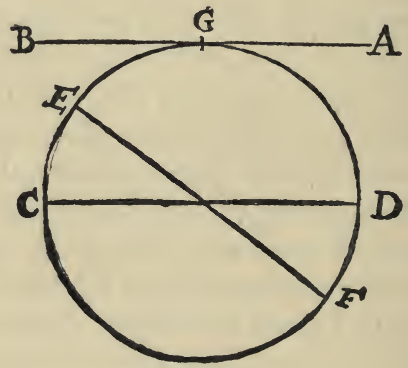


DIP INSTRUMENT.

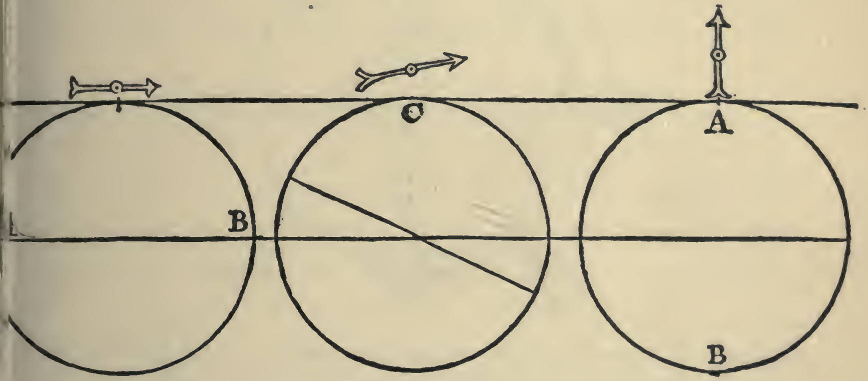
rately that it may not turn away from any one degree or point marked on the circumference more than from any other, but may rest easily at any one point. Have the instrument fastened upright to the face of the post, and on the edge of the base set a very small magnetized versorium. The needle thus nicely balanced, now rub skilfully at both ends with the opposite poles of a loadstone, but do this with the greatest care lest the wire be in the least bent; for unless you do all this with great skill and dexterity, you will reach no result. Next get a second brass ring, a little larger than the first, so as to go round it, and to one rim fit a cover of glass or of very thin mica; this, when placed over the other ring, encloses the whole space, and the needle is protected from dust and currents of air. The instrument being now complete, set it up perpendicularly with the small versorium on the base, so that when thus erected exactly upright it may tend to the true point of the magnetic direction. Then that one of the needle's ends which in northern latitudes looks to the north dips below the horizon; but in southern latitudes the end of the needle that looks south tends toward the earth's centre in a certain ratio (afterward to be explained) of the latitude of the region in question from the equator on either side. But the needle must be rubbed with a powerful loadstone, else it does not dip at the true point or goes beyond it and is not always at rest in it. A larger instrument can also be employed, of ten or twelve finger-lengths diameter, but in that case there is more trouble in balancing the needle exactly. Care must be taken to have the needle of steel, also that it be straight, and that the sharp points of the axis on both ends be at right angles with the needle itself, and that it pass through the very centre.

As in other magnetic movements there is strict agreement and a clearly visible, sensible accordance between the earth and the loadstone in our demonstration, so in this inclination is the accordance of the globe of the earth and the loadstone positive and manifest. The true and definite cause of this great and hitherto unknown effect is as follows: The loadstone moves and revolves until one of its poles, being impelled toward the north, comes to rest in its predetermined point on the horizon; the pole that comes to a stand looking north is (as appears from the foregoing rules and demonstrations) southern, not northern, though till now every one has supposed it to be northern because it turns to the north. An iron wire or versorium touched with this pole of the stone turns south, and is made northern because rubbed at the south end of the stone; just as when the point of a versorium is magnetized in that way it will be directed toward the earth's south pole and to that will turn, while the other end, the crotch, will be southern and will turn to the northern regions of the earth (the earth itself causing the motion), for thus does direction result from the bearings of the stone and the needle, and from the earth's verticity. But inclination (dip) is when the needle turns to the body of the earth, its south end pointed to the north, in any latitude away from the equator. For it is a fixed and unchanging law that exactly beneath the celestial equator, or rather on the equator of the terrestrial globe, the magnetic inclination or dip of the needle is *nil;* and in whatever way it may have been excited or rubbed, it rests exactly on the plane of the horizon in the inclination instrument, provided it be first duly balanced. The reason of this is, that the needle, being at equal distance from the two poles, does not in its rotation dip toward either, but stands balanced, pointing to the level of the equator, as it does when mounted on a sharp point or floating free and unhindered on water.

But when the needle is in any latitude from the equator, or when one of the earth's poles is raised (I do not say raised above the visible horizon, like what is commonly reputed to be the pole of the revolving world in the heavens, but raised above the horizon of the centre or above its own diameter, equidistant from the plane of the visible horizon, which is the true elevation of the earth's pole), then inclination appears and the needle dips in its meridian towards the body of the earth. Thus, let *AB* be the visible horizon of a region; *CD* the earth's horizon, dividing the earth into equal parts; *EF* the earth's axis; *G* a place within the region: plainly the north pole *E* rises above the point *C* by as much as *G* is distant from the equator; therefore, since at *E* the magnetized needle is raised



to perpendicular just by its turning (to the north), as has already been shown, so now at *G* there is a sort of beginning of such a turning, proportioned to the latitude (the magnetized body departing from the plane of the horizon), and the needle intersects at unequal angles the horizon and shows dip beneath the horizon; for this reason, if the dipping needle be placed at *G*, its south end (that which points north) descends below the plane of the visible horizon *AB*. Thus there is very great difference between a right and a polar or parallel sphere, in which the pole is in the true zenith. For in a right sphere the needle is parallel to the plane of the horizon. But when the celestial pole is in the vertical point, or when the earth's pole is itself the place in question (*locus regionis*), then the needle is perpendicular to the horizon. This is shown on a terrella; suspend in air, like the beam of a balance, a small dip needle of only two fingers-width (*duorum digitorum*) rubbed at a loadstone, and carefully bring the terrella under it, and first let the terrella stand properly (*recta*) as in a right sphere, and, as in the first of the figures following, the needle will now remain in equilibrium. But in an oblique position of the terrella, as in an oblique sphere and in the second figure, the needle dips at one end obliquely toward the neighboring pole, but does not rest on the pole, nor is its dip governed by the pole, but by the whole body and mass; for the dipping needle in a higher latitude sinks —passes (*labitur*)—beyond the pole. But in the third position of the terrella the needle is perpendicular, because the pole of

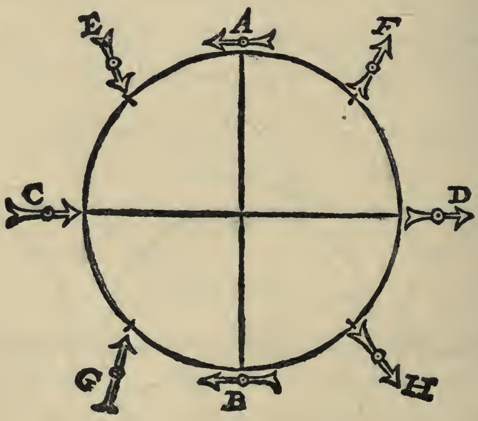


the stone is uppermost, and the needle tending straight toward the body attains the pole. The crotch in the foregoing figures always turns toward the north pole of the terrella, having been touched with its north pole; the point having been touched by the south pole of the terrella tends toward its south pole. Thus may we see the level, the oblique, and the perpendicular position of the needle on a terrella.[1]

CHAPTER II.

DIAGRAM SHOWING DIP OF THE MAGNETIC NEEDLE IN DIFFERENT POSITIONS OF A SPHERE AND HORIZONS OF THE EARTH IN WHICH THERE IS NO VARIATION OF DIP.

Let *AB* be the equator, *C* the Arctic and *D* the Antarctic pole, *E*, *G* dipping needles in northern regions, and *H*, *F* in



southern regions of the earth or the terrella. All the needles have been touched with the true Arctic pole of the terrella.

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[1] At two points of the earth's globe, the needle will rest in a vertical position. These are the magnetic poles of the earth. The northern magnetical pole was discovered June 1, 1831, by Sir James Clark Ross, during the second voyage he made to the Arctic Regions under his uncle Sir John Ross,

The figure shows the needles in horizontal position at *A* and *B*, the earth's and the terrella's equator; they are perpendicular at the poles *C* and *D*; but in the mid spaces, at distances of 45 degrees, the crotches dip toward the south, but the points look toward the north at the same angle.

Diagram showing the direction and dip of a terrella representing the earth relative to the standard representation of the globe of the earth, at north latitude 50 *degrees.* *

A is the north pole of the earth or of the large terrella; *B* its south pole, *C* is the smaller terrella, and *E* the south pole of the smaller terrella that dips toward the north region (of the larger). Its centre *C* is placed on the superficies of the larger terrella, because the smaller terrella varies a little on account of the length of the axis (*quia terrella minor aliquantulum variat propter axis longitudinem*), but in the earth the variation is very little. As the needle dips in the latitude of a region of 50 degrees, so, too, the axis of the stone—which is spherical—is depressed beneath the horizon, and its south pole, which is within the circumference of the larger terrella dips, while

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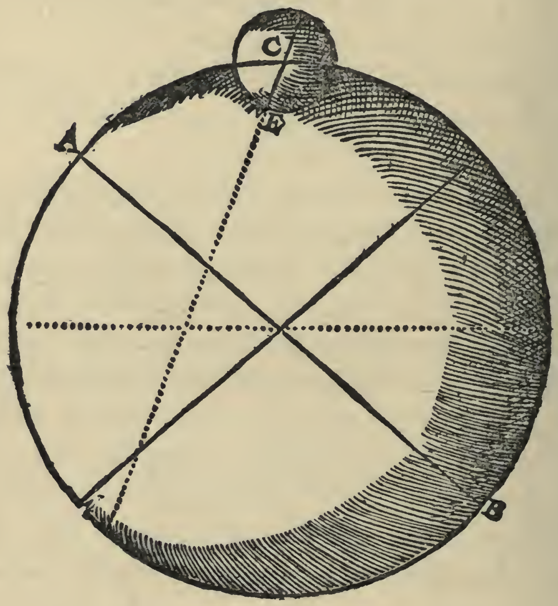
and lies near Boothia Felix Land in 70° 5′ 17″ N. lat. and 96° 46′ 45″ W. long., the dip being 89° 59′, or "within one minute of the vertical." He was not successful, however, in reaching the southern magnetic pole, but he assigned to it a position in 75° 5′ S. lat. and 154° 8′ E. long. The north magnetic pole is the point of the earth's surface where the dipping-needle rests with its magnetic axis vertical and its true *south* pole downwards; the south magnetical pole is the point where the dipping-needle rests with its axis vertical and its true *north* pole downwards. As the magnetism of the north magnetic pole corresponds to that of the south pole of the magnet, Prof. Silvanus P. Thompson named the latter "the north-seeking pole." By Prof. Faraday the north-seeking end was designated as the "marked" and the other end the "unmarked," the French calling them the "astral" and the "boreal," while others allude to them as the "negative" and "positive" ends, respectively. (See Capt. Sir John Ross' "Narrative of a Second Voyage....," published in 1835; Humboldt, "Cosmos," article on Magnetic Inclination; Sir Wm. Thomson's "Terrestrial Magn. and the Magn. Compass;" "The Earth a Magnet," in "Cornhill Mag.," Vol. XVII, page 727.)

in the south (of the larger terrella) its (the smaller terrella's) north pole is raised toward the zenith. And a flat circular piece of iron carefully magnetized at opposite points of its

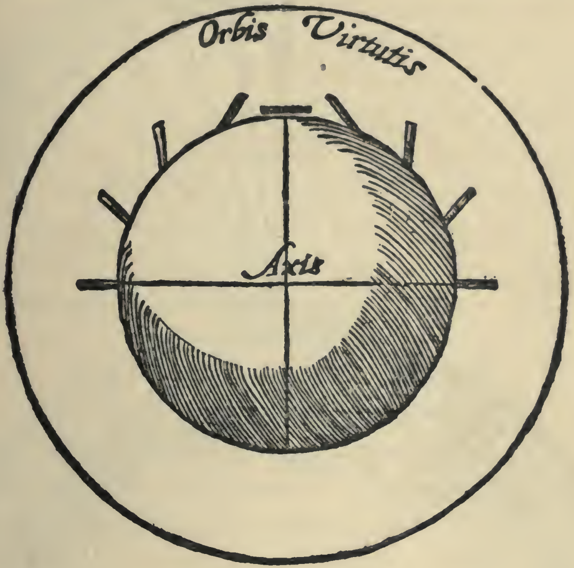


circumference acts in the same way; but these magnetic experiments are less striking because in iron disks the magnetic force is rather sluggish. The figure below shows, with bits of iron, the differences in dip at various latitudes in the terrella.[1]

Below is shown the dip of the needle on a terrella by means of a number of bits of iron wire of equal size, one barley-corn in length, and placed in a meridian. At the equator the bits of iron are directed toward the poles, and lie upon the

[1] Consult Airy's "Magnetism," more particularly for figures and explanations of the magnetic dip and the variations of total terrestrial magnetic intensity.

body of the terrella in the plane of its horizon. The nearer they are placed to the poles the more do they rise from the



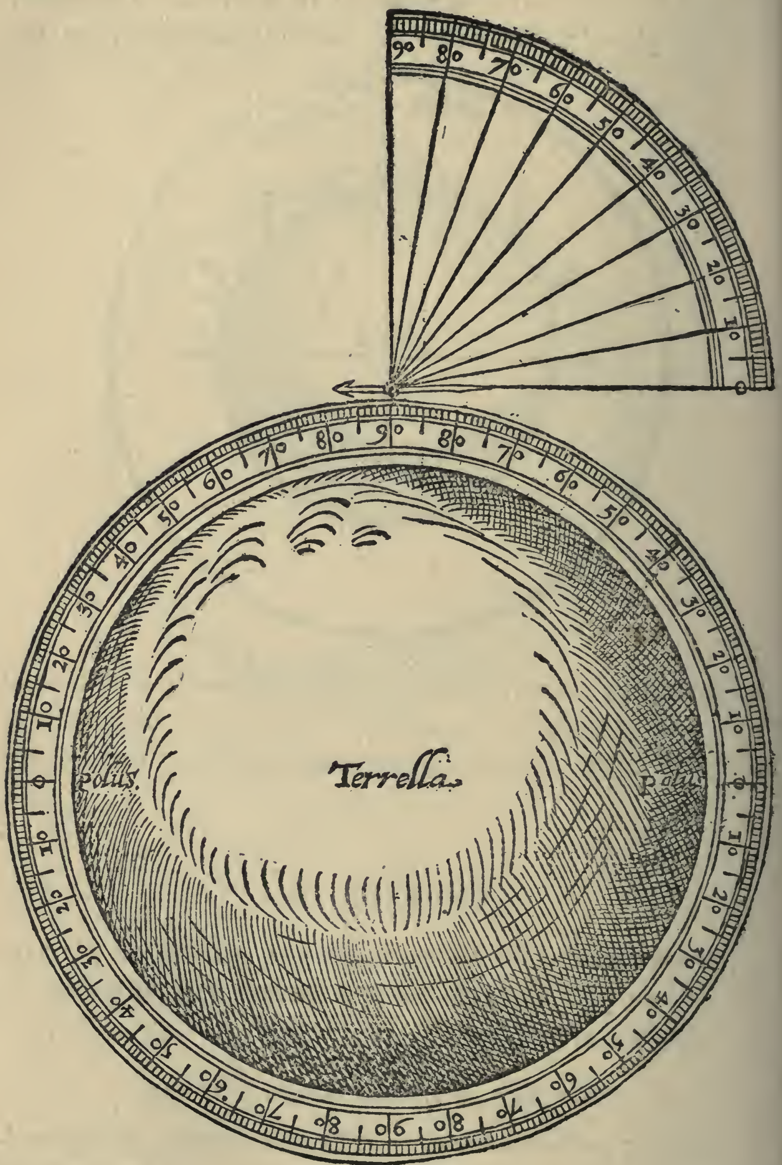
horizontal by reason of their turning poleward; at the poles they tend straight to the centre. But bits of iron will not stand up aright, save on a good loadstone, if they be too long.

CHAPTER III.

AN INSTRUMENT FOR SHOWING BY THE ACTION OF A LOAD-* STONE THE DEGREE OF DIP BELOW THE HORIZON IN ANY LATITUDE.

Description of the instrument; its uses.

MAKE a perfectly round terrella of a superior strong loadstone, one homogeneous throughout, not injured anywhere by

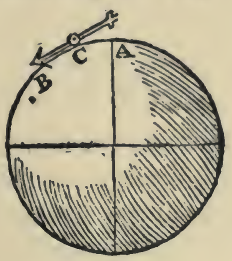

Terrella
polus.
polus.

decay or corrosion, of proper size, so that its diameter shall be six or seven finger-breadths. Having, by the method heretofore given, found the poles, mark them with some iron instrument, also mark the equinoctial circle. Next, in a squared block of wood, one foot in diameter, make a hemispherical cavity to hold half of the terrella, so that just one half of the terrella shall rise above the block. Where the limb of the terrella is nearest the rim of this cavity draw a circle around it for a meridian, and then divide it into four equal parts or quadrants, and the quadrants each into 90 degrees. Let one end of the quadrants on the limb be near the centre of a quadrant on the block, and divide this also into 90 degrees. At that centre, place a small short versorium having one of its ends sharp and longer than the other, for use as a pointer, and let it be poised on a fitting sharp fulcrum. Evidently, whenever the poles of the terrella are at the beginnings (zero) of the quadrants, then the versorium will lie in a right line on the terrella as in equilibrium. But, if the terrella be moved so that one of the poles rises on the left, then the needle elevates itself in the meridian according to the latitude, just as a piece of magnetized iron rises; and the needle indicates upon the quadrant described on the block the degrees of the dip. The rim of the cavity in the block represents a meridian circle, and to it answers some meridian circle of the terella, for the poles on both sides are upon the inner circumference of the rim. This is precisely what takes place on the earth itself where there is no variation; but when there is variation either of direction or of dip, i.e., a disordering of the proper magnetic revolution for causes later to be set forth, then there is some difference. The quadrant described on the block must be near the limb of the terrella, or its centre must be at the limb itself, and the needle must be very short so as not to touch the terrella; for there is error when the needle is long or placed at a distance, as it has a truly proportionate movement only at the superficies of the terrella. But were the quadrant —being remote from the terrella—to be moved into its sphere of influence toward the pole on a circle concentric with the terrella, then the needle would indicate on the quadrant the degrees of dip in ratio and symmetry with that circle, not with the terrella.

CHAPTER IV.

OF A SUITABLE LENGTH OF NEEDLE ON THE TERRELLA FOR SHOWING THE DIP.

WHEN it is sought to define the dip by means of a dip-indicating instrument on the earth itself, we may use either a short versorium or one ever so long, provided only the magnetic property of the loadstone with which it has been stroked is able to pervade its whole substance and length. For the greatest length of a versorium, as compared with the earth's diameter, is insignificant and has no ratio perceptible by sense. But on a terrella, or on a plane nigh a meridian of a terrella, a short needle is required, one barley-corn's length; for longer versoria (because they reach farther), in the first degrees of dip, descend suddenly and irregularly, and turn to the body of the terrella. For example, as soon as the long versorium in the figure is moved onward from the equator *A* to *C*, it lays hold of the stone with its point *C* as though with a long outspread wing, when the point reaches the parts around *B*, which give it a greater revolution than those at *C*. And the ends of rather long pieces of wire or little rods are also made to rotate irregularly, just as pieces of iron wire and iron balls and other spherical loadstones are made to rotate irregularly by an oblong loadstone not rounded into a ball. Yet magnetic bodies



or pieces of iron on the surface of a terrella should not have a long but a very short axis, so that they may dip true and naturally; for a long versorium situated near a terrella does not easily stand in a right sphere on the horizon, and wavers and suddenly dips to one side or the other, especially its magnetized end, or, if both ends are magnetized, then the end magnetized last.

CHAPTER V.

THAT DIP IS NOT CAUSED BY THE ATTRACTION OF A LOADSTONE, BUT BY ITS POWER OF GIVING DIRECTION AND ROTATION.

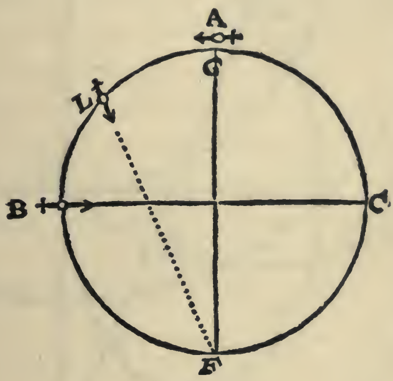
THROUGHOUT nature we have to recognize that wondrous work of the Maker whereby the principal bodies are restricted within particular localities and, as it were, hedged round with fences, nature so ordering. Hence it is that heavenly bodies do not get confused in their motions and in their progressions beyond each other. Similarly are the magnetic revolutions produced by the force of a greater and dominant body as well as by that of a lesser and subject body, though that be of very small volume. For the work is not done by attraction but by incitation on the part of both, and that with a proportionate movement toward fixed points beyond which there is no further motion. For did the versorium dip under the action of an attractive force, then a terrella fashioned out of a very powerful loadstone would pull it to itself more than would one made of an indifferent loadstone, and iron stroked by a strong loadstone would have greater dip; but that is never so. Further, a piece of iron attached to and projecting from the terrella at any latitude does not cause a little iron bar to rise more to perpendicular than does the unarmed stone, though when so armed the stone does seize and lift far heavier weights. But if a loadstone be somewhat fashioned to a point at one end, and rather obtuse at the other, the acute end or pole solicits with greater force magnetized iron, the obtuse, thick end makes the iron turn to itself more powerfully; but a spherical stone makes it *turn to itself powerfully and in true direction according to magnetic laws and the form of spheres; while a loadstone of some length from pole to pole stirs the versorium unequally, for in such a stone the pole of the versorium always is pointed toward the pole of the loadstone itself. So, too, if the loadstone take a disk shape, with the poles in the circumference, but with the body plane and not spherical, when the plane is brought near to the versorium, the versorium does not move with the regular magnetic movement as with a terrella, but turns round always pointing toward the pole of the loadstone situated in the circumference of the plane. Besides, if the stone caused the versorium to revolve by attraction, then in the first degrees of latitude it would attract toward the mass of the terrella itself the end of a short versorium ; but it does not so attract as to bring the two together and into coition—the versorium simply revolves so far as nature demands, as is shown in the following instance.

For here the point of a versorium in a low latitude neither touches the stone nor comes into coition with it, only inclines toward it. Further, when the versorium rotates as it dips, the pole of the versorium is not stayed nor held by the pole of the earth or the terrella, but revolves regularly, nor remains in any point or terminus, nor looks straight to the pole toward which the centre of the versorium advances, save at the pole itself, and that only once between the pole and the equator ; but the inclination goes on according as the change in the site of the centre produces a dip in conformity to magnetic laws. The dip of the needle in water, demonstrated in the sequel, is also constant : the needle does not dip toward the bottom of the vessel, but stands in mid direction poised on its centre according to its due dip ; yet this would not be the case if the earth or its poles by attraction made the extremity of the needle to dip.

CHAPTER VI.

OF THE RATIO OF DIP TO LATITUDE AND THE CAUSES THEREOF.

We have spoken of the construction of the instrument for determining the dip, of the causes and modes of the dip, and of the different inclinations of the needle for different localities; of the inclination of the loadstone, too, and of an instrument for showing the power of the stone at any latitude, as well as of the demonstrated rotation (by erection) of pieces of iron on a meridian of the stone, according to latitude. We have now to treat more at length of the causes of this proportionate inclination. A loadstone and a piece of iron wire, when moved in a meridian from the equator to the pole, turn toward a spherical loadstone, and toward the earth also, with a circular motion. In a right horizon (as also upon the equinoctial circle of the stone) the axis of the iron, which is its middle, is a line parallel with the earth's axis. When that axis reaches the pole, which is its centre, it stands still in the same right line with the earth's axis. The same end of the iron that at the equator points south turns to the north; for it is not a movement of centre to centre, but of one magnetic body to another, and a natural turning of the axis of the body to the axis of the terrella, not caused by the pole's attraction, so that the iron should regard the earth's polar point. On the equator the magnetic iron stands in horizontal equilibrium, but toward the pole on either side of the equator, at every latitude from the beginning of the first degree even to the 90th, it dips; yet, not in ratio to the number of degrees or the arc of the latitude does the magnetic needle dip so many degrees or over a like arc; but over a very different one, for this movement is in truth not a dipping movement, but really a revolution movement, and it describes an arc of revolution proportioned to the arc of latitude. Hence the magnetic body *A*, while it



passes round the earth, or an earthkin or terrella, from the equinoctial circle *G* toward *B* (the pole), rotates on its centre, and, midway in its progress from the equator to pole *B*, points to the equator *F* as the mean of the two poles: therefore ought the versorium to rotate much more quickly than the centre travels in order to regard the point *F* in a right line by rotating. For this reason the movement of this rotation is quick in the first degrees from the equator, from *A* to *L*, but slower in the subsequent degrees, from *L* to *B*, that is, with reference to the equatorial point *F*, toward *C* (*in respectibus ab æquatore F ad C*). But were dip equal to the latitude, i.e., always so many degrees from the horizon as the centre of the versorium has gone away from the equator, then the magnetic needle would obey the potency and the peculiar virtue of the centre as a point operating of itself; but it obeys the whole and its mass and outer limits, the powers of both coöperating, * to wit, those of the magnetized versorium and of the earth.

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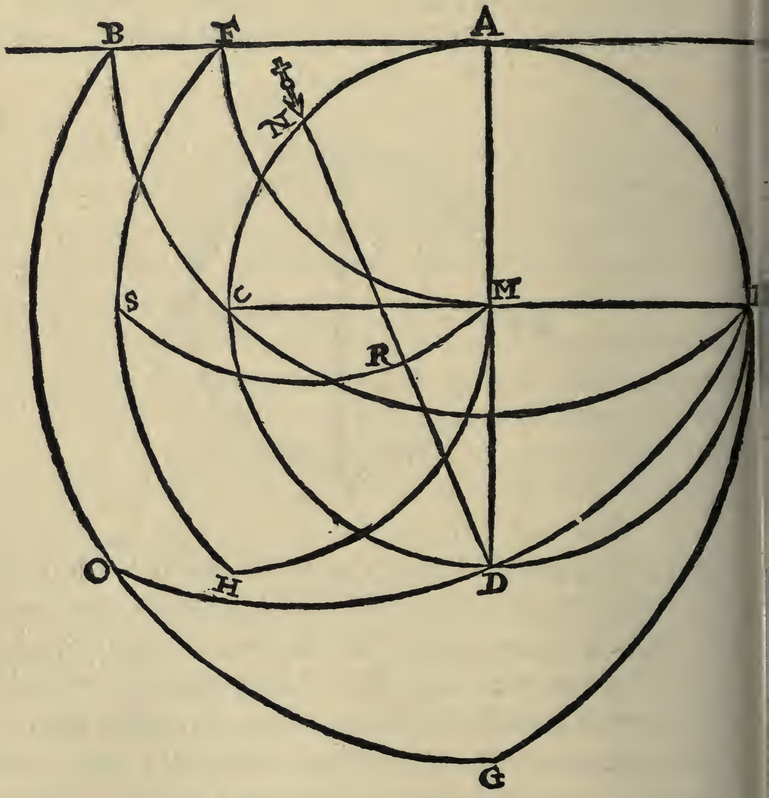


CHAPTER VII.

EXPLANATION OF THE DIAGRAM OF THE ROTATION OF MAGNETIZED IRON.

LET *ACDL* be the body of the earth or of a terrella, *M* the centre, *AD* the equator, *CL* the axis, *AB* the horizon, which changes according to the locality. From the point *F* in the horizon, at a distance from the equator *A* equal to the semi-diameter *CM* of earth or terrella, is described an arc to *H* as terminus of the quadrants of dip: for all quadrants of dip that belong (*inserviunt*) to the parts between *A* and *C* begin at that arc and terminate in the earth's centre, *M*. The semi-diameter of this arc is a chord drawn from the equator *A* to the pole *C*. And a line equal to that chord, drawn in the horizon to *B*, gives the starting point (*principium*) of the arc of the termini of the arcs of revolution and rotation, which arc is continued on to *G*. For as the quadrant of a circle around the earth's centre (the starting-point of it being in the horizon, at a distance from the equator equal to the earth's semi-diameter) is the terminus of all the quadrants of dip produced from every horizon to the centre, so a circle round the centre from the starting point of the first arc of rotation *B* to *G* is the terminus of the arcs of rotation. Between the arc of rotation *BL* and *BG* are intermediate arcs of revolution and rotation of the magnetic needle. The centre of the arc is the region or place where the observation is obtained; the beginning of the arc is taken from the circle that is terminus of the revolutions, and it ends at the opposite pole, as from *O* to *L*, in 45 degrees latitude. Divide any arc of revolution into 90 equal parts from the terminus of the arcs of revolution to the pole; for whatever the degree of latitude of the place, that part of the arc of revolution is to be reckoned as cognominal to it which the magnetic pole in rotating upon or around terrella or earth regards: in the large diagram that follows, this is indicated by the right lines. In the middle latitude of 45 degrees the magnetic rotation is directed to the equator, and there also the arc from its terminus to the pole is the quadrant of a circle; but at latitudes above this (*ante hunc*, i.e., nearer the equator) all the arcs of revolution are greater than a quadrant; in latitudes below this (*post hunc*, i.e., higher, farther from the equator) they are less: in the former the needle rotates quickly; in the latter it gradually rotates more slowly. Each region has its own arc of revolution, in which is, according to the number of the degree of latitude of the place, the terminus toward which the needle turns; so that a right line drawn from the region to a point in that arc cognominal to the number of the degree of latitude indicates the magnetic direction, and shows the degree of the inclination at the intersection of the quadrant of dip that belongs (*inservit*) to the given region. Take away the arc of the quadrant of dip from the centre to the line of magnetic direction, and what remains is the arc of dip beneath the horizon. Thus, in the rotation of the versorium *N*, whose line of magnetic direction extends to *D*, take away from the quadrant of dip *SM* its arc *RM*, and what remains will be the arc of dip, that is, it shows how much the needle dips in latitude 45 degrees.

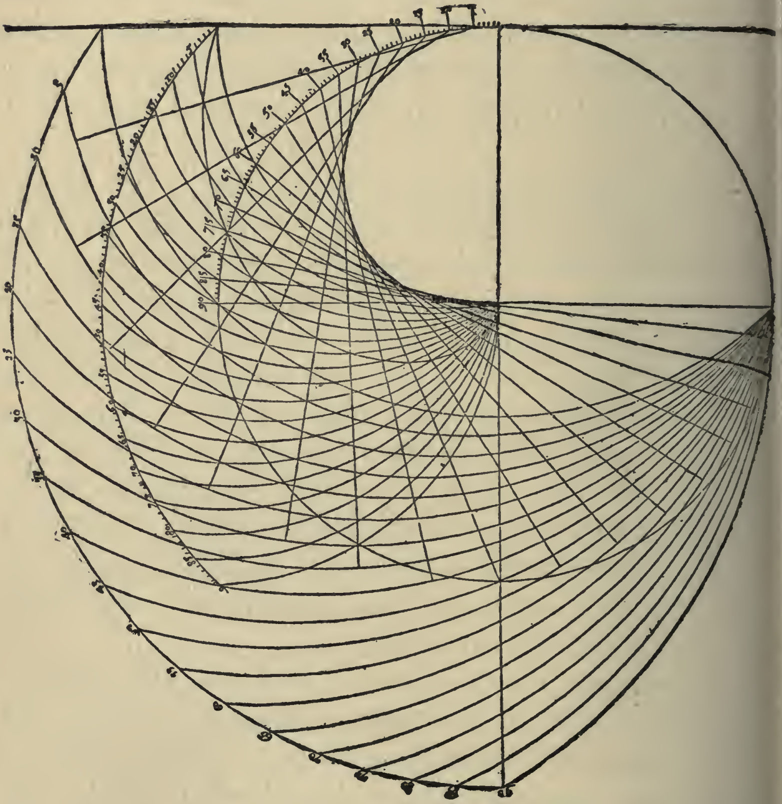
CHAPTER VIII.

DIAGRAM OF THE ROTATION OF MAGNETIZED IRON, SHOWING THE MAGNETIC DIP IN ALL LATITUDES, AND SHOWING THE LATITUDE FROM THE ROTATION AND DIP.

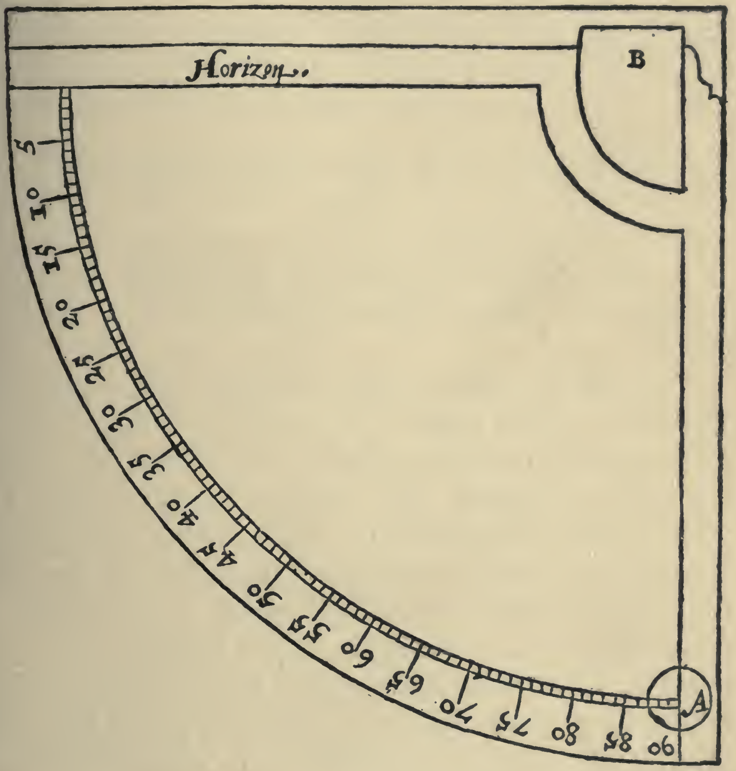
IN the foregoing diagram, around the body of the earth or of the terrella are drawn a circle of rotation and a circle of dip, together with a first, a last, and a middle arc of rotation and dip. Now from each one fifth part of that arc which terminates all the arcs of rotation (and each of which also is supposed to be divided into 90 equal parts) are drawn arcs to the pole, and from every fifth degree of the arc terminating the quadrants of dip are drawn quadrants to the centre, and at the same time is drawn a spiral line indicating (by the aid of a movable quadrant) the dip in every latitude. Right lines of magnetic direction are drawn from the degrees marked on the meridian of earth or terrella to their proper arcs and to the parts answering to those arcs.

How to ascertain the elevation of the pole, or the latitude of any place, by means of the following diagram, turned into a magnetic instrument, in any part of the world, without the help of the heavenly bodies, sun, planets, or fixed stars, and in foggy weather as well as in darkness.

We can see how far from idle is the magnetic philosophy; on the contrary, how delightful, how beneficial, how divine! Seamen tossed by the waves and vexed with incessant storms, while they cannot learn even from the heavenly luminaries aught as to where on earth they are, may with the greatest ease gain comfort from an insignificant instrument, and ascertain the latitude of the place where they happen to be. With a dip instrument an observation is taken of the degree of the needle's dip beneath the horizon; that degree is noted on



the inside arc of the quadrant, and the quadrant is turned round at the centre of the instrument until that degree on the quadrant touches the spiral line: then in the open space *B*, at the centre of the quadrant, the latitude of the region on the periphery of the globe is found by the *linea fiduciæ AB*. Draw the diagram on a suitable planed board, and to its centre attach the centre of the angle of the quadrant *A*, so that the quadrant may rotate on that centre. But it must be remembered also that in some places there is variation in dip for the causes aforesaid (albeit the variation is not great): this variation also it will be well to study, and to account for on some probable



hypothesis, and it will be of very great interest to observe it in different localities, for this variation of dip seems to present more difficulty than the variation of direction; but it is readily understood with dip instruments when it disagrees either by plus or by minus with the diagram.

Observing the magnetic dip at sea.

Place the dip instrument upon our variation instrument, a wooden ball being put between the round movable compass-box and the dip instrument; but first remove (*eximito*) the versorium, lest it interfere with the dip instrument. In this way, when the sea is in commotion the compass-box will remain erect on the level of the horizon. The dip compass is to be directed, by means of a small versorium at its base, to the point of the variation, to the greater circle of which (commonly called the magnetic meridian) the plane of the upright compass conforms; thus the dip instrument, in virtue of its property of rotating, shows the degree of the dip.

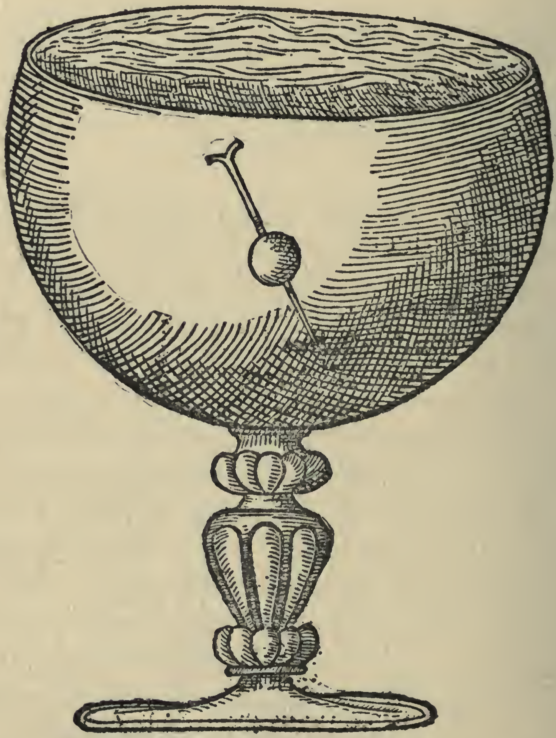
In a dip instrument the magnetic needle which when on a meridian circle descends, hangs perpendicular when it lies on a parallel.

The magnetic needle, in due position, while it conforms itself to the earth in virtue of its rotatory property, dips in an oblique sphere to a certain extent. But when the plane of the instrument is removed from the plane of the meridian, the needle (which tends poleward) no longer remains in the degree of its dip, but inclines more toward the centre, for the directional force is greater than that of the dip; and all power of dip is taken away if the plane of the instrument be on a parallel. For then the needle, its axis being transverse, cannot take its due position, and so tends perpendicular to earth, and remains only in its own meridian, or in what is commonly called the magnetic meridian.

CHAPTER IX.

DEMONSTRATION OF DIRECTION, OR OF VARIATION FROM THE TRUE DIRECTION, TOGETHER WITH DIP, SIMPLY BY THE MOVEMENT IN WATER, DUE TO THE POWER OF CONTROLLING AND ROTATING.

PASS through a round cork three finger-breadths of thin iron* wire, so that the cork may support the iron in water. Let the water be contained in a vase or large goblet of glass. With a very sharp knife pare the cork away gradually (still preserving its rotundity) till it will stand a finger-breadth or two under the surface motionless, with the wire evenly balanced. Then stroke one end of the wire on the north pole of a loadstone, the other end on the south pole (very carefully, so that the cork may not be moved ever so little out of its place), and put the instrument again in the water. The wire will dip with a circular movement on its centre below the plane of the horizon, according to the latitude of the place, and even as it dips will show (the true direction being disordered) the point of variation. The loadstone with which it is rubbed should be a powerful one, such as is required in all magnetic demonstrations. When the wire having been thus put in the water, and treated with the loadstone, comes to a standstill in the line of the dip, its lower end remains in the point of variation in an arc of a great circle, or meridian, passing through the zenith and the point of variation in the horizon, and through that lowermost point of the heavens called nadir: all this is demonstrated by bringing a rather long magnetized needle near the vessel on one side. This is a demonstration of the absolute conforming of a magnetic body to unity with the earth's body; here in the natural way is manifested direction with variation thereof and dip. But it is to be understood that delicate and



difficult as this experiment is, so it does not continue, for the apparatus does not remain in the midst of the water, but at last sinks to the bottom when the cork has taken in too much water.[1]

[1] "It is also manifest in a needle pierced through a globe of cork so cut away and pared by degrees that it will swim under water, yet sink not untc the bottom, which may be well effected; for if the cork be a thought too light to sink under the surface, the body of the water may be attenuated with spirits

CHAPTER X.

OF VARIATION OF DIP.

WE have already spoken of direction and of variation as a sort of derangement of direction. Now we observe a like irregular movement in the dip, when it descends beneath the limits or when, as sometimes happens, it does not reach its due bounds. Thus the variation of the dip is an arc of the magnetic meridian betwixt the true and the apparent dip. For as, because of elevations of the earth, magnetized bodies are pulled to one side, so, too, the needle (its rotation being a little increased) dips beyond the due measure. And as variation is a deviation in direction, so, for the same reason, there is some error of dip, albeit usually a trifling one. Sometimes, too, though there be no variation of direction on the horizon, there may nevertheless be a variation of the dip, to wit, when either in a direct meridian line, i.e., on the meridian itself, there projects some magnetically powerful earthmass, or when such elevations have less force than is called for by the general con-

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of wine; if too heavy, it may be incrassated with salt; and if by chance too much be added, it may again be thinned by a proportionable addition of fresh water. If then the needle be taken out, actively touched and put in again, it will depresse and bow down its Northern head toward the bottom, and advance its Southern extremity toward the brim. This way invented by *Gilbertus* may seem of difficulty; the same with lesse labour may be observed in a needled sphere of cork equally contiguous unto the surface of the water; for if the needle be not exactly equiponderant, that end which is a thought too light, if touched becometh even; that needle also which will but just swim under water, if forcibly touched, will sink deeper and sometime unto the bottom" (Dr. Thos. Brown, *Pseudoloxia Epidemica*, 1658, Book II, page 67).

stitution of the globe, or when the energy is overconcentrated in one part, and in another is diffused, as we may see in the Atlantic Ocean. And this discrepancy of constitution, this variance of effect, we easily recognize in certain parts of every spherical loadstone. The inequality of force in the various regions of a terrella is shown by the conclusive experiment described in Chapter 2 of this Book. And the effect is clearly shown by the demonstrational (*ostensivum*) instrument, an account of which is contained in Chapter 3 of the same Book.

CHAPTER XI.

OF THE FORMAL MAGNETIC ACT SPHERICALLY EFFUSED.

* REPEATEDLY we have spoken of the poles of earth and terrella and of the equinoctial circle; last we treated of the dip of magnetized bodies earthward and terrellaward, and the causes thereof. But having with divers and manifold contrivances labored long and hard to get at the cause of this dip, we have by good fortune discovered a new and admirable science of the spheres themselves—a science surpassing the marvels of all the virtues magnetical. For such is the property of magnetic spheres that their force is poured forth and diffused beyond their superficies spherically, the form being exalted above the bounds of corporeal nature; and the mind that has diligently studied this natural philosophy will discover the definite causes of the movements and revolutions. The potencies of a terrella, too, are of the same kind throughout the whole sphere of its influence, and the spheres (of influence) themselves, at whatever distance from the body of the

terrella, have, in the ratio of their diameter and the quantity of their superficies, termini of their forces, or, in other words, there are points whereat magnetic bodies turn toward them; and these bodies do not regard the same part or point of the terrella at every distance whatever therefrom (unless they be in the axis of the spheres and the terrella), but ever do tend toward those points of the spheres (of influence) which are equal arcs distant from their common axis. Thus in the following diagram we show the body of a terrella, with its poles and equator; also a magnetic needle in three other concentric spheres around the terrella and at some distance therefrom. In these spheres (and they may be imagined as infinite) the magnetic needle or versorium regards its own sphere in which it is placed and its diameter, poles, and equator, not those of the terrella; and it is by these and in accordance with the magnitude of these that it is made to rotate and is directed, both while its centre stands still and while it advances in any arc whatever of that sphere. Still we do not mean that the magnetic forms and spheres exist in the air, or water, or any other medium not magnetical, as though the air or water took them on or were by them informated; for the forms are only effused and really subsist when magnetic bodies are present: hence the magnetic body within the forces and limits of the spheres is taken hold of, and in the several spheres magnetic bodies control other bodies magnetical and excite them even as though the spheres of influence were solid materiate loadstones; for the magnetic force does not proceed through the whole of the medium, nor exists really as in a continuous body; and so the spheres are magnetical, and yet are not real spheres existing by themselves.

AB is the axis of a terrella and its spheres; *CD* the equator. In all the spheres, as on the terrella, at the equator the versorium lies in the plane of the horizon; in the axis it everywhere regards the centre perpendicularly; in the mid spaces, *E* regards *D*, and *G* regards *H*, not *F*, which is re-

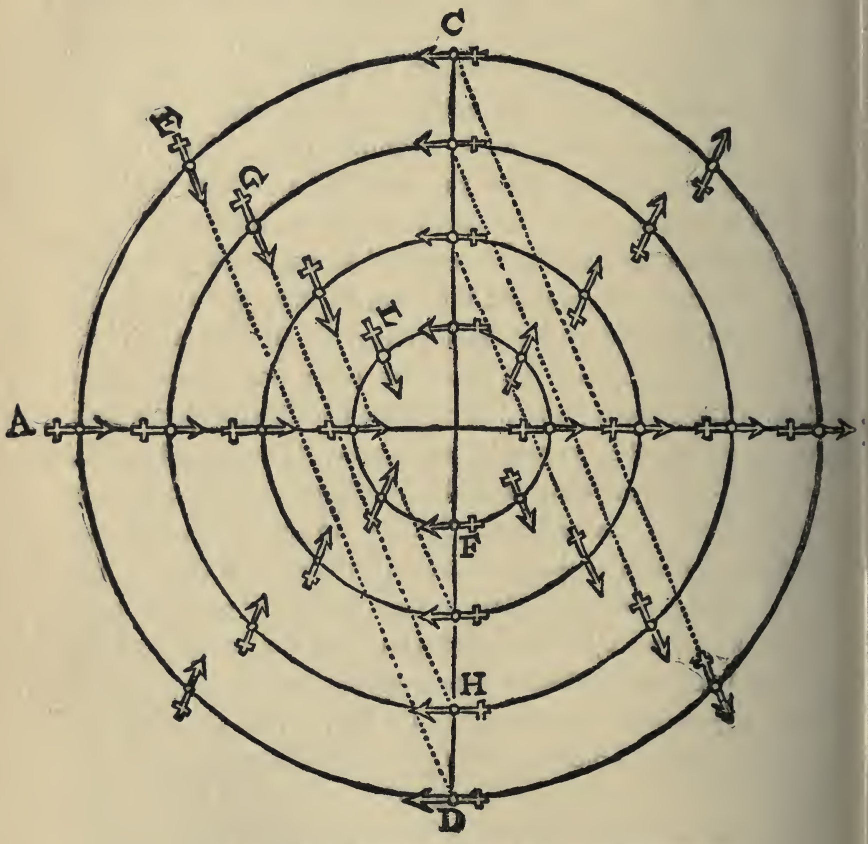

DIAGRAM OF THE MOVEMENTS IN THE MAGNETIC SPHERES.

garded by the versorium *L* on the superficies of the terrella. But as is the proportion of *L* to *F* on the terrella's superficies, such is that of *G* to *H* in its own sphere, and of *E* to *D* in its own sphere; so all the revolutions in the spheres to the termini of the spheres are such as are the revolutions at the surface of the terrella or to its termini. But if in the more distant spheres there is now and then some error, that is to be charged to the inertia of the loadstone or to weakened power, because of the too great distance of the spheres from the terrella.

DEMONSTRATION.

Upon the instrumental diagram above described, place, a small board or a strong disk of brass or tin on which are inscribed the magnetic spheres, as in the diagram; and in the middle make a hole proportioned to the size of the terrella, so that the board may lie evenly on the middle of it along the meridian circle above the wood. Then in one of the spheres of influence place a small versorium one barley-corn long; the versorium, as it there moves into various positions in the same circle, will always have regard to the dimensions of that sphere and not those of the terrella, as is seen in the diagram of the effused magnetic forms. While some writers posit as causes of the wonderful effects of the loadstone occult and recondite virtues of things, and others regard a property of the loadstone's substance as the cause, we have discovered the primary substantial form not in some more or less probable foreshadowing of truth or in reasons that admit of controversy; but as in many other demonstrations, so in this most indisputable diagram of the forces magnetical effused by the form, we grasp the true efficient cause. And this (the form), though it is subject to none of our senses and is therefore less perceptible to the intellect, now appears manifest and visible before our very eyes through this formal act, which proceeds from it as light proceeds from a source of light. And here it is to be noted that a magnetic needle moved over the earth, or over a terrella, or over the effused spheres, rotates completely twice in one circuit of its centre, like an epicycle round its circle.

CHAPTER XII.

THE MAGNETIC FORCE IS ANIMATE, OR IMITATES A SOUL; IN MANY RESPECTS IT SURPASSES THE HUMAN SOUL WHILE THAT IS UNITED TO AN ORGANIC BODY.

WONDERFUL is the loadstone shown in many experiments to be, and, as it were, animate. And this one eminent property is the same which the ancients held to be a soul in the heavens, in the globes, and in the stars, in sun and moon. For they deemed that not without a divine and animate nature could movements so diverse be produced, such vast bodies revolve in fixed times, or potencies so wonderful be infused into other bodies; whereby the whole world blooms with most beautiful diversity through this primary form of the globes themselves. The ancient philosophers, as Thales, Heraclitus, Anaxagoras, Archelaus, Pythagoras, Empedocles, Parmenides, Plato and all the Platonists,—nor Greek philosophers alone, but also the Egyptian and Chaldean,—all seek in the world a certain universal soul, and declare the whole world to be endowed with a soul. Aristotle held that not the universe is animate, but the heavens only; his elements he made out to be inanimate; but the stars were for him animate. As for us, we find this soul only in the globes and in their homogenic parts, and albeit this soul is not in all globes the same (for that in the sun or in certain stars is much superior to that in other less noble globes). Still in very many globes the souls agree in their powers. Thus, each homogenic part tends to its own globe and inclines in the direction common to the whole world, and in all globes the effused forms reach out and are projected in a sphere all round, and have their own bounds—hence the order and regularity of all the motions and revolutions of the planets, and their circuits, not pathless, but fixed and determinate, wherefore Aristotle concedes to the spheres and heavenly orbs (which he imagines) a soul, for the reason that they are capable of circular motion and action and that they move in fixed, definite, tracks. And I wonder much why the globe of earth with its effluences should have been by him and his followers condemned and driven into exile and cast out of all the fair order of the glorious universe, as being brute and soulless. In comparison with the whole creation 'tis a mere mite, and amid the mighty host of many thousands is lowly, of small account, and deformate. And to it the Aristotelians add allied elements that by like ill-fortune are also beggarly and despicable. Thus Aristotle's world would seem to be a monstrous creation, in which all things are perfect, vigorous, animate, while the earth alone, luckless small fraction, is imperfect, dead, inanimate, and subject to decay. On the other hand, Hermes, Zoroaster, Orpheus, recognize a universal soul. As for us, we deem the whole world animate, and all globes, all stars, and this glorious earth, too, we hold to be from the beginning by their own destinate souls governed and from them also to have the impulse of self-preservation. Nor are the organs required for organic action lacking, whether implanted in the homogenic nature or scattered through the homogenic body, albeit these organs are not made up of viscera as animal organs are, nor consist of definite members; indeed in some plants and shrubs the organs are hardly recognizable, nor are visible organs essential for life in all cases. Neither in any of the stars, nor in the sun, nor in the planets that are most operant in the world, can organs be distinguished or imagined by us; nevertheless, they live and endow with life small bodies at the earth's elevated points. If there is aught of which man may boast, that of a surety is soul, is mind; and the other animals, too, are ennobled by soul; even God, by whose rod all things are governed, is soul. But who shall assign organs to the divine intellects, seeing that they are superior to all organ-structure, nor are comprised in material organs? But in the bodies of the several stars the inborn energy works in ways other than in that divine essence which presides over nature; and in the stars, the sources of all things, in other ways than in animals; finally, in animals in other ways than in plants. Pitiable is the state of the stars, abject the lot of earth, if this high dignity of soul is denied them, while it is granted to the worm, the ant, the roach, to plants and morels; for in that case worms, roaches, moths, were more beauteous objects in nature and more perfect, inasmuch as nothing is excellent, nor precious, nor eminent, that hath not soul. But since living bodies spring from earth and sun and by them are animate, and since in the earth herbage springs up without sowing of seeds (e.g., when soil is taken out of the bowels of the earth and carried to some great elevation or to the top of a lofty tower and there exposed to the sunshine, after a little while a miscellaneous herbage springs up in it unbidden), it is not likely that they (sun and earth) can do that which is not in themselves; but they awaken souls, and consequently are themselves possessed of souls. Therefore the bodies of the globes, as being the foremost parts of the universe, to the end they might be in themselves and in their state endure, had need of souls to be conjoined to them, for else there were neither life, nor prime act, nor movement, nor unition, nor order, nor coherence, nor *conactus*, nor *sympathia*, nor any generation, nor alternation of seasons, and no propagation; but all were in confusion and the entire world lapse into chaos, and, in fine, the earth were void and dead and without any use. But only on the superficies of the globes is plainly seen the host of souls and of animate existences, and in their great and delightful diversity the Creator taketh pleasure. But the souls (in the interior of the globes) confined, as it were, by prison bars send not forth their effused immaterial forms beyond the limits of the body, nor are bodies put in motion by them without labor and exertion; a breath carries and bears them forth; but if that breath be fouled or stilled by mischance, the bodies lie like the world's recrement or as the waste matter of the globes. But the globes themselves remain and endure, rotate and move in orbits, and without wasting or weariness run their courses. The human soul uses reason, sees many things, investigates many more; but, however well equipped, it gets light and the beginnings of knowledge from the outer senses, as from beyond a barrier—hence the very many ignorances and foolishnesses whereby our judgments and our life-actions are confused, so that few or none do rightly and duly order their acts. But the earth's magnetic force and the formate soul or animate form of the globes, that are without senses, but without error and without the injuries of ills and diseases, exert an unending action, quick, definite, constant, directive, motive, imperant, harmonious, through the whole mass of matter; thereby are the generation and the ultimate decay of all things on the superficies propagated. For if it were not for the movement whereby the daily revolution is accomplished, all things here on earth were wild and disordered, and worse than desert and unused would they ever remain. Yet these movements in nature's founts are not produced by thoughts or reasonings or conjectures, like human acts, which are contingent, imperfect, and indeterminate, but connate in them are reason, knowledge, science, judgment, whence proceed acts positive and definite from the very foundations and beginnings of the world: these, because of the weakness (*imbecillitatem*) of our soul, we cannot comprehend. Wherefore, not without reason, Thales, as Aristotle reports in his book *De Anima*, declares the loadstone to be animate, a part of the animate mother earth and her beloved offspring.

BOOK VI.

CHAPTER I.

OF THE GLOBE OF EARTH AS A LOADSTONE.

HITHERTO we have spoken of the loadstone and magnetic bodies, how they conspire together and act on each other, and how they conform themselves to the terrella and to the earth. Now we have to treat of the globe of earth itself separately. All the experiments that are made on the terrella, to show how magnetic bodies conform themselves to it, may —at least the principal and most striking of them—be shown on the body of the earth; to the earth, too, all magnetized bodies are associate. And first, on the terrella the equinoctial circle, the meridians, parallels, the axis, the poles, are natural limits: similarly on the earth these exist as natural and not merely mathematical limits. As on the periphery of a terrella a loadstone or the magnetic needle takes direction to the pole, so on the earth there are revolutions special, manifest, and constant, from both sides of the equator: iron is endowed with verticity by being stretched toward the pole of the earth as toward the pole of a terrella; again, by being laid down and suffered to grow cool lying toward the earth's pole, after its prior verticity has been destroyed by fire, it acquires new verticity conformed to the position earthward. And iron rods that have for a long time lain in the poleward direction acquire verticity simply by regarding the earth; just as the same rods, if they be pointed toward the pole of a loadstone, though not touching it, receive polar force. There is no magnetic body that draws nigh in any way to a loadstone which does not in like manner obey the earth. As a loadstone is more powerful at one end and at one side of the equator, so the same thing is shown with a small terrella on a large one. According to the difference in amount and mode of friction in magnetizing a piece of iron at a terrella, it will be powerful or weak in performing its functions. In movements toward the body of the earth, just as on a terrella, variation is produced by unlikeness and inequality of prominences and by imperfections of the surface; and all variation of the versorium or the mariner's compass all over the earth and everywhere at sea—a thing that has so bewildered men's minds—is found and recognized through the same causes. The dip of the magnetic needle (that wonderful turning of magnetic bodies to the body of the terrella by formal progression) is seen also in the earth most clearly. And that one experiment reveals plainly the grand magnetic nature of the earth, innate in all the parts thereof and diffused throughout. The magnetic energy, therefore, exists in the earth just as in the terrella, which is a part of the earth and homogenic in nature with it, but by art made spherical so it might correspond to the spherical body of the earth and be in agreement with the earth's globe for the capital experiments.

CHAPTER II.

THE MAGNETIC AXIS OF THE EARTH REMAINS INVARIABLE.

THE earth's magnetic axis, just as it passed through the mid-earth in the very beginnings of the moving world, so to-day tends through the centre to the same points of the superficies, the equinoctial line and plane also persisting the same. For not, save with a vast demolition of the terrestrial mass, may these natural bounds be altered, as is easily shown by magnetic demonstrations. Wherefore the opinion held by Dominicus Maria of Ferrara, a man of rare ability, and who was the preceptor of Nicolaus Copernicus, is to be rejected. It was based on certain observations, and was as follows: "Some years ago," he writes, "while considering Ptolemy's geography, I found the elevations of the north pole given by him for the several regions to fall short by one degree and ten minutes of what they are in our time, which difference can by no means be referred to an error of the table, for it is not credible that the whole book should be throughout equally wrong in the figures contained in the tables; therefore we must suppose the north pole brought toward the vertical point. Thus a protracted observation began to disclose to us things hid from our ancestors—not through any sloth on their part, but because they lacked observation of a long period by their predecessors. For very few places before Ptolemy's time were observed in elevations of the pole, as he himself testifies in the beginning of his Cosmographia: 'Hipparchus alone,' he writes, 'hath handed down to us the latitudes of a few places; but many latitudes of distances, especially of distances to east and west, have been fixed on a basis of general tradition, and this is not from any indolence of writers, but because they were unacquaint with a more accurate mathematic.' Hence it is no wonder if our predecessors have not noted the very slow movement, seeing that in 1700 years it has advanced about one degree toward the uttermost point of human habitation. This is shown at the Strait of Gibraltar, where in Ptolemy's day the north pole was raised 36¼ degrees above the horizon, while now it is 37⅖ degrees. A like difference is shown by Leucopetra (Capo dell' Armi) in Calabria and sundry other places in Italy, namely, places that have not changed from Ptolemy's time to ours. Thus, in consequence of this movement, places that now are inhabited will one day be deserted, while those that now are scorched by the tropic sun will, albeit after a long time, be reduced to our temperature. For this very slow movement will be completed in 395,000 years."

Thus, according to Dominicus Maria's observations, the north pole is raised higher and the latitudes of places are greater now than in the past: from this he infers a change of latitudes. But Stadius, holding the directly opposite opinion, proves by observations that the latitudes have grown less. "The latitude of Rome," says he, "is given in the *Geographica* of Ptolemy as 41⅔ degrees; and lest any one should say that some error has crept into the text of Ptolemy, Pliny relates, and Vitruvius in his ninth book testifies, that at Rome on the day of the equinox the ninth part of the gnomon's shadow is lacking. But recent observation (as Erasmus Rheinhold states) gives the latitude of Rome in our age as 41⅙ degrees; so that you are in doubt whether one half of a degree has been lost (*decrevisse*) in the centre of the world, or whether it is the result of an obliquation of the earth." From this we may see how, on the basis of inexact observations, men conceive new and contrary opinions as to the earth's mechanism, and postulate absurd motions. For, as Ptolemy simply took from Hipparchus a few latitudes and did not himself observe them in many places, it is likely that, knowing the position of the countries, he made a conjectural estimate of the latitude of cities, and set such conjectures down in his tables. So, here, in Britain, the latitudes of cities vary two or three degrees, as we know by experience. Hence no new movement is to be postulated on the ground of these miscalculations, nor is the grand magnetic nature of the earth to be deformed for the sake of a judgment so rashly arrived at. And these errors have crept into geography all the more easily because the magnetic force was quite unknown to authors. Besides, observations of latitudes cannot be made with exactitude save by experts, with the help of large instruments, and by taking account of refraction of lights.

CHAPTER III.

OF THE DAILY MAGNETIC REVOLUTION OF THE GLOBES, AS AGAINST THE TIME-HONORED OPINION OF A *primum mobile*: A PROBABLE HYPOTHESIS.

AMONG the ancients, Heraclides of Pontus, and Ecphantus, the Pythagoreans Nicetas of Syracuse and Aristarchus of Samos, and, as it seems, many others, held that the earth moves, that the stars set through the interposition of the earth, and that they rise through the earth's giving way: they do give the earth motion, and the earth being, like a wheel, supported on its axis, rotates upon it from west to east. The Pythagorean Philolaus would have the earth to be one of the stars, and to turn in an oblique circle toward the fire, just as the sun and moon have their paths: Philolaus was an illustrious mathematician and a very experienced investigator of nature. But when Philosophy had come to be handled by many, and had been given out to the public, then theories adapted to the capacity of the vulgar herd or supported with sophistical subtleties found entrance into the minds of the many, and, like a torrent, swept all before them, having gained favor with the multitude. Then were many fine discoveries of the ancients rejected and discredited—at the least were no longer studied and developed. First, therefore, Copernicus among moderns (a man most worthy of the praise of scholarship) undertook, with new hypotheses, to illustrate the *phænomena* of bodies in motion; and these demonstrations of reasons, other authors, men most conservent with all manner of learning, either follow, or, the more surely to discover the alleged (φαινομένην) "symphony" of motion, do observe. Thus the suppositions and purely imaginary spheres postulated by Ptolemy and others for finding the times and periods of movements, are not of necessity to be accepted in the physical leetures of philosophers.

It is then an ancient opinion, handed down from the olden time, but now developed by great thinkers, that the whole earth makes a diurnal rotation in the space of twenty-four hours. But since we see the sun, the moon, and the other planets, and the whole heavenly host, within the term of one day come and depart, then either the earth whirls in daily motion from west to east, or the whole heavens and all the rest of the universe of things necessarily speeds about from east to west. But in the first place, it is not probable that the highest heaven and all those visible splendors of the fixed stars are swept round in this rapid headlong career. Besides, what genius ever has found in one same (Ptolemaic) sphere those stars which we call fixed, or ever has given rational proof that there are any such adamantine spheres at all? No man hath shown this ever; nor is there any doubt that even as the planets are at various distances from earth, so, too, are those mighty and multitudinous luminaries ranged at various heights and at distances most remote from earth: they are not set in any sphæric framework or firmament (as is supposed), nor in any vaulted structure. As for the intervals (between the spheres) imagined by some authors, they are matters of speculation, not of fact; those other intervals do far surpass them and are far more remote; and, situated as they are in the heavens, at various distances, in thinnest æther, or in that most subtile fifth essence, or in vacuity—how shall the stars keep their places in the mighty swirl of these enormous spheres composed of a substance of which no one knows aught? Astronomers have observed 1022 stars; besides these, innumerable other stars appear minute to our senses; as regards still others, our sight grows dim, and they are hardly discernible save by the keenest eye; nor is there any man possessing the best power of vision that will not, while the moon is below the horizon and the atmosphere is clear, feel that there are many more indeterminable and vacillating by reason of their faint light, obscured because of the distance. Hence, that these are many and that they never can be taken in by the eye, we may well believe. What, then, is the inconceivably great space between us and these remotest fixed stars? and what is the vast immeasurable amplitude and height of the imaginary sphere in which they are supposed to be set? How far away from earth are those remotest of the stars: they are beyond the reach of eye, or man's devices, or man's thought. What an absurdity is this motion (of spheres).

It is evident, therefore, that all the heavenly bodies, being, as it were, set down in their destined places, in them are conglobed whatever elements bear to their own centres, and around them are assembled all their parts. But if they have a motion, it will be motion of each round its proper centre, like the earth's rotation; or it will be by a progression in an orbit, like that of the moon; in so multitudinous a scattered flock there will be no circular motion. And of the stars, those situate nigh the equator would seem to be borne around with greatest rapidity, while others nigher the pole have a rather less rapid movement; and others still, as though motionless, have but a small revolution. Yet no differences in the light, the mass, or the colors of the light are perceptible for us; for they are as brilliant, as clear, as resplendent, or as faint (sombre, *fuscæ*) toward the poles as nigh the equator and the zodiac; and in their seats do they remain and there are they placed, nor are they suspended from aught, nor fastened nor secured in any vault. Far more extravagant (*insanior*) yet is the idea of the whirling of the supposititious *primum mobile*,[1] which is

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[1] *Primum mobile* (first cause of motion), name given in the Ptolemaic System to the imaginary huge outermost sphere, in the centre of which stood the earth, and by the revolutions of which from east to west diurnal motion was given to all the heavens, creating the phenomena of day and night. According to Aristotle, the FIRST heaven was that of the Moon, the SECOND Mercury, THIRD Venus, FOURTH the Sun, FIFTH Mars, SIXTH Jupiter, SEVENTH Saturn, and the EIGHTH that of the fixed stars. Two more heavens were added by later theorists: a NINTH, moving slowly round the poles of the ecliptic and carrying the entire system forward in longitude, to produce the phenomena arising from the precession of the equinoxes, the TENTH being the *primum mobile* beyond which was the empyreal heaven.

"It was the errour of Aristotle," says Hakewill, "that *via lactea* was a meteor; and not onely of Aristotle, but almost all before him, that there were still higher, deeper, more immeasurable; and yet this incomprehensible *primum mobile* would have to be of matter, of enormous altitude, and far surpassing all the creation below in mass, for else it could not make the whole universe down to the earth revolve from east to west, and we should have to accept a universal force, an unending despotism, in the governance of the stars, and a hateful tyranny. This *primum mobile* presents no visible body, is in no wise recognizable; it is a fiction believed in by some philosophers, and accepted by weaklings who wonder more at this terrestrial mass here than at those distant mighty bodies that baffle our comprehension.

But there cannot be diurnal motion of infinity or of an infinite body, nor, therefore, of this immeasurable *primum mobile*. The moon, neighbor of earth, makes her circuit in twenty-seven days; Mercury and Venus have a tardy movement; Mars completes his period in two years, Jupiter in twelve, Saturn in thirty. And the astronomers who ascribe motion to the fixed stars hold that it is completed, according to Ptolemy, in 36,000 years, or, according to Copernicus's observations, in 25,816 years; thus in larger circles the motion and the completion of the course are ever more slow; and yet this *primum mobile*, surpassing all else in height and depth, immeasurable, has a diurnal revolution. Surely that is super-

but EIGHT Celestiall Spheres; after this Timocaris, about 330 years B.C., found out NINE; but about the yeare of Christ 1250, Alphonsus discovered TEN, and the received opinion now is that there are ELEVEN, the highest of all being held *immoveable*, the seate of Angels and blessed spirits."

Tycho Brahe was of the same opinion with Ptolemy, viz., that the earth is at rest in the centre of the world and that the whole machine of the heavens is turned about it from east to west in the space of a day, by action of the *primum mobile* (Jacobi Rohaulti, *Physica*, Londini 1718, Par. II, Cap. VIII and XXIII, or Rohault's "System of Nat. Phil.," London 1728, Vol. II, pages 24, 58).

As is well known, the doctrine of a fixed central earth was doomed by the brilliant investigations of Galileo, Kepler, and Newton.

stition, a philosophic fable, now believed only by simpletons and the unlearned; it is beneath derision; and yet in times past it was supported by calculation and comparison of movements, and was generally accepted by mathematicians, while the importunate rabble of philophasters egged them on.

The motions of the heavenly bodies (i.e., of the planets) seem all to be eastward, and according to the succession of the zodiacal signs; and mathematicians and philosophers of the vulgar sort do also believe that the fixed stars progress in the same way with a very slow movement: to these stars they must needs, through their ignorance of the truth, add a ninth sphere. But now this inadmissible *primum mobile*, this fiction, this something not comprehensible by any reasoning and evidenced by no visible star, but purely a product of imagination and mathematical hypothesis, accepted and believed by philosophers, and reared into the heavens and far beyond all the stars,—this must needs by a contrary incitation wheel from east to west, counter to the tendence of all the rest of the universe.

Whatever in nature moves naturally, the same is impelled by its own forces and by a consentient compact of other bodies. Such is the motion of the parts to a whole, of the globes and stars throughout the universe with each other accordant; such is the circular propulsion of the planets' bodies, each the other's career observing and inciting. But as regards this *primum mobile* with its contrary and most rapid career,—where are the bodies that incite it, that propel it? Where is the nature conspiring with it? and what mad force lies beyond the *primum mobile?*—for the agent force abides in bodies themselves, not in space, not in the interspaces.

But he who supposes that all these bodies are idle and inactive, and that all the force of the universe pertains to those spheres, is as foolish (*insanit*) as the one who, entering a man's residence, thinks it is the ceilings and the floors that govern the household, and not the thoughtful and provident good-man of the house. So, then, not by the firmament are they borne, not from the firmament have they movement or position; and far less are those multitudes of stars whirled round *en masse* by the *primum mobile*, and taken up at random and swept along in a reversed direction at highest velocity.

Ptolemy of Alexandria, it seems to me, was over-timid and scrupulous in apprehending a break-up of this nether world were earth to move in a circle. Why does he not apprehend universal ruin, dissolution, confusion, conflagration, and stupendous celestial and supercelestial calamities from a motion that surpasses all imagination, all dreams and fables and poetic licenses—a motion ineffable and inconceivable? So, then, we are borne round and round by the earth's daily rotation—a more congruous sort of motion; and as a boat glides over the water, so are we whirled round with the earth, the while we think we stand still and are at rest. This seems to some philosophers wonderful and incredible, because of the ingrained belief that the mighty mass of the earth makes an orbital movement in twenty-four hours: it were more incredible that the moon should in the space of twenty-four hours traverse her orbit or complete her course; more incredible that the sun and Mars should do so; still more that Jupiter and Saturn; more than wonderful would be the velocity of the fixed stars and firmament; and let them imagine as best they may the wonders that confront them in the ninth sphere. But it is absurd to imagine a *primum mobile*, and, when imagined, to give to it a motion that is completed in twenty-four hours, denying that motion to the earth within the same space of time. For a great circle of earth, as compared to the circuit of the *primum* *mobile* is less than a stadium[1] as compared to the whole earth. And if the rotation of the earth seems headlong and not to be permitted by nature because of its rapidity, then worse than insane, both as regards itself and the whole universe, is the motion of the *primum mobile*, as being in harmony or proportion with no other motion. Ptolemy and the Peripatetics think that all nature must be thrown into confusion, and the whole structure and configuration of this our globe destroyed by the earth's so rapid rotation. The diameter of the earth is 1718 German miles; the greatest elongation of the new moon is 65, the least 55, semi-diameters of the earth; but probably its orbit is still larger. The sun at his greatest eccentricity is distant 1142 semi-diameters from earth; Mars, Jupiter, Saturn, as they are slow in movement, so are far more distant from the earth. The best mathematicians regard the distances of the firmament and the fixed stars as indeterminable; to say nothing of the ninth sphere, if the convexity of the *primum mobile* be fairly estimated in its proportion to the rest, it must travel over as much space in one hour as might be comprised within three thousand great circles of the earth, for on the convexity of the firmament it would travel over more than eighteen hundred such circles: but what structure of iron can be imagined so strong, so tough, that it would not be wrecked and shattered to pieces by such mad and unimaginable velocity? The Chaldees believed the heavens to be light. But in light there is no such firmness, neither in the fire-firmament of Plotinus, nor in the fluid or watery heavens of God-inspired Moses, nor in the supremely tenuous and transparent firmament that stands between our eye and the lights of the stars, but does not intercept the same. Hence we must reject the

[1] Stadium—ancient measure of length, equal to 600 Greek or 625 Roman feet, or 125 Roman paces, or to 606 feet 9 inches English.

deep-seated error about this mad, furious velocity, and this forceful retardation of the rest of the heavens. Let the theologues reject and erase these old wives' stories of a so rapid revolution of the heavens which they have borrowed from certain shallow philosophers. The sun is not swept round by Mars' sphere (if sphere he have) and its motion, nor Mars by Jupiter's sphere, nor Jupiter by Saturn's: the sphere of the fixed stars, too, seems moderate enough, save that movements are attributed to the heavens that really are earth movements, and these produce a certain change in the phenomena. The higher do not tyrannize over the lower, for the heaven both of the philosopher and of the divine must be gentle, happy, tranquil, and not subject to changes; neither will the violence, fury, velocity, and rapidity of the *primum mobile* bear sway. That fury descends through all the celestial spheres and heavenly bodies, enters the elements of the philosophers, sweeps the fire along, whirls the air around, or at least the greater part thereof; leads in its train the universal ether, and causes it to whirl round as though it were a solid and firm body, whereas it is a most tenuous substance, that neither offers resistance nor is ductile; and leads captive the fires of the upper heavens. O wondrous steadfastness of the globe of earth, that alone is unconquered! And yet the earth is holden nor stayed in its place by any chains, by no heaviness of its own, by no contiguity of a denser or a more stable body, by no weights. The substance of the terrestrial globe withstands and resists universal nature.

Aristotle imagines a philosophy of motions simple or complex, holds that the heavens move with a simple circular motion, and his elements with motion in a right line; that the parts of the earth tend to the earth in right lines; that they impinge upon it at the superficies at right angles and seek its centre, and there always rest; and that hence the whole earth stands in its place, held together and compacted by its own weight. This coherence of parts and this consolidation of matter exists in the sun, the moon, the planets, the fixed stars, —in short, in all those spherical bodies whose parts cohere and seek their several centres; else would the heavens rush to destruction and their grand order disappear. But these heavenly bodies have a circular motion, and hence the earth, too, may have its motion, for this motion is not, as some suppose, adverse to cohesion nor to production. For, inasmuch as this motion is intrinsic in the earth and natural, and as there is nothing without that may convulse it or with contrary motions impede it, it revolves untroubled by any ill or peril; it moves on under no external compulsion; there is nought to make resistance, nothing to give way before it, but the path is open. For since it revolves in a space void of bodies, the incorporeal æther, all atmosphere, all emanations of land and water, all clouds and suspended meteors, rotate with the globe: the space above the earth's exhalations is a vacuum; in passing through vacuum even the lightest bodies and those of least coherence are neither hindered nor broken up. Hence the entire terrestrial globe, with all its appurtenances, revolves placidly and meets no resistance. Causelessly, therefore, and superstitiously, do certain faint-hearts apprehend collisions, in the spirit of Lucius Lactantius, who, like the most unlearned of the vulgar, or like an uncultured bumpkin, treats with ridicule the mention of antipodes and of a round globe of earth.[1]

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[1] "Yet that which to me seemeth more strange, is that those two learned Clearkes, Lactantius ('Divinarum Institut.,' 31, c. 24) and Augustine ('De Civitat. Dei,' i. 16, c. 9), should with that earnestnesse deny the being of any Antipodes. . . . Zachary, Bishop of Rome, and Boniface, Bishop of Mentz, led (as it seemes) by the authority of these Fathers, went farther herein, condemn-

From these arguments, therefore, we infer, not with mere probability, but with certainty, the diurnal rotations of the earth; for nature ever acts with fewer rather than with many means; and because it is more accordant to reason that the one small body, the earth, should make a daily revolution than that the whole universe should be whirled around it. I pass by the earth's other movements, for here we treat only of the diurnal rotation, whereby it turns to the sun and produces the natural day (of twenty-four hours) which we call *nycthemeron*. And, indeed, nature would seem to have given a motion quite in harmony with the shape of the earth, for the earth being a globe, it is far easier and far more fitting that it should revolve on its natural poles, than that the whole universe, whose bounds we know not nor can know, should be whirled round; easier and more fitting than that there should be fashioned a sphere of the *primum mobile*—a thing not received by the ancients, and which even Aristotle never thought of or admitted as existing beyond the sphere of the fixed stars; finally, which the holy Scriptures do not recognize, as neither do they recognize a revolution of the whole firmament.

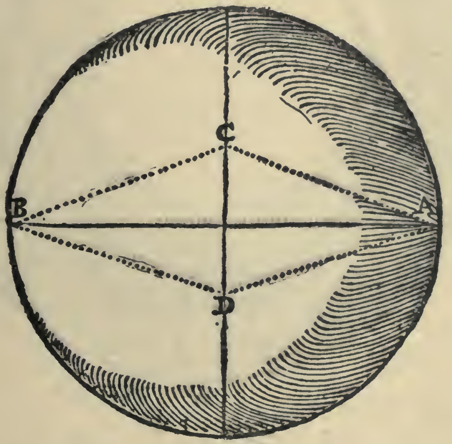
CHAPTER IV.

THAT THE EARTH HATH A CIRCULAR MOTION.

AND now, though philosophers of the vulgar sort imagine, with an absurdity unspeakable, that the whole heavens and the world's vast magnitude are in rotation, it remains that the

ing one Virgilius, a Bishop of Saltzburg, as an heretique, only for holding that there were antipodes" (Dr. Geo. Hakewill, "An Apologie ....," Oxford 1635, Lib. III, page 281).

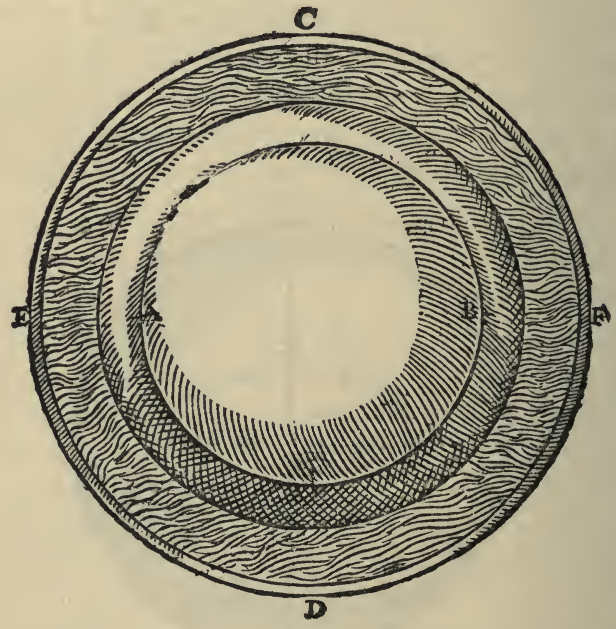
earth daily makes one revolution; for in no third mode can the apparent revolutions be accounted for. The day, therefore, which we call the natural day is the revolution of a meridian of the earth from sun to sun. And it makes a complete revolution from a fixed star to the same fixed star again. Bodies that by nature move with a motion circular, equable, and constant, have in their different parts various metes and bounds. Now the earth is not a chaos nor a chance medley mass, but through its astral property has limits agreeable to the circular motion, to wit, poles that are not merely mathematical expressions, an equator that is not a mere fiction, meridians, too, and parallels; and all these we find in the earth, permanent, fixed, and natural; they are demonstrated with many experiments in the magnetic philosophy. For in the earth are poles set at fixed points, and at these poles the verticity from both sides of the plane of the equator is manifested with greatest force through the co-operation of the whole; and with these poles the diurnal rotation coincides. But no revolutions of bodies, no movements of planets, show any sensible, natural poles in the firmament or in any *primum mobile;* neither does any argument prove their existence; they are the product of imagination. We, therefore, having directed our inquiry toward a cause that is manifest, sensible, and comprehended by all men, do know that the earth rotates on its own poles, proved by many magnetical demonstrations to exist. For not in virtue only of its stability and its fixed permanent position does the earth possess poles and verticity; it might have had another direction, as eastward or westward, or toward any other quarter. By the wonderful wisdom of the Creator, therefore, forces were implanted in the earth, forces primarily animate, to the end the globe might, with steadfastness, take direction, and that the poles might be opposite, so that on them, as at the extremities of an axis, the movement of diurnal rotation might be performed. Now the steadfastness of the poles is controlled by the primary soul. Thus it is for the good of the earth that the collimations of the verticities do not continually regard a fixed point in the firmament and in the visible heavens. For the changes of the equinoxes are caused by a certain inflection of the earth's axis, yet in this inflection the earth hath from her own forces a steadfastness in her motion. In her rotation the earth bears on her own poles; for since the verticity is fixed in *A* and *B*, and the axis horizontal, at *C* and *D* (equinoctial line) the parts are free, all the forces being diffused



on both sides from the plane of the equator toward the poles in the æther,[1] which is without resistance, or in vacuum;

[1] Aether, according to Sir Isaac Newton, is a thin subtile matter much finer and rarer than air. Sometimes it is termed by him a subtil spirit, as in the latter part of his *Principia*, and sometimes a subtil ætherial medium, as in his *Optics*. By many it is supposed to pervade all space, also the interior of solid bodies, and to be the medium of the transmission of light and heat. The æther of Descartes was his *materia subtilis* or his First Element; by which he understood a "most subtil matter very swiftly agitated, fluid, and keeps to no certain figure, but which suits itself to the figure of those bodies that are about

and, *A* and *B* remaining constant, *C* revolves toward *D* both by natural conformity and fitness, as also for the sake of a necessary good and avoidance of ill, but most of all because the effused spheres of solar influence and of solar light do impel. And it revolves not in a new track or one assigned from with-

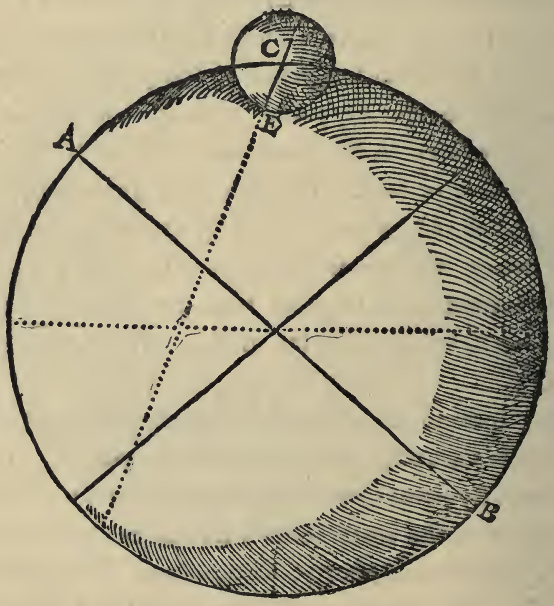


out, but, in the general trend of all the rest of the planets, tends from west to east. For all planets have a like movement to the east, in accordance with the succession of the zodiacal signs, whether it be Mercury or Venus within the sun's orbit, or whether they revolve round the sun. That the earth is fitted

it." His Second Element consists of small globules; that is, bodies exactly round and very solid, which do not only, like the First Element, fill up the pores of bodies, but also constitute the purest substance of the Æther and Heaven (Blome's translation of Descartes' Philos., page 101; R. Lovett, "The Subtil medium prov'd," London 1756, pages 14, 15).

for circular movement is proved by its parts, which, when separated from the whole, do not simply travel in a right line, as the Peripatetics taught, but rotate also. A loadstone placed in a wooden vessel is put in water so that it may float freely, rotate, and move about. If the pole *B* of the loadstone be made to point, unnaturally, toward the south *F*, the terrella revolves round its centre in a circular motion on the plane of the horizon toward the north *E*, where it comes to a rest, and not at *C* or at *D*. So acts a small stone weighing only four ounces; and a powerful loadstone of 100 pounds will make the same movement as quickly; and the largest mountain of loadstone would revolve in the same way were it to be set afloat on a wide stream or in the deep sea; and yet a magnetic body is far more hindered by water than is the whole earth by the air. The whole earth would act in the same way, were the north pole turned aside from its true direction; for that pole would go back, in the circular motion of the whole, toward Cynosura.

Yet this motion is nothing by that circular motion wherewith the parts naturally tend to their own places. The whole earth regards Cynosura by its steadfast nature; and similarly each true part of the earth seeks a like place in the world, and turns with circular motion to that position. The natural movements of the whole and of the parts are alike: hence, since the parts move in a circle, the whole, too, hath the power of circular motion. A spherical loadstone, when floated in water, moves circularly on its centre to become (as it seems) conformed to the earth on the plane of the equator. Thus, too, would it move on any other great circle if it were free to move, so that in the dip compass there is circular movement on the meridian (if there be no variation), or, if there is variation, on a great circle drawn from the zenith through the variation point in the horizon. And this circular movement of the loadstone to its true and natural position shows that the whole earth is fitted, and by its own forces adapted for a diurnal circular motion. I omit what Petrus Peregrinus so stoutly affirms, that a terrella poised on its poles in the meridian moves circularly with a complete revolution in twenty-four hours. We have never chanced to see this: nay, we doubt if there is such move-



ment,[1] both because of the weight of the stone itself, and also because the whole earth, as it moves of itself, so is propelled by the other stars; but this does not occur proportionately in any part of the earth, a terrella for example. The earth moves by its primary form and natural desire, for the conservation, perfecting, and beautifying of its parts, toward the more ex-

[1] Father Nicolao Cabeo clearly explains what Peregrinus advanced, in Lib. III, Cap. IV, of his *Philosophia Magnetica*.

cellent things: this is more probable than that those fixed luminous orbs, and the planets and the sun, foremost of all and divine, while they get no aid of any sort from earth, no refreshment, no force whatever, should vainly circle round it, and that the whole host of heaven should make everlasting rounds about the earth, without any profit whatever to those stars themselves.

The earth therefore rotates, and by a certain law of necessity, and by an energy that is innate, manifest, conspicuous, revolves in a circle toward the sun; through this motion it shares in the solar energies and influences; and its verticity holds it in this motion lest it stray into every region of the sky. The sun (chief inciter of action in nature), as he causes the planets to advance in their courses, so, too, doth bring about this revolution of the globe by sending forth the energies of his spheres—his light being effused.

And were not the earth to revolve with diurnal rotation, the sun would ever hang with its constant light over a given part, and, by long tarrying there, would scorch the earth, reduce it to powder, and dissipate its substance, and the uppermost surface of earth would receive grievous hurt: nothing of good would spring from earth, there would be no vegetation; it could not give life to the animate creation, and man would perish. In other parts all would be horror, and all things frozen stiff with intense cold: hence all its eminences would be hard, barren, inaccessible, sunk in everlasting shadow and unending night. And as the earth herself cannot endure so pitiable and so horrid a state of things on either side, with her astral magnetic mind she moves in a circle, to the end there may be, by unceasing change of light, a perpetual vicissitude, heat and cold, rise and decline, day and night, morn and even, noonday and deep night. So the earth seeks and seeks the sun again, turns from him, follows him, by her wondrous magnetical energy.

And not only from the sun would ill impend, were the earth to stand still and be deprived of the benefit of his rays; from the moon also great dangers would threaten. For we see how the ocean swells and comes to flood under certain positions of the moon. But if by the daily rotation of the earth the moon did not quickly pass, the sea would rise unduly at some parts and many coasts would be overwhelmed by mighty tides. Lest the earth, then, should in divers ways perish and be destroyed, she rotates in virtue of her magnetic and primary energy. And such are the movements in the rest of the planets, the motion and light of other bodies especially urging. For the moon also turns round during its menstrual circuit that it may on all its parts successively receive the sun's light, which it enjoys, with which it is refreshed like the earth itself; nor could the moon without grave ill and sure destruction stand the unceasing incidence of the light on one of its sides only.

Thus each of the moving globes has circular motion, either in a great circular orbit or on its own axis or in both ways. But that all the fixed stars, and the planets, and all the higher heavens, still revolve simply for the earth's sake is for the mind of a philosopher a ridiculous supposition. The earth then revolves, and not the whole heavens; and this movement brings growth and decay, gives occasion for the generation of animated things, and arouses the internal heat to productiveness. Hence does matter vegetate to receive forms, and from this primary revolution of the earth natural bodies have prime incitation and original act. The motion of the whole earth, therefore, is primary, astral, circular about its poles, whose verticity rises on both sides from the plane of the equator, and the energy is infused into the opposite ends, so that the globe by a definite rotation might move to the good, sun and stars inciting. But the simple right-downward motion assumed by the Peripatetics is the movement of weight, of coacervation, of separated parts, in the ratio of their matter, by right lines toward the earth's centre, these tending to the centre by the shortest route. The motions of separate magnetical parts of the earth are, besides that of coacervation, those of coition, revolution, and direction of the parts to the whole, into harmony and agreement of the form.

CHAPTER V.

ARGUMENTS OF THOSE WHO DENY THE EARTH'S MOTION; AND REFUTATION THEREOF.

It will not be superfluous to weigh also the arguments of those who deny that the earth moves, to the end we may the better satisfy the herd of philosophers who deem the steadfastness and immobility of the globe to be proved by incontrovertible arguments. Aristotle does not allow that the earth moves circularly, for, says he, then every part thereof would take the same motion; but inasmuch as all separated parts tend to the middle point in right lines, that circular motion were something imposed by force, were contrary to nature, were not perpetual. But we have already proven that all true parts of the earth do move circularly, and that all magnetic bodies (when fitly arranged) are borne round in a circle. But they tend to the earth's centre in a right line (if the way is open) by the motion of coacervation, as to their origin; they move with various motions to conformation of the whole; a terrella moves circularly by its inborn forces. "Besides," says Aristotle, "all things that move in a circle seem afterward to lose the first movement and to be carried on by several motions other than the first. The earth, too, whether situate in the middle or near the middle of the world, must needs have two movements; and were that the case there must needs be progressions and retrogressions of the fixed stars: no such thing is seen, however, but evermore the same stars are rising and setting in the same places." Yet it by no means follows that a twofold motion is attributed to the earth. And if there be but the one diurnal motion of the earth round its poles, every one sees that the stars must always rise and set in the same way, at the same points of the horizon, even though there be another movement for which we are not contending; because the changes in the smaller sphere produce in the fixed stars no variation of aspect on account of the great distance, unless the earth's axis changes position: of this we treat in the chapter treating of the cause of the precession of the equinoxes.

In this reasoning (of Asritotle's) are many flaws. For if the earth rotates, that, as we have shown, must be due not to the action of the first sphere, but to its own native forces. And if the motion were produced by the first sphere, there would be no alternations of days and nights, for the globe would then make her revolution along with the *primum mobile*. And it does not follow, because the rest of the heavenly bodies move with a twofold motion, that the earth has a twofold motion when it rotates round its centre. Then, too, Aristotle does not clearly apprehend the reason of the case, nor do his translators either. *τούτον δὲ συμβαίνοντος, ἀναγκαῖον γίγνεσ-*

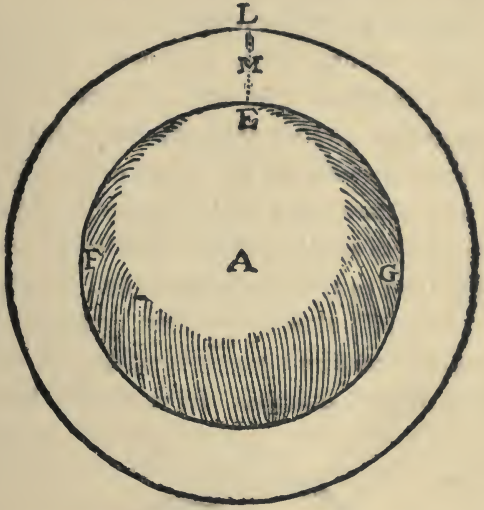
θαι παρόδους καὶ τροπὰς τῶν ἐνδεδεμένων ἄστρων (de Cælo, Cap. 14)—i.e., if that be so there must needs be mutations and regressions of the fixed stars. Some translate *τροπὰς* "regressions" or "retrogressions," others "diversions": these terms can in no wise be understood of axial motion unless Aristotle means that the earth is whirled by the *primum mobile* round other poles different even from those of the first sphere—which is quite absurd.

More recent writers hold that the Eastern Ocean must needs, in consequence of this motion, so be driven toward the regions to the west that parts of the earth which are dry and waterless would of necessity be daily submerged beneath the waters. But the ocean gets no impulsion from this motion, as there is no resistance, and even the whole atmosphere is carried round also; for this reason, in the rapid revolution of the earth, things in the air around are not left behind nor do they have the appearance of moving westward; the clouds stand motionless in the atmosphere, save when impelled by the force of the winds; and objects thrown up into the air fall back again to their places. But they are dullards who think that steeples, churches, and other edifices must necessarily be shaken and topple down if the earth moves: antipodes might fear lest they should slip over to the other side of the globe; navigators might dread lest in making the circle of the whole globe they might, once they had descended below the plane of our horizon, drop down into the opposite part of the sky. But these are old-wives' imaginings and ravings of philosophasters who, when they undertake to discourse of great things and the fabric of the world and attempt aught, are unable to understand hardly anything *ultra crepidam*. The earth they hold to be the centre of a circle and to stand motionless in the general revolution. But the stars or the planetary globes do not move in a circle round the centre of the earth; nor is the earth the centre—if it be in the centre—but a body around the centre.

And it is inconsistent that the Peripatetics' heavenly bodies should rest on so frail, so perishable, a thing as the earth's centre.

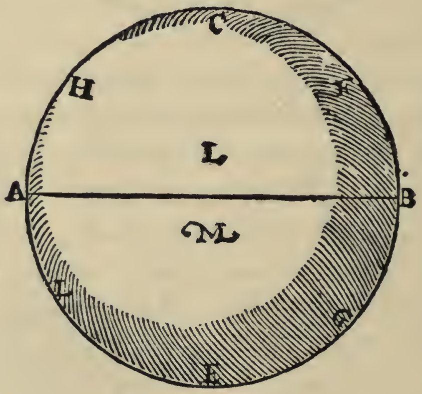
Now generation results from motion, and without motion all nature would be torpid. The sun's motions, the moon's motions, produce changes; the earth's motion awakens the inner life of the globe; animals themselves live not without motion and incessant working of the heart and the arteries. As for the single motion in a right line to the centre, that this is the only movement in the earth, and that the movement of an individual body is one and single,—the arguments for it have no weight, for that motion in a right line is but the inclination toward their origin, not only of the earth, but also of the parts of the sun, the moon, and all the other globes; but these move in a circle also. Joannes Costeus, who is in doubt as to the cause of the earth's motion, regards the magnetic energy to be intrinsic, active, and controlling; the sun he holds to be an extrinsic promovent cause; nor is the earth so mean and vile a body as it is commonly reputed to be. Hence, according to him, the diurnal motion is produced by the earth, for the earth's sake and for the earth's behoof.

They (if such there be) who assert that this movement of the earth takes place not only in longitude but also in latitude, speak nonsense; for nature has set in the earth definite poles and has established definite and not confused revolutions. Thus the moon turns round to the sun in its monthly course, the while ever regarding with definite poles definite parts of the heavens. It were absurd to suppose that the atmosphere moves the earth; for the air is but exhalation and the effluvium of the earth given out in every direction; winds, too, are only motions of the exhalation here and there along the earth's surface; the depth of the air current is trifling, and there are in every region various winds from different and opposite points. Some authors, not finding the cause of the revolution in the earth's matter—for there they say they find only solidity and consistence—maintain that it is not to be found in the form, and will admit as qualities of the earth only cold and dryness, which cannot produce the earth's motion. The Stoics attribute to the earth a soul, and hence they declare, amid the derision of the learned, that the earth is an animal. This magnetical form, be it energy or be it soul, is astral. Let the learned lament and weep for that neither the early Peripatetics, nor the common run of philosophasters, nor Joannes Costeus, who mocks at this sort of thing, were capable of appreciating this grand and most extraordinary fact of nature. As for the objection that the superficial unevenness produced by mountains and valleys would prevent diurnal revolution, it is of no weight; for mountains do not mar the rotundity of the earth—as compared with the entire earth, mountains are but trifling excrescences: besides, the earth does not rotate without carrying along with it its effluences. Beyond the effluences there is no resistance. The earth's motion is performed with as little labor as the motions of the other heavenly bodies: neither is it inferior in dignity to some of these. To say that it is folly to suppose the earth is more eager for the face of the sun than the sun for the face of the earth, is mere wilfulness and ignorance. Of the cause of the rotation I have oft spoken. If any one were to look for the cause of the rotation or any other tendency of the earth on the globe-encircling ocean, or in the movement of the atmosphere, or in the heaviness of the earth's mass, he would reason as stupidly as do those who obstinately cling to an opinion because it was held by the ancients. Ptolemy's arguments are of no account; for our true principles once laid down, the truth is visible, and it is useless to refute Ptolemy. So let Costeus and the philosophers recognize how unprofitable and vain a thing it is to take their stand on the doctrines and unproved theories of certain ancient writers. Many persons cannot see how it is (if the earth rotates) that a ball of iron or lead dropped from a very high tower falls exactly on the spot right below; or how cannon-balls fired from a large culverin with equal charges of gunpowder of the same quality, and with the gun pointed at the same angle with the horizon, have exactly the same range to eastward and to westward, the earth moving to the east. But they who urge such arguments are mistaken through not understanding the nature of primary globes and the combination of parts with their globes, albeit not conjoined thereto with bonds of solid matter. But the earth in its diurnal revolution does not so move that its more solid circumference is separated from the bodies circumfused; on the contrary, all the circumfused effluences, and all heavy bodies therein, howsoever shot thereinto, advance simultaneously and uniformly with the earth because of the general coherence. This is the case in all primary bodies,—the sun, moon, earth,—the parts betaking themselves to their origin and founts, whereunto they are attached with the same appetence with which what we call heavy bodies are attached to earth. Thus lunar bodies tend to the moon, solar to the sun, within the respective spheres of their effluences. These effluences cohere through continuity of substance; and heavy bodies, too, are united to earth by their heaviness and advance with it in the general movement, especially when no resistance of bodies hinders. And, for this reason, the diurnal revolution of the earth does not sweep bodies along nor retard them: they neither outstrip the earth's motion nor fall behind when shot with force, whether to east or to west. Let *EFG*



be the earth, *A* the centre, *LE* the ascending effluences. As the sphere of the effluences moves with the earth, so the part of the sphere on the right line *LE* proceeds undisturbed in the general rotation. In *LE* the heavy body *M* falls perpendicularly to *E*, the shortest route centreward; nor is this right motion of *M* a composite motion, i.e., resultant of a motion of coacervation and a circular motion, but simple and direct, never going out of the line *LE*. And an object shot with equal force from *E* toward *F*, and from *E* toward *G*, has the same range in both directions, though the diurnal rotation of the earth goes on;—even as twenty steps taken by one man cover the same distance eastward as westward. Hence the diurnal revolution of the earth is not at all refuted by the illustrious Tycho Brahe through such arguments as these.

The tendence to its centre (called by philosophers, weight) works no resistance to the diurnal revolution, neither does it give direction to the earth, nor keep in place the parts of the earth, which have no weight when resting in the earth's solid substance: there they have no longer any tendence, but are at rest in its mass. If there be a flaw in the mass, a cavity of 1000 fathoms for example, a homogenic part of the earth or compacted terrestrial matter descends through that space, be it filled with water or with air, to a more definite centre (*principium*) than air or water, and seeks the solid globe. But the centre of the earth, as also the whole earth itself, has no weight: separated parts tend to their *principium*, and this tendence we call weight: parts in union are at rest, and even if they had weight, they would cause no impediment to the diurnal revolution. For if around the axis *AB* a weight be at *C*, it is



balanced by *E*; at *F* it is balanced by *G*; if at *H*, by *I*. And, similarly, if it is at *L*, it is balanced by *M*. Thus the whole globe, having a natural axis, is balanced in equilibrium and is set in motion easily by the slightest cause, but chiefly for the reason that the earth, in its own place, is in no wise heavy nor needs any balancing. Hence no weight hinders the diurnal revolution, and no weight gives to the earth direction or continuance in its place. It is therefore plain that no argument of sufficient force has yet been formed by philosophers to refute the earth's motion.

CHAPTER VI.

OF THE CAUSE OF THE DEFINITE TIME OF THE TOTAL REVOLUTION OF THE EARTH.

THE causes of the diurnal motion are to be found in the magnetic energy and in the alliance of bodies: that is to say, why a revolution of the earth is performed in the term of 24 hours. For no ingenious artifice, whether of clepsydra,[1] or of hour-glasses, or of time-pieces with toothed wheels and driven by the tension of a steel plate, can show any difference of time. But the diurnal revolution once accomplished comes on again. Now we will take a day to mean a complete revolution of a meridian of the earth from sun to sun. This is a little less than the total revolution; for in 365¼ turnings of a meridian to the sun a year is completed. Because of this fixed and

[1] The Clepsydra, or water clock, is said by Vitruvius to have been first made by the Egyptians or Persians. Perhaps the most remarkable one was that sent as a present by Haroun, grandson of Almansor, to Charlemagne in A.D. 799. In the dial-plate were 12 doors, equally distant, upon which were inscribed the hours successively; each door opened in its turn, and let fall, upon a brazen bell, a sufficient number of balls to strike the proper hour. The doors continued open till 12 o'clock, when 12 little knights, mounted on horseback, issued simultaneously from a part of the machine, paraded around the dial, and, having closed the 12 doors, as suddenly retired (Morel, "Elem. Ph. and Sc.," London 1827, pars. 210, 224. Consult M. Delambre, "Hist. de l'Astr. Anc ," Paris 1817, Vol. I, Table page lvii).

constant motion of the earth the number and time of 365 days 5 hours 55 minutes are always fixed and settled, barring that for other causes there are certain trifling differences. Thus the earth revolves, not fortuitously nor by chance, nor with a headlong motion, but evenly, with a certain high intelligence and with a wonderful steadiness, even like the rest of the movable stars which have fixed periods for their movements.

Thus, inasmuch as the sun itself is the mover and inciter of the universe, the other planets that are situate within the sphere of his forces, being impelled and set in motion, do also with their own forces determine their own courses and revolve in their own periods, according to the amplitude of their greater rotation and the differences of the forces effused and the perception of a greater good. Hence it is that Saturn, having a greater course to run, revolves in a longer time, while Venus revolves in nine months, and Mercury in 80 days, according to Copernicus; and the moon makes the circuit of the earth in 29 days 12 hours 44 minutes. We have asserted that the earth turns on its centre, making one day in its revolution sunward. The moon goes round the earth in a monthly course, and when after its prior conjunction with the sun it comes to conjunction again, it constitutes one month, or one lunar day. The mean distance of the moon's orbit, according to the calculations of Copernicus and other later astronomers, is distant from the earth's centre about 29⅚ diameters of the earth. A solar revolution of the moon in her orbit takes 29 days 12 hours 44 minutes. We reckon her periodic time by her return to the same position relatively to the sun, making the moon's *solar* revolution, not by her return to the same absolute position, making the complete or stellar revolution, just as one day on earth is reckoned as the planets return to the same position relatively to the sun, and not absolutely; because the sun is the cause of both the earth's and the moon's motions. Also, because (as more recent astronomers suppose) the month, as measured between solar conjunctions, is really the full period of revolution, because of the earth's motion in her great orbit. Diameters bear a constant ratio to circumferences. And the moon's orbit is a little more than twice 29½ times the length of great circles on the earth.

Thus the moon and the earth agree in a twofold ratio of motion, and the earth rotates in its diurnal motion in the space of 24 hours; because the moon has a motion proportioned to the earth, and the earth has a motion agreeing in a twofold proportion with the moon's motion. There is some difference in minutes, for the distances of the stars are not sufficiently determined in minutes, nor are astronomers agreed thereupon. So, then, the earth rotates in the space of 24 hours, even as the moon does in her monthly course, by a magnetical compact of both, the globes being impelled forward according to the ratio of their orbits, as Aristotle admits (*de Cœlo*, Book II, Chap. X). "It comes about," says he, "that the motions of each are performed in a ratio, to wit, in the same intervals whereby some are quicker, others slower." But as between the moon and the earth, it is more reasonable to believe that they are in agreement, because, being neighbor bodies, they are very like in nature and substance, and because the moon has a more manifest effect on the earth than have any of the other stars, except the sun; also the moon alone of all planets directs its movements as a whole toward the earth's centre, and is near of kin to earth, and as it were held by ties to earth.

Such, then, is the symmetry and harmony of the moon's and the earth's movements, very different from the oft-mentioned harmony of the celestial motions, which requires that the nearer any sphere is to the *primum mobile* and to the imaginary and fictitious rapid first motion, the less it opposes it (*contranitatur*) and the more slowly it is borne by its own motion from west to east; but that the farther it is away the more rapidly and the more freely it performs its motion, and hence that the moon (being farthest from the *primum mobile*) revolves with greatest rapidity. These absurdities have been accepted for the sake of the *primum mobile*, and so that it might seem to have some effect in retarding the movements of the nether heavens; as though the motion of the stars was due to retardation, and was not inborn and natural to them, and as though the rest of the heavens (the *primum mobile* alone excepted) were ever driven by a mighty force with a mad impulsion. Far more probable is it that the stars revolve symmetrically, with a certain mutual concert and harmony.[1]

[1] Dr. Wm. Whewell says ("Hist. of the Ind. Sc.," 1859, Vol. I, page 394) that Gilbert had only some vague notions that the magnetic virtue of the earth in some way determines the direction of the earth's axis, the rate of its diurnal rotation, and that of the revolution of the moon about it. He died in 1603, and in his posthumous work (*De Mundo nostro Sublunari Philosophia nova*, 1631) we have already a more distinct statement of the attraction of one body by another. "The force which emanates from the moon reaches to the earth, and, in like manner, the magnetic virtue of the earth pervades the region of the moon: both correspond and conspire by the joint action of both, according to a proportion and conformity of motions, but the earth has more effect in consequence of its superior mass; the earth attracts and repels the moon, and the moon, within certain limits, the earth; not so as to make the bodies come together, as magnetic bodies do, but so that they may go on in a continuous course." Though this phraseology is capable of representing a good deal of the truth, it does not appear to have been connected, in the author's mind, with any very definite notions of mechanical action in detail.

CHAPTER VII.

OF THE EARTH'S PRIMARY MAGNETIC NATURE, WHEREBY HER POLES ARE MADE DIFFERENT FROM THE POLES OF THE ECLIPTIC.

HAVING shown the nature and causes of the earth's diurnal revolution, produced partly by the energy of the magnetic property and partly by the superiority of the sun and his light, we have now to treat of the distance of the earth's poles from those of the ecliptic—a condition very necessary for man's welfare. For if the poles of the world or the earth were fixed at the poles of the zodiac, then the equator would lie exactly under the line of the ecliptic, and there would be no change of seasons,—neither winter, nor summer, nor spring, nor fall,—but the face of things would persist forever unchanging. Hence (for the everlasting good of man) the earth's axis declined from the pole of the zodiac just enough to suffice for generation and diversification. Thus the declination of the tropics and the inclinations of the earth's pole always stand in the 24th degree, but is at present only 23 deg. 28 min., or, according to others, 29 minutes; but formerly the declination was 23 deg. 52 min., and that is the uttermost limit of declination so far observed. This has been wisely ordered by nature and settled by the earth's primary eminency. For were those poles—those of the earth and the ecliptic—to be much farther apart, then as the sun approached the tropic all things would be waste and ruin, in any high latitude of the other and neglected portion of the globe, because of the protracted absence of the sun. But now all things are so disposed that the entire globe of earth has its own changes in due succession, its own fitting and needful seasons, either through a more direct radiation from overhead or by a longer tarrying of the sun above the horizon.

Around these poles of the ecliptic the bearing of the earth's poles rotates, and because of this motion we have the precession of the equinoxes.

CHAPTER VIII.

OF THE PRECESSION OF THE EQUINOXES BY REASON OF THE MAGNETIC MOVEMENT OF THE EARTH'S POLES IN THE ARCTIC AND ANTARCTIC CIRCLE OF THE ZODIAC.

THE early astronomers, not noting the inequality of years, made no distinction between the equinoctial or solstitial revolving year and the year determined from a fixed star. They also deemed the Olympian years, which were reckoned from the rising of the Dog Star or Sirius (*Canicula*) to be the same as those reckoned from the solstice. Hipparchus the Rhodian was the first to notice that there is a difference between the two, and found another year, calculated from fixed stars, of greater length than the equinoctial or solstitial: hence he supposed that the stars too have a consequent motion, though a very slow one, nor readily noticeable. After Hipparchus, Menelaus, a Roman geometer, then Ptolemy, and, a long time afterward, Machometes Aracensis and several others, in all their writings have held that the fixed stars and the whole firmament have a consequent forward movement (*in consequentia procedere*), for they contemplated the heavens and not the earth, and knew nothing of the magnetic inclination. But we will prove that this motion proceeds from a certain revolution of the earth's axis, and that the eighth sphere, so called, the firmament, or *aplanes*, with its ornament of innumerable globes and stars (the distances of which from earth have never been by any man demonstrated, nor ever can be), does not revolve. And surely it must seem more probable that the appearances of the heavens should be produced by a deflection and inclination of the small body, the earth, than by a whirling of the whole system of the universe—especially as this movement is ordered for the good of the earth alone, and is of no benefit at all to the fixed stars or the planets. For by this motion the rising and setting of stars in all horizons are changed, as also their culminations in the zenith, so that stars that once were vertical are now some degrees distant from the zenith. Provision has been made by nature for the earth's soul or its magnetic energy—just as in attempering, receiving, and diverting the sun's rays and light in fitting seasons, it was necessary that the bearings of the earth's pole should be 23 degrees and more distant from the poles of the ecliptic; so that now in regulating and in receiving in due order and succession the luminous rays of the fixed stars, the earth's poles should revolve at the same distance from the ecliptic in the arctic circle of the ecliptic, or rather that they should creep with slow gait, because the actions of the stars do not always persist in the same parallel circles, but have a slower change; for the influences of the stars are not so powerful that the desired course should be more rapid. So the axis is inflected slowly, and the rays of the stars are changed in such length of time as the diameter of the arctic or polar circle extends; hence the star in the extremity of the tail of Cynosura, which once (i.e., in the time of Hipparchus) was 12 degrees 24 minutes distant from the pole of the world or from the point which the earth's pole regarded, now is distant from it only 2 degrees 52 minutes; hence from its nearness to the pole it is called by the moderns the Pole Star.[1] It will not be only ½ degree from the pole, but thereafter will begin to recede till it reaches a distance of 48 degrees; that, according to the Prutenic tables,[2] will be A.D. 15,000. So the bright star (which for us here, in southern Britain, now almost culminates) will in time come within five degrees of the world's pole. Thus do all the stars change their light rays at the earth's surface, because of this admirable magnetic inflection of the earth's axis. Hence the ever new changes of the seasons; hence are regions more or less fruitful, more or less sterile; hence changes in the character and the manners of nations, in governments and in laws, according to the power of the fixed stars, the strength thence derived or lost, and according to the individual and specific nature of the fixed stars as they culminate; or the effects may be due to

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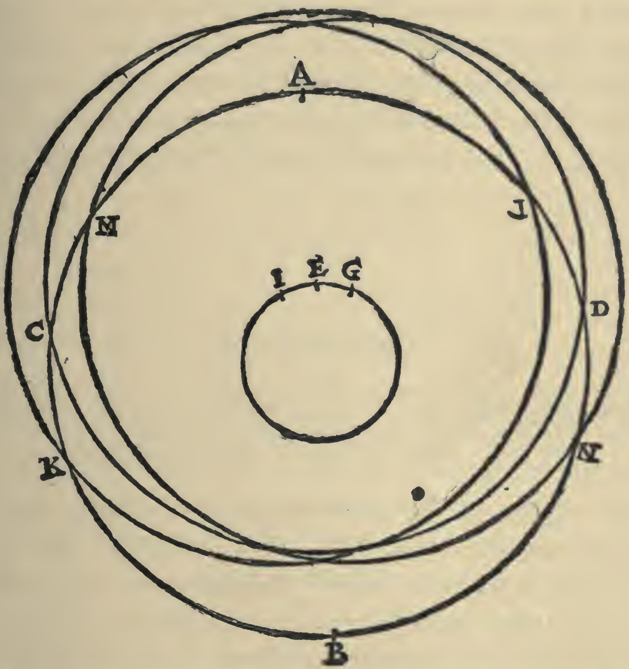
[1] Hakewill alludes (*Apologie*, 1635, Lib. ii, page 97) to Hipparchus, "who reports that in his time the starre commonly called the Polar Starre, which is in the tayle of the lesser Beare, was 12 degrees and two-fifths distant from the Pole of the Æquator. This starre, from age to age, hath insensibly still crept nearer to the Pole, so that at this present it is not past three degrees distant from the Pole of the Æquator. When this starre then shall come to touch the Pole, there being no farther place left for it to go forward (which may well enough come to pass with five or six hundred yeares) it is likely that then there shall be a great change of things, and that this time is the period which God hath prefixed to Nature." (See Morell's "Elem....Phil. and Sc.," London 1827, pp. 116–119 *et seq.*)

[2] The Prutenic (Prussian) Astronomical Tables,—*Prutenicæ Tabulæ Cœlestium Motuum*, 1551, 1571, 1585,—based upon the observations of Copernicus, Hipparchus, and Ptolemy, were the result of seven years' labor on part of the German astronomer Erasmus Reinhold, who named the work after his benefactor, Albert, Duke of Prussia.

their risings and settings or to new conjunctions in the meridian.

The precession of the equinoxes from the equal motion of the earth's pole in the zodiacal circle is here demonstrated.



Let *ABCD* be the ecliptic; *IEG* the Arctic zodiacal circle. Now if the earth's pole looks toward *E*, then the equinoxes are at *D*, *C*. Suppose this to be in the time of Metho,[1] when

[1] The celebrated astronomer Meton flourished at Athens B.C. 432–430. The mean length of the Metonic Cycle, or Metonic Year, was 6939¾ days, which coincides with 19 Julian Years and nearly corresponds to 235 lunations. An improvement on the Metonic Cycle was proposed by Calippus of Cyzicus, a disciple of Plato. The Calippic Period consisted of 76 years, representing four Metonic Cycles, or about 940 complete lunations, 1020 nodal and 1016 complete sidereal revolutions. After this, says Hakewill, (*Apologie* 1635, Lib. III, page 279), Hipparchus framed another Cycle, "containing foure of Calippus his periods, each of them (all in turn) finding some errour in the former obser-

the horns of Aries were in the equinoctial colure.[1] But if the earth's pole has advanced to *I*, then *K*, *L* will be the equinoxes, and stars in the ecliptic *C* will seem to have moved forward over the whole arc *KC*, following the signs; *L* advances by precession over the arc *DL*, counter to the order of the signs; but the opposite would be the case if the point *G* were to regard the earth's poles, and the motion be from *E* toward *G*; for then *M*, *N* would be the equinoxes, and the fixed stars would anticipate at *C* and *D*, counter to the order of the signs.

CHAPTER IX.

OF THE ANOMALY OF THE PRECESSION OF THE EQUINOXES AND OF THE OBLIQUITY OF THE ZODIAC.

THE change in the equinoxes is not always equal, but becomes sometimes more rapid, sometimes more slow; for the earth's poles travel unequally in the Arctic and in the Antarctic zodiacal circle, and recede from the middle line on both

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vations which they diligently amended...." Hipparchus, first and greatest of Greek astronomers, is the inventor of the astrolabe as well as the discoverer of the "precession of the equinoxes," and left many important works including a catalogue showing the latitude and longitude of over 1000 stars. It was Copernicus, however, who first gave the true explanation of the phenomenon known as the *precession of the equinoxes*, and Newton who discovered its physical cause (G. J. Chambers, "Descrip. Astronomy," Oxford 1867, page 240).

[1] The colure is one of two great circles which intersect at right angles in the poles of the equator. To Eratosthenes, the Librarian at Alexandria, who flourished about A.C. 280, is attributed the invention and construction of an ingenious and useful instrument or machine, having some resemblance to the armillary sphere, which exhibited the relations of the meridian to the equatorial and ecliptic lines, and thus indicated the solstitial and equinoctial colures.

sides; hence the obliquity of the zodiac seems to change to the equator (*ad æquatorem immutari*). And when this became known through protracted observations, it was apparent that the true equinoctial points were elongated from the mean equinoctial points 70 minutes to one side or the other in the greatest *prostaphæresi*; while the solstices either approach the equator equally by 12 minutes or recede to the same extent; so that the nearest approach is 23 deg. 28 min. and the greatest elongation 23 deg. 52 min. Astronomers in accounting for this inequality of precession and of declination of the tropics have offered various theories. Thebitius, to establish a law for these great inequalities in the movements of the stars, held that the eighth sphere does not advance by continued motion from west to east, but that it has a sort of tremulous motion (*motu quodam trepidationis concuti*) whereby the leading stars in Aries and in Libra of the eighth heavens describe around the leading stars of Aries and Libra of the ninth sphere certain small circles with diameters equal to about nine degrees. But as this "motion of trepidation"[1] is full of absurdities and impossible motions, this movement has gone out of fashion. Other astronomers, therefore, are compelled to ascribe motion to the eighth sphere, and atop of this to construct a ninth heaven, nay a tenth and an eleventh.[2] We must pardon slips in mathematicians, for one may be permitted in the case of movements difficult to account for to offer any hypotheses whatever in order to establish a law and to bring in a rule that will make the facts agree. But the philosopher never can admit such enormous and monstrous celestial constructions.

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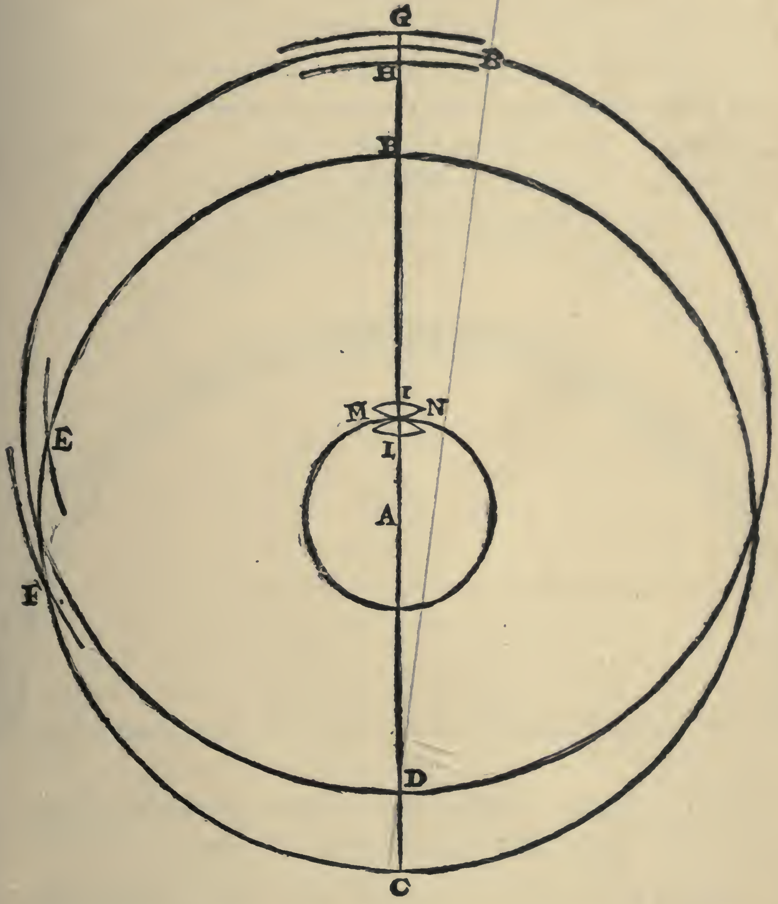
[1] See note, Book III, Chap. I.
[2] See note, Book VI, Chap. III.

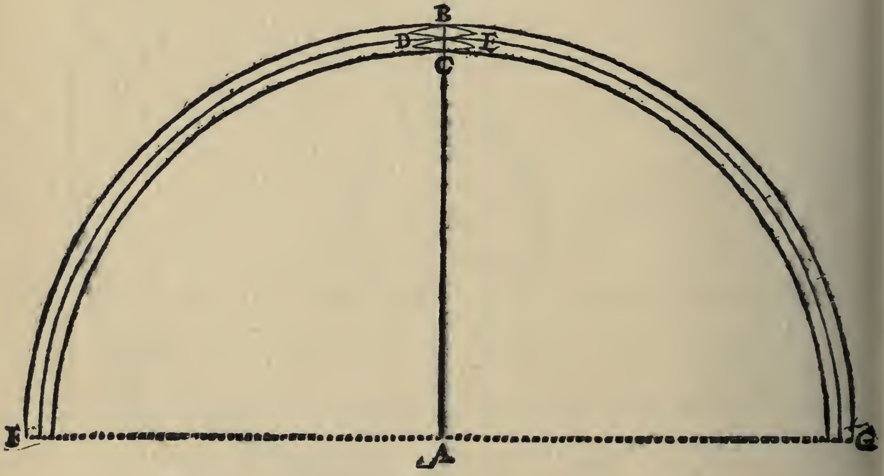
Now though we see in all this how loath these mathematicians are to ascribe any motion to the earth, which is a very small body, nevertheless they drive and whirl the heavens, which are vast and immense beyond human comprehension and human imagination: they construct three heavens, postulate three inconceivable monstrosities, to account for a few unexplained motions. Ptolemy, comparing with his own observations those of Timochares and Hipparchus, of whom the one lived 260 years before his day and the other 460 years, deemed this to be the motion of the eighth sphere and of the whole firmament, and proved it with many phenomena on the poles of the zodiac; and, still thinking its motion to be equal, he held that the fixed stars in 100 years travel only one degree beneath the *primum mobile.* Seven hundred and fifty years after him, Abitegnius found that one degree is travelled over in 66 years, so that the whole period would be 23,760 years. Alphonsus would have this motion still slower—1 degree 28 minutes in 200 years; and thus would the course of the fixed stars proceed, but unequally. At last Copernicus, through his own observations and those of Timochares, Aristarchus the Samian, Menelaus, Ptolemy, Machometes Aracensis and Alphonsus, discovered the anomalies of the motion of the earth's axis; though I have no doubt that other anomalies also will appear some centuries hence, for it is difficult, save in periods of many ages, to note so slow a movement, wherefore we still are ignorant of the mind of nature, what she is aiming at through this inequality of motion. Let *A* be the pole of the ecliptic, *BC* the ecliptic, *D* the equator; when the earth's pole regards the point *M* near the arctic circle of the zodiac let the anomaly of the precession of the equinox be at *F*, but when it regards *N*, let the anomaly of the precession be at *E*. So long as it regards *I* directly there is observed the maximum obliquity *G* in the solstitial colure; but while it regards *L*,



then there is minimum obliquity *H* in the colure of the solstices.

Copernicus's intorta corolla in the arctic zodiacal circle.

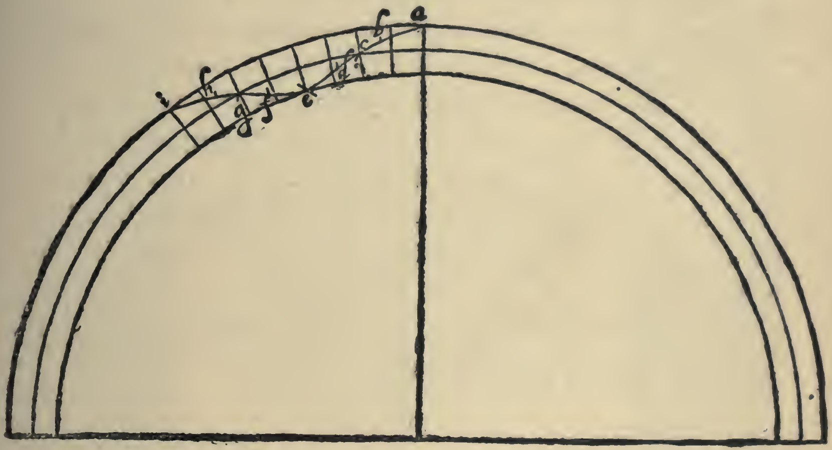
FGB is one half of an arctic circle described around the pole of the zodiac ; *ABC* is the colure of the solstices ; *A* the pole of the zodiac ; *DE* the anomaly of longitude 140 minutes on either side, with twofold terminus (*duplici termino*) ; *BC* anomaly of obliquity, 24 minutes ; *B* the greater obliquity, 23 degrees 52 minutes ; *D* the mean obliquity, 23 degrees 40 minutes ; *C* the minimum obliquity, 23 degrees 28 minutes.



True movement and natural axis (or poles) of the earth directed toward the arctic circle of the zodiac.

Let *AI* be part of the arctic circle of the zodiac in which is performed one period of the obliquity. From *A* to *E* is the period of the anomaly or variation of the precession of the equinoxes. *AI* is the curved line described by the earth's pole in a true motion made up of three motions, i.e., of the motion of the precessions, and of the anomaly of the precessions, and of obliquity.

The period of the precession of the equinoxes is 25,816 Egyptian years; the period of the obliquity of the zodiac is 3434 years and a little more; the period of the anomaly of the precession of the equinoxes is 1717 years and a little more. If we divide the whole time of the motion from *A* to *I* into eight equal parts, in the first eighth part the pole travels faster from *A* to



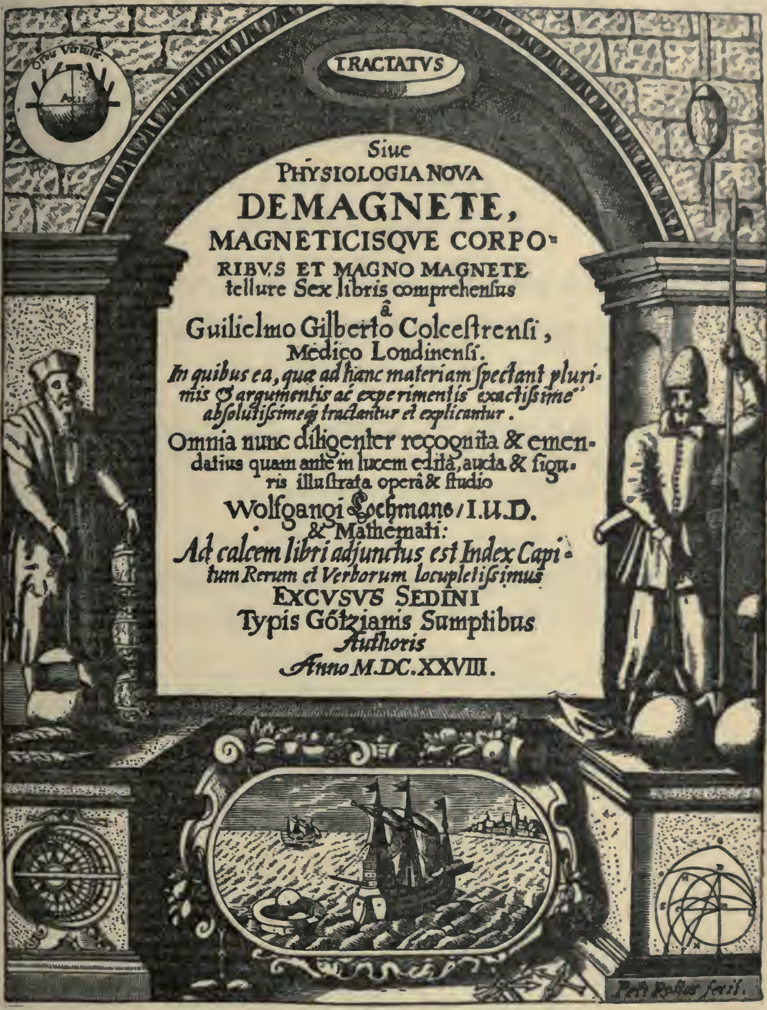
B; in the second more slowly from *B* to *C*; in the third, with the same slowness from *C* to *D*; in the fourth, more rapidly again from *D* to *E*; in the fifth, with equal rapidity from *E* to *F*; again more slowly from *F* to *G*; with the same slowness from *G* to *H*; in the last eighth again more rapidly from *H* to *I*, and this is Copernicus's *intorta corolla*[1] with mean motion fused into a curved line, which is the true path of the

[1] See *Nicolai Copernici Torinensis, De Revolutionibus orbium cœlestium,* Norimbergiæ 1543, pages 66, 67, or the Amstelrodami ed. of 1617, pages 154–157. The *intorta corolla* is not an inverted but an irregular crown: a figure representing the successive positions produced by the projection of the earth's pole upon the stellar sphere, resembling a crown, but distorted by the irregularities of motion. (Consult, also, Rheticus, "Narratio prima de Lib. Rev. Copernici;" Kepler, "De Temporis æquatione plenaria et motu octavæ sphæræ.)

motion. And so the pole reaches the extreme limit of variation of the precession of the equinoxes twice, but the limit of inclination or obliquity once only. Thus do the moderns, and in particular Copernicus, restorer of astronomy, describe the variations of the movement of the earth's axis, so far as the same is made possible by the observations of the ancients down to our day; but we still lack many and more exact observations to fix anything positively as to the anomaly of the movement of the precessions, as also of the obliquity of the zodiac. For since the time when in various observations this anomaly was first noted, only one half of a period of obliquity has passed. Hence all these points touching the unequal movement of precession and obliquity are undecided and undefined, and so we cannot assign with certainty any natural causes for the motion.

Wherefore we here bring to an end and conclusion our arguments and experiments magnetical.

FINIS.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