

THE ORIGINS OF WILLIAM GILBERT'S SCIENTIFIC METHOD*

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William Gilbert's *De Magnete* appeared in 1600, six years before Galileo's first publication, five years before Bacon's *Advancement of Learning*; it is the first printed book, written by an academically trained scholar and dealing with a topic of natural science, which is based almost entirely on actual observation and experiment. In the learned literature of the period, among the writings of both contemporary university scholars and the humanistic literati, it is an isolated case. An analysis of the origins of its scientific method, therefore, is not only interesting in itself but is likely to throw some light on the origins of modern natural science in general. The results of Gilbert's investigation of magnetism and electricity being generally known, we shall consider first a few characteristics of his method and shall then try to trace its sources. Unfortunately very little is known of Gilbert's life and nothing at all of his way of working. The investigation, therefore, must be based entirely on his two printed books.¹

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¹ *De Magnete Magneticisque Corporibus et de Magno Magnete Tellure, Physiologia Nova plurimis et argumentis et experimentis demonstrata*, Londini, 1600. If no other source is given all quotations in the following paper refer to this work and this edition. An English page-for-page version by Silvanus P. Thompson has been edited by the William Gilbert Society, Chiswick Press, London 1900. It contains valuable notes. Gilbert's second work is quoted from the only edition, *De Mundo nostro sublunari Philosophia nova, Opus posthumum. Ab Authoris fratre collectum pridem et dispositum*. . . . Amstelodami, 1651.—*De Mundo* does not shed much light on the origin of Gilbert's ideas. We are not even sure whether it was composed before or after *De Magnete*. At the margin of page 139 of *De Mundo* a reference to *De Magnete* VI, 4 is given and a similar remark is added at the end of the chapter. But since the author's brother who edited *De Mundo* declares himself in the preface not to know which of the books was composed earlier, obviously both remarks have been added by the editor later on. On the other hand in *De Mundo* (pp. 118 and 151) two statements of Patrizzi are criticised. These quotations can refer only to Patrizzi's *Nova de Universis Philosophia*, part Pancosmia, book 26 and book 12 respectively (in the second edition, Venice 1593, fol. 132 col. 2 and fol. 91 col. 3). The first edition of Patrizzi's work was printed in 1591. *De Mundo*, therefore, must have been composed after 1591 (Gilbert died in 1603). Altogether *De Mundo* gives

I

1. Gilbert's scientific method combines essentially modern with metaphysical, Scholastic, and animistic elements. Several of his experimental devices are still in use today. He dresses the poles of his spherical loadstones with sheet-iron and thus invents the armature of magnets (II, chap. 17). In order to examine weak magnetic forces he fixes small iron pieces on cork floating on water or suspends them on threads (I, 12 and 13; III, 8; V, 9). He even uses a few physical instruments. One of them is of his own invention and is the first of its kind in the history of physics. It is a—still somewhat imperfect—electroscope which obviously is constructed after the pattern of a magnetic needle (II, 2 p. 49). Besides Gilbert describes at length and illustrates by woodcuts four magnetic measuring instruments, two declinometers and two inclinometers (IV, 12; V, 1; V, 3). They had, however, been neither invented nor essentially improved by him, though Gilbert omits that point.²

It is significant with respect to the origin of Gilbert's interest in scientific accuracy that all of his physical instruments are actu-

the impression of greater immaturity; it is more pedantic and contains more remnants of Scholastic terminology than *De Magnete*. The first book of *De Mundo* combats the doctrine of the four elements, the second deals with astronomy, books 3 to 5 discuss "meteorological" problems, beginning with comets, the milky way, and clouds, and ending with the sea and the air. Very few experiments are given. *De Mundo* contains some modern-looking results—e.g., space above the terrestrial atmosphere is thought to be empty and cold—but the methods and arguments are in no way outstanding.

² Gilbert's electroscope consists of a light horizontal metal needle, which is put on a point so that it can be turned easily. In *De Magnete* it is called by the same name *versorium* that is employed for magnetic needles.—The description of Gilbert's four magnetic measuring instruments must be omitted here. The declinometer was invented in 1525 by Felipe Guillen. It was improved before Gilbert by Francisco Falero (*Tratado del Esphera*, Sevilla 1535), Pedro Nunes (*Tratado da Sphera*, Lisbon 1537), William Borough (*A Discourse of the Variation of the Compass*, London 1581), and Simon Stevin (*De Havenwinding*, Leyden 1599). The inclinometer had been invented by Robert Norman (*The Neue Attractive*, London 1581). These works are reprinted in G. Hellman: *Rara Magnetica, 1269–1599*. (*Neudrucke von Schriften . . . über Erdmagnetismus No. 10*) Berlin 1898. As quotations at other places of *De Magnete* show, the cited works of Nunes, Borough, Norman, and Stevin were known to Gilbert. Gilbert also invented and constructed two nomograms. The first (IV, 12, p. 176) simplifies determination of the astronomical meridian by means of graphic calculus. The second (V, 8)—which, however, is based on incorrect assumptions—is meant to determine graphically geographic latitude.

ally nautical instruments or are at least nearly related to the mariner's compass. On the whole he performs measurements practically only when he deals with quantities which are important in navigation, such as magnetic declination and inclination, altitudes of stars, and geographical latitudes (*e.g.*, IV, 4 p. 160; IV, 12 p. 176; V, 8; VI, 1 p. 214). In other fields he usually restricts himself to qualitative observations and experiments. His best quantitative experiment verifies the hypothesis that magnetism is imponderable by weighing pieces of iron "on most exact gold scales" before and after magnetization (III, 3). It is taken over, however, from the compass-maker Robert Norman without the source being given. The few quantitative investigations which are original with him are not very outstanding.³ Altogether, quantitative investigation appears considerably developed in *De Magnete* if compared with physics in the Middle Ages; it cannot compare, however, with the use of scientific measurements in the works of Galileo and his followers. Calculations are lacking entirely.

Mechanics also plays a very small part in *De Magnete*. Twice Gilbert shows some mechanical insight. Once (II, 35) he vehemently attacks medieval attempts to construct a perpetual motion engine. At another time (II, 24 p. 92) he knows that unstable equilibrium cannot persist for a long time and that, therefore, Fracastoro's story of a piece of iron suspended in the air between the earth and a magnet is "absurd." These two passages, however, are the only ones in his book dealing with mechanical questions. Both the interest in mechanics and the mechanical interpretation of all natural phenomena which dominated physics from Galileo to the nineteenth century are still lacking in Gilbert.

2. It is not easy to draw the picture of Gilbert's scientific attitude correctly. He is usually as critical-minded as a modern experimentalist, does not rely on any authority, and always tests reports of others by his own experiments. Superstitious ideas are emphatically rejected by him. He derides the ancient and medieval stories of diamonds and garlic destroying magnetism, the stories of magnets detecting faithlessness of women and unlocking locks (pp. 2 f. and 6 f.). He vehemently attacks alchemists and their obscure language (pref. fol. iij; I, 3 pp. 19 f. and 24). He rejects the explanation of electric and magnetic attraction by

³ II, 17 p. 86; II, 25 p. 92; II, 29 p. 97; II, 32 p. 99; III, 15 p. 145; III, 17 p. 150.

means of sympathy and, on that account, scoffs at Fracastoro (II, 2 p. 50; II, 3 p. 63 f.; II, 4 p. 65; II, 39 p. 113). On the other hand he believes in horoscopes, like most of his contemporaries: the magnetizing effect of the earth on pieces of iron being forged in the smithy is compared by him to the influence of the stars on a child during its birth (p. 142).⁴

Aristotelian and Scholastic concepts play a major part in his theoretical conceptions. Gilbert believes in the two basic principles matter and form, "out of which all bodies are produced" (II, 2 p. 52). In his opinion electric effects get their strength (*invalescunt*) from matter, magnetic effects from a "distinguished" (*praecipua*) form (p. 53), for he thinks that the spherical form of the stars and especially the earth, being "primary and powerful" (I, 17 p. 42), is "the true magnetic potency" (II, 4 p. 65). Obviously his explanation of magnetism is based on the Scholastic metaphysics of active forms. In all his experiments he uses spherical loadstones, although he himself knows (II, 15 p. 83; III, 31 p. 99) that bar-like magnets are more effective. He calls them "little earths" (*terrellae* I, 3) and presumably clings to the medieval shape of his magnets because he believes in a metaphysical connection of spherical form and magnetism.

Cardanus's story that "the magnet lives and feeds on iron" is derided by Gilbert as old women's talk (I, 16 p. 37; II, 3 p. 63). He refutes it, using experimental methods, by ascertaining that the weight of the iron filings in which a magnet is kept does not diminish. Again he proves himself an empiricist, but he is opposed to vitalistic explanations only in so far as they contradict single empirical facts. His own "philosophy" of magnetism, so far as it can neither be confirmed nor disproved by observation, is as animistic as the theory of Cardanus. A chapter of his book (V, 12) is entitled: "The magnetic force is animated or is similar to soul; it by far surpasses the human soul as long as that is bound to an organic body." The chapter refers to ancient philosophers from Thales to the Neoplatonists, who taught the existence of a soul of the universe, and adds the Egyptians, Chaldeans and (p. 209) even authorities on occult science, such as Hermes, Zoroaster and Orpheus. It explains (p. 209 f.) that the earth and the stars have

⁴ The astrological theory of correspondence between metals and planets, however, is called "insane" (p. 20). In Gilbert's opinion metals, especially iron, are the very essence of the earth and, therefore, do not depend on the stars.

souls, although they have no sense-organs, and that God himself is soul;⁵ and, quoting Thales, it calls the magnet "an animated stone, that is a part and beloved offspring of the animated mother, Earth."

The last quotation shows that Gilbert's theory of magnetism is embedded in a vitalistic philosophy of the terrestrial globe. To him the earth is "the common mother" of all things. Again and again in *De Magnete* this term is repeated, whenever the earth is mentioned.⁶ We can therefore scarcely doubt the strongly emotional background of the idea of the maternal earth. The power of the magnet derives directly from the earth in Gilbert's opinion. For nothing but the magnet has preserved (I, 17 p. 42) "this distinguished substance which is homogenous to the internal nature of the earth and most akin to its marrow itself." Iron and magnets are (I, 16 p. 37) "the true and most intimate parts of the earth," because "they retain the first faculties in nature, the faculties of attracting each other, of moving, and of adjusting by the position of the world and the terrestrial globe."

Gilbert was the first to conceive the earth as a large magnet (I, 17; VI, 1). He was the first to teach that the interior of the earth consists of pure iron and that its surface and rim only are "soiled by other impurity" (I, 16 p. 39). Thus he has anticipated important empirical results of modern geophysics. But the resemblance of his magnetic philosophy to modern science is merely a matter of chance. Gilbert's terms "interior" and "intimate" combine spatial and metaphysical meaning and are always used as concepts of value. How near his "magnetic philosophy" still is to medieval vitalism is revealed by the fact that he believes in a metaphysical correlation of magnetism and rotation. He speaks of the "magnetic rotation" of the terrestrial globe (VI, 3 p. 214), and would like to accept the statement of Pierre de Maricourt that a spherical magnet rotates continuously by itself, were it not for his

⁵ Gilbert's religious belief obviously is rather Neoplatonic than Protestant. The whole chapter is strongly influenced by Patrizzi. Cf. below § 4, footnote 13.

⁶ *E.g.* pref. at the beginning and pp. 12, 26, 38 (twice), 41, 117, 152, 210.—Moreover Gilbert likes to compare the interior of the earth with the mother's womb. In his opinion all metals originate from exhalations of the innermost part of the earth that are condensed and congeal nearer the surface in warm cavities "as the sperm or embryo congeals in the warm uterus" (I, 7 p. 20). *De Mundo* advocates the doctrine (p. 39) that all kinds of matter originate in earth and that earth, therefore, is the only element.

conscience as a cautious experimentalist. He reproduces Pierre's statement and adds (VI, 4 p. 223): "until now we have not succeeded in seeing this. We even doubt this movement because of the stone's weight and because the whole earth moves by itself, as it is moved by the other stars also. That does not hold proportionally of some part [the *terrella*]." Everyone who remembers how vehemently Gilbert attacks the reports on perpetual motion machines must notice the difference in emphasis.⁷

II

3. The material thus far presented may serve for a general indication of Gilbert's way of thinking. Animistic and Neoplatonic ideas are abundant in his book; the traces of Scholasticism and astrology are scarcer. But it is not these pre-scientific features that are conspicuous, for his work shares them with the whole learned literature of his period. What really counts is that his animistic metaphysics is nothing but the emotional background of his thinking and does not affect the empirical content of his science. The writings both of the Scholastics and the Renaissance philosophers abound with superstitious stories and magic. Gilbert rejects all that with unswerving criticism and bases his findings on experience and experiment only. This attitude is so exceptional in his period that the question arises where it originates. Since critical minded experimentalists appear more and more frequently among the scholars a few decades after Gilbert, a satisfactory answer would at the same time contribute to the solution of the problem of the origin of modern science in general.

Even in a period in which quoting was more favored by scholars than nowadays, Gilbert is remarkable for the number of his references and his wide reading. He stresses, nevertheless, the novelty of his ideas. His attitude to contemporary literature is explained in the preface of *De Magnete*. There Gilbert says:

What business have I in that vast ocean of books? . . . By the more silly ones among them the crowd and most impudent people get intoxicated, insane and haughty. . . . They declare themselves to be philosophers, physicians, mathematicians, and astronomers and neglect and despise the

⁷ The story of the rotating spherical magnet is mentioned in *De Mundo* also (p. 138). There Gilbert gives the same reasons why the *terrella* does not rotate "although it is fit and inclined by nature to rotation."—In order to understand Gilbert's argument we have to realize that he was among the earliest adherents of Copernicus in England and was already convinced of the rotation of the earth.

learned men. Why should I add any thing to this disturbed literary republic? Or am I to offer this eminent philosophy that because of its unknown contents, as it were, is new and unbelievable to people who blindly trust authorities, to most absurd destroyers of the good arts, to literary idiots, grammarians, sophists, pettifoggers, and perverse mediocrities? . . . No! I have presented these principles of magnetism that belong to a new kind of philosophy, to you true philosophers . . . who look for knowledge not in books only but in things themselves.

Continuing, he announces that he will not call upon ancient writers for help, "because neither Greek arguments nor Greek words" can assist in finding truth. He promises that he will avoid "the ornament of eloquence" and will not darken things by words "as the Alchemists are wont to do." He plans to write with the same "liberty of mind" (*licentia*) as the ancient Egyptians, Greeks, and Romans. The "sciolists" of present times still keep the errors of the ancients, but Aristotle, Theophrastus, Ptolemy, Hippocrates, and Galen themselves are sources of wisdom. "Yet our own period has discovered and brought to light very many things which those men too would be glad to accept if they were alive."

These vehement attacks on believers in authority and words, and the emphasis on the novelty of his ideas, are characteristic of the period of the expiring Renaissance, and anticipate Francis Bacon, and in some degree Galileo also. As the mention of grammarians, Greek words and eloquence shows, Gilbert's attack is aimed at declining humanism. Similar attacks are repeated several times in *De Magnete*.⁸ Gilbert's other book, *De Mundo*, contains less polemics and is written more dispassionately. But it also opposes belief in authority: the slogan "he himself has said so, Aristotle has said so, Galen has said so" is considered a nuisance (*De Mundo* I, 3 p. 5).⁹

4. We shall therefore not expect to meet with much agreement with other authors in Gilbert's book. In fact most of the numer-

⁸ Gilbert scoffs (I, 1 p. 2) at "precocious sciolists and copyists" who add fictitious stories to ancient authors. He accuses "the modern philosophers" (I, 10 p. 28) of having drawn their knowledge from books rather than from things. He derides (II, 2 p. 48) the books "cramping the bookshops" that deal with mysterious stories instead of experiments, and are as fond of Greek words as barbers who try to impress people by using scraps of Latin. He charges Fracastoro (II, 39 p. 113) with his predilection for Greek words and reproaches "the crowd of philosophers and copyists" (II, 38 p. 109) with repeating old opinions and errors.

⁹ As is generally known, the *ipse dixit* (αὐτός ἔφα) was the slogan of the Pythagorean school by which they referred to their master.

ous references he gives are critical and negative, whereas the real sources of his ideas are chiefly to be sought elsewhere.

Ancient authors are often quoted. Comparatively favorable judgments are pronounced on philosophers who believe in universal animation, such as Plato and most of the Pre-Socratics. Atomists and mechanists are rejected. The Stoics are not mentioned. Although Gilbert is still greatly influenced by the concept of substantial form, he is opposed to Aristotle. In *De Magnete* (p. 116 and 209) Aristotle's astronomical doctrines are chiefly attacked, in *De Mundo* (I, 3) his doctrine of the four elements. The first book of *De Mundo* is even entitled "New Physiology against Aristotle," the third, "New Meteorology against Aristotle."¹⁰

References to medieval authors are rarer. Thomas Aquinas is twice quoted (I, 1 p. 3 and II, 3 p. 64) and his ingenuity and scholarship are highly praised. Yet Gilbert adds that Thomas did not experiment and consequently committed errors. A few Arabian authors are mentioned, but for the most part their opinions are attacked.¹¹

Almost the same holds of the authors of the modern era. Gilbert does not seem to have known the humanists very well. Among modern scholars cited most frequently are the philosopher-physician Fracastoro, the mathematician and physician Cardanus, the philologist and physician Scaliger, and the learned compiler of curiosities, Giambattista Porta. The first three authors were among the most famous scholars of the late Renaissance. Nearly always Gilbert derides all four of them, Fracastoro because of his belief in "sympathy," the others because of their credulity and superstition. Gilbert—he was physician in ordinary to Queen Elizabeth—wrote two chapters (I, 14 and 15) on the medical effects of iron. There he proves to be familiar with modern medical literature, but practically all authors cited are refuted. He vehe-

¹⁰ Thales, Empedocles, Anaxagoras, Pythagoreans, Plato praised V, 1; Plato attacked p 61; Aristotle: his importance admitted (pref. about the end), his (and Galen's) opinions on iron approved, p. 39; Hippocrates praised because he did not advocate the doctrine of the four elements *De Mundo*, p. 5, attacked *De Magnete* p. 35; Galen criticized, p. 35 and 62, his importance admitted, pref. about the end; Strabo, Ptolemy, Tacitus, and Pliny the Elder quoted on iron mines p. 25; Pliny the Elder (on glass-making) attacked, p. 112.

¹¹ Avicenna is quoted on meteorites, p. 26; the medical opinions of Avicenna, Razès (= Abu Bekr al Rasi), and unnamed Arabian physicians attacked, p. 34f.; the alchemists Geber and Gilgil Mauretanus attacked, p. 19.

mently attacks Paracelsus, who among the physicians was the first to rebel against the authority of Aristotle and Galen, and he twice mentions (pp. 34 f.) the eminent and empirical-minded anatomist Fallopius without bringing him into any prominence. Gilbert's personal medical opinions are remarkably sound and free of superstition. Contemporary astronomical literature is well known to him (*De Mundo* II, 10 and 20) and Copernicus is highly praised in *De Magnete* (VI, 3). In the preface to *De Magnete*, written by Gilbert's friend Wright, the heliocentric theory is defended at length against scientific and religious objections.¹²

More may be learned of the origin of Gilbert's ideas from the references lacking than from those he gives. Among ancient authors three are conspicuous by their absence in *De Magnete*: Euclid, who is most important for the development of geometrical knowledge in the fifteenth and sixteenth centuries; Archimedes, who greatly influenced mechanics in the same period; and Vitruvius, who is the main source of knowledge in the field of ancient engineering. The three omissions show that Gilbert was not concerned with the mathematical literature of the period, that he was not interested in mechanics, and that he had connections neither with the humanists nor the architects of the Renaissance, who often quoted Vitruvius. With artists, presumably, Gilbert did not have any contacts at all. He could have found real experiments in the papers of the Italian artist-engineers (Brunelleschi, Ghiberti, Leonardo), which, however, were not yet printed. He never mentions Biringuccio either, who belonged with the architects of the Renaissance. Biringuccio's work *Della Pirotechnia*, printed in 1540, treats metallurgy quite empirically and by experiments, but still discusses the magnet in a rather superstitious way.

The omission of one more group of authors is instructive. Gilbert's opposition to belief in books and authorities and his pride

¹² Nicolaus Cusanus ("not to be despised"), p. 64; Marsilius Ficinus, p. 3 ("ruminates ancient opinions") and p. 16; Fracastoro *De Sympathia* (1545), mentioned, pp. 5, 9, 110, 113; his theory of planetary movements (given in his *Homocentricorum seu de Stellis Liber*) discussed in *De Mundo* II, 10; Cardanus's *De Subtilitate* (1552) attacked, pp. 5, 27, 37, 42, 63, 107, 110, 169; Scaliger's *Exercitationes Esotericae* (1557) attacked, pp. 5, 27, 37, 42, 63, 107, 110, 169; Porta's *Magia Naturalis* (1589) quoted, pp. 6, 24, 63, 137f., 143f., 166ff.; Paracelsus's "shameless charlatanry" attacked, p. 93, his merits admitted but Paracelsists attacked, *De Mundo* p. 7; the Antiparacelsist Thomas Erastus quoted, pp. 3 and 23. Tycho Brahe (on the coordinates of the Polaris) referred to, p. 174.

in the novelty of his ideas, are greatly reminiscent of Bernardino Telesio. Telesio was the first among the scholars of the Renaissance to oppose his "own principles" to Aristotelian natural philosophy (*De Rerum Natura iuxta propria Principia*, 1565 and 1570). Actually the influence of Telesio appears a few years after *De Magnete* in the works of Bacon, in which the anti-Aristotelian rebellion is carried on with even greater impetus. Gilbert, however, neither mentions Telesio nor seems to have known his work. The case of Telesio's pupil Patrizzi is somewhat different. Patrizzi always attacks Aristotle but is not much of a champion of originality: he likes quoting Plato and the authorities of occult science too well. He was known to Gilbert and is twice quoted in *De Mundo* (II, 2, p. 118 and II, 10, p. 151). Both times, however, statements of Patrizzi—on the shape of the globe and on the cause of the motions of the stars—are rejected. In *De Magnete* also both content and wording of the Neoplatonic chapter on universal animation (V, 12) obviously are influenced by Patrizzi, although he is not even mentioned.¹³ Campanella and Giordano Bruno are also intellectually related to Telesio. Both attacked Aristotle and rejected the humanistic veneration of books with the same vehemence. Yet they are never mentioned in Gilbert. Bruno lived in England from 1583 to 1585; it would have been easy, therefore, for our author to make contact with him.

Gilbert's ideas—he describes, as we have seen, parts of *De Mundo* as *Physiologia nova contra Aristotelem*, *Nova Meteorologia contra Aristotelem*—belong to the same intellectual current as those of Telesio, Patrizzi, Campanella, and Bruno. Modern technology and modern economy had changed civilization too thoroughly for the Scholastic belief in Aristotle or the humanistic veneration of antiquity to endure. Telesio, Patrizzi, Campanella, and Bruno, however, were metaphysicians, not experimentalists, though Telesio and Campanella, theoretically at least, emphasized the importance of experience. It is rather instructive to realize that

¹³ Patrizzi's main work *Nova de Universis Philosophia* appeared in Venice, 1591. We quote, however, from the second edition, Venice, 1593. The part *Panpsychia*, book 4 refers to the Presocratics, Plato, the Neoplatonists, the Egyptians and Chaldeans, and to Zoroaster, Hermes, and Orpheus; it stresses the fact that stars do not need organs, though they have souls; it three times (fol. 55 col. 2 and 3) calls Aristotle's philosophy a "monstrum," because in his doctrine the whole universe is animated except for the earth. Quite the same theses and references are repeated in *De Magnete* V, 12 and even the term "monstrum" appears there (p. 209).

three of these philosophers exerted no influence at all on Gilbert and only Patrizzi contributed a few Neoplatonic ideas to his philosophy. In a sociological analysis the young experimental science of the early seventeenth century and the antidogmatic but fantastic metaphysics of the late Renaissance might prove to be connected: in both the same rebellion of the nascent modern society against the antiquated erudition and authorities of the past manifests itself. Yet the natural philosophy of the late Renaissance was the older brother of experimental science, not its father. The experimental method did not and could not have descended from the metaphysical ideas of the natural philosophers. We have to look elsewhere and in other social ranks for its immediate predecessors.

Among all the scholars quoted by Gilbert there is one who really did influence his investigation and method a great deal, although he does not at all emphasize this indebtedness. This is the medieval nobleman Pierre de Maricourt, who in 1269 wrote a short but remarkable account of his magnetic experiments. About his life almost nothing is known. Written copies of his letter on magnetism were circulated until the sixteenth century, when it was printed under the title *Petri Peregrini Maricurtensis De Magnete, seu Rota perpetui motus libellus*, Augsburg, 1558. Gilbert mentions Petrus Peregrinus five times in *De Magnete* and once in *De Mundo*.¹⁴

The first reference is in the first chapter of *De Magnete* which compiles the opinions on magnetism of the authors of the past. There (p. 5) Gilbert says: "About 200 years before Fracastoro there is a short work, sufficiently learned considering the period, under the name of a certain Petrus Peregrinus, which many think to have originated in the opinions of the Englishman Roger Bacon of Oxford. From that Johannes Taysner of Hainolt excerpted a booklet and published it as a new one."¹⁵ Twice (III, 1 p. 116 and IV, 1 p. 153) Petrus is mentioned among the advocates of the erroneous opinion that "the magnetic needle is attracted by the celestial pole." In a short chapter (II, 35) Gilbert vehemently

¹⁴ On Pierre and his letter cf. Silvanus P. Thompson: *Petrus Peregrinus de Maricourt and his Epistola de Magnete*, *Proc. Brit. Acad.* vol. 2 (1905/6), pp. 377-408, and Erhard Schlund: *Archivum Franciscanum Historicum* vol. 4 (1911) and vol. 5 (1912). The letter on magnetism is reprinted in G. Hellmann: *Rara Magnetica* (Neudrucke etc.) Berlin, 1898.—On the origin of Pierre's scientific method cf. below § 8.

¹⁵ As a matter of fact Roger Bacon depends more on Pierre than Pierre on Bacon.—Taysner's plagiarism was printed Coloniae 1562.

rejects the perpetual motion engines of Cardanus, Antonius de Fantis, Petrus Peregrinus, and Johannes Taysner. And, finally, in *De Magnete* VI, 4 (p. 223) and *De Mundo* II, 7 (p. 13) he criticizes Pierre's story of the always rotating *terrella* (cf. §2, above). Except for the first passage, which, however, is rather general and rather tepid, Gilbert always differs with and criticizes the opinions of Pierre de Maricourt.

But in fact he owes more to Pierre than his words indicate. Pierre already knew (Chap. 6) that unlike poles attract, like ones repel one another. He knew (Chap. 9) that, when a magnet is divided, the pieces become new magnets with new poles. But Gilbert's knowledge of these facts need not have been taken over directly from the medieval experimentalist. The case is different with the spherical shape of the magnets. This shape is not a matter of course, but is, from the modern point of view, rather inexpedient. Pierre uses spherical loadstones, and the complicated way of determining the magnetic poles of the sphere—short pieces of iron wire are put on them and meridians are drawn with chalk until they intersect—is so completely identical in both authors (Pierre, Chap. 4, Gilbert I, 3, p. 12 f.) that literary influence cannot be doubted. Gilbert is indebted to the outstanding medieval experimentalist as well for one of his experimental devices. Pierre (Chap. 5–7) had already made his loadstones float on water by means of wooden vessels. The cork pieces which are used by Gilbert of course were not yet known to him.

5. Up to this point we have not been able to give many positive contributions in answer to our main question. We have traced numerous authors to whom Gilbert was not indebted for his scientific method and only one—Pierre de Maricourt—to whom he was. The origins of his experimental technique and his scientific criticism are almost as enigmatic as they were before we started collecting his quotations. But we may have proceeded incorrectly. It was wrong, in fact, to look for his intellectual predecessors among scholars and philosophers. One has but to turn over the leaves of *De Magnete* in order to realize that he was interested in unscholar-like people and non-scholastic subjects too. Of the 240 pages of the book only 97 (40%) explain physical experiments. On the other hand 60 pages (25%) deal with nautical instruments and navigation, 25 pages (10%) with mining, melting, and fashioning of iron. The rest discusses astronomical questions (25 pp.), the

opinions of numerous authors (18 pp.), the terrestrial globe as a magnet (11 pp.), and the medical effects of iron (4 pp.). Obviously *De Magnete* differs a great deal from a modern textbook on magnetism. The very first printed book on experimental physics deals so extensively with practical problems, that in some respects it is nearer to a technological than to a physical work of our time. And this gives the clue to the solution of our problem.

We may discuss first Gilbert's interest in mining and metallurgy. The literature on the subject is well known to him. George Agricola, the best known sixteenth century author in this field, is quoted most frequently. Gilbert esteems him highly but corrects errors uncritically taken over by Agricola from antiquity. Not less than three chapters of *De Magnete* (I, 2, 7, and 8) give extensive accounts of the distribution of iron in the world, describe the various ores, and quote ancient, Arabian, and modern authors on the subject.¹⁶ Iron-manufacturing also is discussed at length (I, 7). Gilbert reports (p. 23) on the manufacturing of cast iron, wrought iron, and steel in Styria and Spain, he refers to the description of iron-foundries in Porta's *Magia Naturalis*, and gives (p. 24) a list, eleven lines long, of iron devices. It contains among other things various kinds of guns, "the plague of mankind," and ends with a hint at other "numerous devices unknown to Latins." His reports on England are most interesting, as they are obviously based on

¹⁶ The books of Agricola (1490-1555) on mining and metallurgy are still the best source of knowledge on this branch of technology in the 16th century. Gilbert (I, 1 p. 2) calls him "most outstanding in science," but regrets that he took over the ancient stories of antimagnetic effects of garlic and diamond. He rejects (I, 38 p. 110) Agricola's statement that the magnet is useful in glass-manufacturing and reproaches Agricola for being influenced on this point by the "ignorant philosophy" of Pliny the Elder. Of course Gilbert knows that glass is not attracted by magnets. He approves (I, 7 p. 19) Agricola's chemical opinion that iron is composed of earth and water. Agricola and other—unnamed—"learned metallurgists" are referred to (I, 2 p. 10) on occurrences of iron-ore in Germany and Bohemia. On a special kind of iron-ore the opponent to Paracelsus, Thomas Erastus, is given as literary informant (I, 7 p. 23). *De Magnete* I, 8 quotes Strabo, Ptolemy, Tacitus, and Pliny on iron-mines in various parts of Europe and emphasizes that iron is the most frequently occurring mineral, as "every expert on metallurgy and chemistry" can confirm. Again Agricola is given as a reference for the occurrence and working of meadow-ore (p. 26). "As some authors write," (obviously Spanish cosmographers or mariners), there is iron in the West Indies too, "but Spaniards are looking for gold only." The chapter ends with a report on iron meteorites and quotes on that subject Avicenna, Scaliger, and Cardanus.

personal experience. He tells (I, 2 p. 11) that "newly" in an English mine, owned by the gentleman Adrian Gilbert, magnetic iron ore was found.¹⁷ He reports (I, 7 p. 23) on the handling of iron in English gun foundries. And he knows (I, 8 p. 26) that English clay always contains iron and that, if bricks are baked in open kilns, "which are called *clampa* with us," the bricks next to the fire show "ferruginous vitrification."

Gilbert is also familiar with forging. In a chapter dealing with magnetic experiments (I, 11 p. 29) he describes how he himself manufactures the wrought iron he needs for his experiments, and adds: "out of that the hammersmiths (*fabri*) form quadrangular pieces but mostly ingots (*bacillas*) which are bought by merchants and blacksmiths (*ferrarii*) and out of which various devices are manufactured in the workshops (*officinis*)."

In a chapter (III, 12) which explains how iron is magnetized by the magnetic field of the earth he even gives a large woodcut of a smithy with furnace, bellows, anvil, and tools.

That very woodcut, which would be impossible in a modern textbook on magnetism, illustrates the intimate connection of Gilbert's theoretical investigation with practical metallurgy. Moreover, we must not forget that Gilbert did not live in the period of tradition-bound medieval handicraft. The mining and metallurgy he is interested in is the mining and metallurgy of rapidly advancing early capitalism. As we know from Agricola, hauling engines, stamping mills, ventilators, and tracks for the dogs came into use in mining during the sixteenth century. In the same period the introduction of the blast furnace revolutionized the whole technique of iron manufacture. English mining and English metallurgy participated in that development.¹⁸ Since the miners and foundrymen of the period belonged to the lower ranks of society and were uneducated we know neither their names nor their ideas. Yet we cannot doubt that many of them, stimulated to improvements by economic competition, were wont to try new techniques and to observe natural processes. Technology could not have progressed so rapidly if the laborers in the manner of the medieval guilds had simply

¹⁷ The owner was no relation of the author. Cf. the family-tree in Silvanus B. Thompson: *The Family and Arms of Gilbert of Colchester*, Trans. Essex Archaeol. Soc., vol. 9, new series (1906) p. 211.

¹⁸ Cf. Ludwig Beck: *Geschichte des Eisens*, Braunschweig 1893-95, vol. 2, pp. 879-97.

clung to the traditional working-processes of the past. Obviously, among such manual laborers there were experimentalists, though experimentalists with practical aims only and without theoretical knowledge. With their ranks Gilbert must have had many contacts. By a lucky accident we are even able to prove that he must have himself descended into an iron mine. Once (III, 2 p. 119 f.) he tells how he verified the hypothesis that the direction of magnetism in magnetic iron ore is induced by the earth. He says:

We had a twenty pounds' heavy loadstone dug and hauled out after having first observed and marked its ends in its vein. Then we put the stone in a wooden tub on water, so that it could turn freely. Immediately the surface which had looked to the North in the mine turned itself to the North on the water.

It is almost symbolic that Gilbert performed a laboratory experiment just after having left a pit and talked to miners. Of course Gilbert's experiments were not plain copies of the trials of the miners and foundrymen. But his spirit of observing and experimenting was taken over not from scholars but from manual workers. Sometimes, however, even his experiments simply repeated the working processes of contemporary iron manufacture. In three chapters of *De Magnete* (I, 9-11) he describes magnetic experiments with iron ore and wrought iron: he makes pieces of ore and iron float on water, he suspends them by threads, and has them attracted by magnets; but first he heats the ore for hours in a furnace and melts it; then he hammers the product, puts it into a second furnace and so on. All this is described, not as a mere preparation, but as a part of the experiments themselves. At least a part of his laboratory must have looked like a smithy.

6. Navigation and nautical instruments play an even greater part in *De Magnete* than mining and metallurgy. About 32 pages (13%) of the book are dedicated to nautical instruments, about 28 (12%) to general navigation. Already at the very beginning of *De Magnete*, in Wright's preface, geographic discoveries and circumnavigations of the globe are mentioned. In his survey of previous writers on magnetism (I, 1 p. 4) Gilbert reports (erroneously) the history of the invention of the compass and remarks that "no invention of human arts has ever been of greater use to mankind." He mentions Sebastian Cabot as the discoverer of magnetic declination and gives (p. 7) the names of four men "who

have observed the variety of magnetic declination on long voyages": Thomas Hariot, Robert Hues, Edward Wright, and Abraham Kendall.¹⁹ Gilbert proves to be familiar with mariners also in a chapter on the terrestrial globe. There (I, 17 p. 39) he gives numerical statements on the depth of the ocean according to the soundings of the mariners. He must have been told of their results by personal friends.²⁰

The full extent of his nautical knowledge appears in the fourth book of *De Magnete* which deals with magnetic declination. Gilbert knows (IV, 1 p. 152) that declination differs at different places and gives its amount for places dispersed over all oceans and continents.²¹ The remarkably wide range of his statements proves his familiarity with the reports of the English, Spanish, Portuguese, and Dutch navigators and the books of the learned cosmographers of the period. Moreover he mentions (IV, 5 and 10) that declination is great in high latitudes and that it is not influenced by the iron mines of the island of Elba in the Mediterranean. He knows

¹⁹ Since Gilbert's authorities on navigation are characteristic of the social soil from which modern natural science has sprung, their activities and occupations are important. The mathematician and astronomer Hariot or Harriot (1560–1621) who was mathematical tutor to Sir Walter Raleigh as a young man, was sent by him as a surveyor to Virginia, and came back to England later. He published a report on Virginia, and mathematical works. The mathematician Robert Hues (1553–1632) accompanied Thomas Cavendish on his circumnavigation of the globe and published a *Tractatus de Globis et eorum Usu*, London 1594, dedicated to Sir Walter Raleigh. The mathematician Edward Wright (1558–1615) accompanied the Earl of Cumberland on his voyage to the Azores. He was lecturer on navigation to the East India Company. In his book *Certain Errors in Navigation*, London 1599, he introduced the cartographic projection that usually is ascribed to Mercator. Abraham Kendal or Kendall is the only non-scholar among the four men. He was sailing-master of Sir Robert Dudley's ship the Bear and later joined Drake's last expedition (cf. *The Oxford Dictionary of National Biography* and the Chiswick Press translation of *De Magnete*, London 1900, notes p. 19). Wright wrote the second preface to *De Magnete*. Most probably the three other men also were personal friends of Gilbert (cf. footnote 22 below).

²⁰ He states that the depth of the ocean reaches one mile at a few places only and generally is no more than 50 to 100 fathoms. As the greatest depth of mines he gives 400 to 500 fathoms, as the diameter of the earth 6,872 miles.

²¹ P. 153f. East coast of the Atlantic from Guinea to Norway, West coast from Florida to Cape Race in New Foundland; p. 161 Azores; p. 163f. London; p. 167 North Cape in Norway, Corvo in the Azores, Plymouth; p. 178f. on the equator and in the South Atlantic (St. Helena); pp. 179–182 Nova Zembla (from Dutch observations), South Pacific, Mediterranean, Indian Ocean.

(IV, 8 p. 165 f.) that the Portuguese royal cosmographer Pedro Nuñez (*Tratado da Sphera*, Lisboa, 1537) disregards declination entirely and that the Spanish historian Pedro de Medina (*Arte de Navegar*, Valladolid 1545) is wrong on it. He complains of the inexactness of most mariners in determining declination and warns especially of the reports of Portuguese navigators on their voyages to the East Indies. He knows that the Portuguese mariner Roderigos de Lagos, the Spanish mariner Diego de Alfonso, the Dutchmen, and "the experienced Englishman" Abraham Kendall contradict each other in their numerical statements (IV, 13 p. 177 f).²² Since determination of geographic longitude was a difficult and, consequently, an often discussed problem at that period, he tries to solve it by means of the declination of the magnetic needle. He mentions (IV, 9 p. 167) that the learned compiler of curiosities Giambattista Porta (*Magia Naturalis*, 1589), the Venetian geographer Livio Sanuto (*Geografia*, 1588) and the mathematician Giambattista Benedetto give wrong solutions of the problem, since declination does not vary proportionally with the distance on the surface of the earth, as had been assumed by them. In the end he quotes the correct solution of Simon Stevin, the eminent Dutch expert in military engineering, navigation and book-keeping.²³

Gilbert is familiar with the astronomical aids to navigation too. He knows how geographic latitude is determined astronomically, even takes into account atmospheric refraction, and gives a long list of bright stars with their declinations and right ascensions for the practical use of navigators (IV, 12 p. 174f.).

Gilbert got his nautical knowledge not from reading only. Again, as with the miners, an occasional mention in *De Magnete*

²² The sailing-master Kendall (cf. footnote 19) did not publish any book. Since Gilbert is familiar with his experiences, he must have known him personally.

²³ The (antiquated) solution is: the declinations at the various places of the surface of the earth have to be listed at first and then the geographic position of the ship can be determined by comparing observed declination with the list. Stevin's paper (*De Havenvinding*, Leyden 1599) is reprinted in G. Hellmann, *Rara Magnetica*, Berlin 1899. Gilbert does not quote the original paper but its Latin translation by Hugo Grotius (the elder) *Portuum Investigandorum Ratio*, 1599. It was in the same year translated as well into English by Gilbert's friend, Edward Wright (*The Havenfinding Art*, London 1599) and into French (*Le trouve Port*, Leyden 1599). The four publications in one year, three vernacular, one Latin, illustrate rather well the rapid development in scientific navigation at this period and the kind of people Gilbert was in touch with. He quotes Stevin just one year after his paper had appeared. In this period this is remarkable.

reveals the personal contacts of the author. Once (III, 1 p. 117f.) Gilbert explains that the compass works under all latitudes from the equator up to the 70th and 80th degree N.L., and adds: "This the most famous captains and also very many of the more intelligent sailors confirm to us. This our most famous Neptunus Francis Drake, and the other circumnavigator of the globe, Thomas Cavendish, have told and confirmed to me." Obviously he is proud of the friendship of the two great circumnavigators who by their naval victories over the Spaniards—and by their successful privateering—had access to the court of Queen Elizabeth. Cavendish was a gentleman by birth, Sir Francis Drake was knighted because of his naval success: the names of the ordinary master mariners and helmsmen Gilbert had contact with are not given by him.²⁴

At the end of the passage just quoted (III, 1 p. 118) Gilbert states that the compass works badly only when the needle has rusted or when the point on which it turns has got blunt. This leads us to his interest in nautical instruments. The measuring instruments described at length in *De Magnete* have already been discussed, and it has been mentioned that they are less new than the reader of Gilbert's description would assume.²⁵ After the publication of *De Magnete* Gilbert was still engaged in improving his instruments and making propaganda for them. One year before Gilbert's death a certain M. Blundeville published a booklet *Theorique of the Seven Planets*, London, 1602. It is written in English and contains as an appendix "the making description and use of two most ingenious and necessarie Instruments for Seamen. . . . First invented by my good friend, Master Doctor Gilbert. . . ." Obviously Gilbert had suggested the publication in English. The two instruments are the nomogram of *De Magnete*, which is supposed to make possible the determination of geographic latitude, and a somewhat more simplified inclinometer than the one in *De Magnete*.²⁶ As this improvement shows, Gilbert does not

²⁴ Gilbert himself in the quotation just given distinguishes "illustrissimi naucleri" and "nautae etiam sagaciores plurimi" among his authorities. The sailing master Abraham Kendall (*cf.* footnotes 19 and 22) was personally acquainted with him. Edward Wright was his friend and so probably were Thomas Harriot and Robert Hues (*cf.* footnote 19). These three men, however, were academically trained mathematicians who had intimate relations with navigators and navigation.

²⁵ § 1, footnote 2.

²⁶ Blundeville is one more of the friends of Gilbert. He wrote popular scientific books in English for gentlemen. Besides the quoted work he published treatises on

deal with instruments as a mere theorist, but is familiar with the practical demands master-mariners make. He realizes (*De Magnete* IV, 12 p. 172) that in navigation simply built instruments are necessary which can be handled in spite of the rolling of the ship, and he invents and draws nomograms because he feels complicated calculations and "the exercises of mathematical genius" to be out of place on shipboard. On the method of preparing, magnetizing, and balancing the needle of the compass he gives a few practical hints (III, 17 p. 147 f.). He discusses at length (IV, 8 p. 165 f.) the various types of compasses that are used by the sailors of the various European nations. This chapter, however, is based on statements of Robert Norman without mentioning his name.

7. Norman's influence on Gilbert's investigation is so important that it must be discussed in greater detail. Gilbert himself does not emphasize it at all, but rather hides it. In the first chapter, after mentioning Wright and his friends, Gilbert goes on (p. 7 f.): "Others invented and made public magnetic instruments and expedient methods of observation, necessary to navigators and long-distance travellers, *e.g.*, William Borough in his booklet on the Declination of the Compass, William Barlow in his Supplement,²⁷ and Robert Norman in his New Attractive." He adds that Norman, "an expert mariner and ingenious artificer," discovered the dip of the needle. A second time also Norman is quoted with approval. There (IV, 6, p. 161f.) Gilbert explains that the adjusting of the magnetic needle with the meridian is not effected by attraction but by some "disposing and turning faculty" of the earth, and adds that this was stressed by Norman as the first.

horsemanship, on Aristotelian logic, on map-making, on morals, and on counsellors of princes. The sub-title of his *Theorique of the seven Planets* illustrates rather well which social ranks outside the universities were interested in astronomy at Gilbert's time. It reads: *A Booke most necessarie for all Gentlemen that are desirous to be skillful in Astronomie and for all Pilots and Sea-men or any others that love to serve the Prince on the Sea or by the Sea to travell into forraine Countries*. This means that astronomical papers—if they were written in English—were of interest to over-sea-traders and ship-owners, their master-mariners and helmsmen, and the gentlemen in the Royal Navy. Blundeville's booklet is based not only on Ptolemy but also on the ephemerides of Peurbach, Copernicus, and his followers Reinhold and Mestlin.

²⁷ Barlow was the son of a bishop and himself a clergyman, and was interested in navigation, though he had never gone to sea. He published among other papers *The Navigators Supply*, London, 1597. He was a personal friend of Gilbert. Cf. Gilbert's letter to him, published in Barlow, *A Brief Discovery of the Idle Animadversions of Mark Ridle*, London, 1618.

Then he describes at length and illustrates by a woodcut an experiment which is supposed to prove the explanation given.²⁸ The experiment in every detail (and its incorrect interpretation) is borrowed from Norman's book. Twice more (I, 1 p. 5 and IV, 1 p. 153) Norman is mentioned in three words as the author who suggested the name "point respective" for the place that all magnetic needles point to, instead of "point attractive." Strangely enough, three of the four quotations refer to an opinion in which Norman is wrong. If we wish to learn what Gilbert actually owes to him, we have to examine Norman's treatise.²⁹

Norman was a retired mariner who had turned to compass-making. That can be inferred from his booklet, which is the only source available on his life. The booklet itself begins with a few mineralogical remarks on magnetic iron ore, and reproduces a story of Paracelsus on loadstones which can be strengthened to such a degree by making them red-hot so that they can draw nails out of a wall. It is the same story which incites Gilbert to abuse Paracelsus as a shameless charlatan (*De Magnete*, p. 93). Norman, however, believes it. It is more important that Norman's very first chapter describes experiments in which magnets are suspended by threads and made to float on water.^{29a} The second chapter discusses earth-magnetism. Norman does not believe that it can be explained by loadstones at the North Pole of the earth, because he knows that the iron mines at Elba do not deflect the magnetic needle—a statement simply taken over by Gilbert. Then Norman discusses (chap. 3) the dip of the magnetic needle "not

²⁸ He makes a magnetic needle float in water by means of a piece of cork and carefully sees to it that it is completely submerged; from the fact that the needle adjusts itself with the direction of earth-magnetism but is not drawn to the rim of the vessel he concludes that there is no attraction. He (and Norman) forget that the needle has two opposite poles which are drawn to opposite directions.

²⁹ *The Newe Attractive, Containing a short discourse of the Magnes or Lodestone and amongst other his vertues, of a newe discovered secret and subtil propertie concerning the Declinyng of the Needle touched therewith under the plaine of the Horizon. Now first founde by Robert Norman Hydrographer. Hereunto are annexed certaine necessarie rules for the art of Navigation by the same R.N.*, London, 1581. The book, reprinted in 1585, 1592, 1596, 1614, and 1720, has become a bibliographical rarity. G. Hellmann, *Rara Magnetica*, Berlin 1898 gives a reprint of the 1720 edition. The preface, the introductory poems, and the astronomical tables are not reproduced by him. We quote from the extremely rare second edition, London, 1592.

^{29a} Norman did this by means of small pieces of cork. It is to be remembered that these new experimental devices were simply taken over by Gilbert in *De Magnete*.

before having heard nor read of any such matter," and describes (chap. 4) and illustrates by a wood-cut the very first inclinometer.³⁰ The descriptions of two outstanding and most carefully performed experiments follow, both taken over by Gilbert. The first (chap. 5) proves by means of a gold balance that magnetism is imponderable; this is experimentally and theoretically entirely correct. The second (chap. 6) has been mentioned above (footnote 28); it is meant to prove that the earth does not attract but only turns the magnetic needle. It is illustrated by a woodcut, is even more carefully performed than in Gilbert—Norman stresses that any current of air must be avoided—but its theoretical interpretation is wrong, just as it is with Gilbert. The same chapter (6) introduces the term "point respective" which we have already mentioned.

The rest of the book does not contain experiments. Norman discusses (chap. 7) how the "point respective" might be determined by comparing magnetic needles at different places on the earth. As a simple mariner and instrument-maker he is unable, so he confesses (chap. 8), to explain the cause of terrestrial magnetism. "I will not offer," he says modestly, "to dispute with the Logitians in so many pointes as here they might seeme to overreach me in Naturall causes." So he restricts himself to a reference to "God in his omnipotent providence." He discusses (chap. 9) magnetic declination and its diversity at different places, stressing—again we remember Gilbert—that there is no "equal proportion" in it, as some navigators had believed who, "notwithstanding their travells mostley have *more followed their Bookes than experience* in this matter." He himself refers to the "18 or 20 years that I have travelled the Seas." He complains that most mariners have but confused ideas on declination because of lack of suitable instruments: "wherefore I have devised one very necessarie." The last chapter (10) discusses the different types of compasses in various countries and is the source of the corresponding chapter in

³⁰ As a matter of fact the dip had been observed before, though less exactly, by the German physician Georg Hartmann. Hartmann's unpublished letter (1544) to Duke Albert of Prussia on his discovery, is reprinted by Hellmann, *loc. cit.* By Norman the dip always is called "declination," whereas magnetic declination is called "variation." This terminology also was taken over by Gilbert. Gilbert's inclinometer is a mere copy of Norman's instrument, but Norman proves to be the more experienced instrument-maker. *E.g.* he makes the bearings of the needle's axle of glass. Gilbert neglects that excellent detail.

De Magnete (IV, 8). It follows a second part containing astronomical tables for the use of navigators.

We have already become acquainted with the empirical temper of this simple instrument-maker who, no less than Gilbert, Francis Bacon, and Galileo, prefers observation to books. His intellectual attitude is expressed even more clearly in the remarkable preface to the book. It is addressed "to the Right Worshipfull, M. William Borough, Esquire, Comptroller of her Maiesties Navie." It starts with the anecdote of Archimedes who, while taking a bath, discovers the law of buoyancy, runs naked to the street, and shouts—Norman avoids Greek—"I have found it." Norman continues:

So I (although in other respects and points of learning and knowledge, I will not presume to compare with Archimedes . . . nor with other learned Mathematicians, being myself an unlearned Mathematician) by occasion of my profession, making sundry experiments of the Magnet stone, found at length amongst many other effects this strange and newe propertie of Declining of the Needle: which forgetting or rather neglecting my own nakedness and want of furniture, to set forth the matter, I have heere in simple sorte proposed . . . to the view of the world.

Again he cites an ancient anecdote, the story of Pythagoras and the hecatomb he offered after having discovered his theorem, and continues:

So that we see these men . . . being carried and overcome *with the incredible delight* conceived of their own devices and inventions, though, they follow partly the peculiar contentation of their privat fancies, yet they seme chiefly to respect either the glory of god or the furtherance of some publike commoditie. . . . And seing it hath pleased God to make mee the instrument to open this noble secret, that his name might be glorified, and the commoditie of my Country procured thereby, I thought it my dutie to aduenture my credite and make my name the object of slaunderous and carping tongues rather then such a secrete should be concealed and the use thereof unknown.

Continuing, Norman stresses the utility of navigation to his country and again explains his resolution to publish his discovery "to frame as it were a theorike" for the use of mariners, and to describe "whatever I could find by exact triall and perfect experiments."

Wherin, although I may seeme to have discovered my nakedness and want of eloquence and orderly Methode to utter my conceits withall, I trust the reader will either of his curtesie take all things for good, that is well ment, or of his grautie, *not regarding the words but the matter*, dissemble my faults, and accept of my paines.

He mentions that he has communicated his findings before publication to a few learned friends and concludes with respectful words to William Borough as "your worships most humble Robert Norman." In his short preface to the reader he emphasizes also that he will "ground his arguments onely upon experience, reason and demonstrations." "Many and divers ancient Authors, Philosophers and other" have written on the magnet, but he intends to write "contrary to the opinions of all them." This remarkable man who, twenty-five years before Galileo's first publication, speaks of the "incredible delight" of experimental discovery, was a craftsman. At the end of the first edition of his booklet a kind of advertisement was printed, stating that the instruments described "are made by Robert Norman and may be had at his home in Ratclif."³¹ When the seamen of the sixteenth century went to sea, they laid the foundation-stone of the British Empire and when they retired and made compasses, of modern experimental science.

The note just quoted refers to Norman's own inclinometer and to two declinometers constructed by the mariner William Borough and described in Borough's *Discourse of the Variation of the Compass or Magneticall Needle*, that in all editions was annexed to Norman's booklet. Borough is mentioned in *De Magnete* (I, 1 p. 7) together with Norman as an inventor of magnetic instruments.³²

Robert Norman is of great importance for our problem. Except for the Latin erudition, the quotations and polemics, and the metaphysical philosophy of nature, he has everything that is pecu-

³¹ Quoted from Hellmann *loc. cit.* The note is omitted in the later editions, presumably because Robert Norman had died.

³² He was born in 1536, travelled to the White Sea, became Comptroller of the Queens Navy in 1583, and was commander of an English ship in the Armada battle of 1588. Socially he belongs to a higher rank of mariners than Norman and is superior to him in education. In the preface to his *Discourse* he urgently recommends mathematics to the seamen, emphasizing that there are sufficient books on that subject written in English. He mentions "Vitriuius" (*sic*), Albert Duerer, and the ship builder Mathew Baker, as outstanding representatives of the "mechanicall sciences" to which also navigation belongs. He praises the good maps of Abraham Ortelius and criticizes the bad ones of the Paris professor Postillus. Ortelius (1527-98), the most famous map-maker of the period, came from handicraft, but became geographer to Philip II of Spain. Guillaume Postel (1505-81) is a learned polyhistor. The navigator Borough with his relations to superior handicraft on the one hand, to practical astronomy, cartography, and a bit of mathematics on the other, illustrates rather well the soil out of which Gilbert's work has grown.

liar to Gilbert. Norman as well as Gilbert proceeds by experiment and, "not regarding the words but the matter," bases his statements on experience rather than on books. Moreover, the measuring-instruments and the details of the experimental technique, the most exact experiments, and many single empirical statements of *De Magnete* are already contained in his booklet. It is true that the compass-maker Norman is a craftsman and Gilbert a scholar; but Norman already feels "incredible delight" at his discoveries and is interested in knowledge for its own sake: neither his experiment on the ponderability of magnetism nor his dilemma concerning "point respective" or "point attractive" has any practical bearing. In things that are farther away from his occupation he is a little less critical than his follower of higher birth: he modestly believes in the story of Paracelsus which is vehemently criticized by Gilbert. On the other hand he is more religious than Gilbert: where Gilbert takes to Neoplatonic theories of universal animation, he retreats to God's impenetrable providence and avoids further explanation. Socially this is the difference between the highly educated scholar of the late Renaissance and the retired mariner. As to scientific value, however, Norman's attitude does not compare at all unfavorably with Gilbert's. Far reaching theories are lacking in his book; but is Gilbert's metaphysics of "distinguished spherical form" that brings about magnetism a useful scientific explanation? The modern scientist may miss it in Norman's paper as little as he does Gilbert's quarrelsome polemics and erudite quotations. By the absence of all these Renaissance paraphernalia the experimenting compass-maker is even nearer than Gilbert to the sober objectivity of modern natural science. Or, if we may put it the other way round: modern science and the modern mind in general are nearer to the experimenting manual workers of early capitalism, in which they had their origin, than to Renaissance humanism, which still influences even Gilbert.

III

8. The last paragraphs have answered our main question. Gilbert's experimental method and his independent attitude towards authorities were derived, not from ancient and contemporary learned literature, but on the one hand from the miners and foundrymen, on the other from the navigators and instrument-makers of the period. Alchemistic experiments probably never

were performed by Gilbert, for he always vehemently attacked the alchemists and derided their attempts to make gold.³³ A rather complete assortment of the sources of his scientific achievements has been given by himself in his discussion of the practical use of the magnetic needle. There (III, 17 p. 147) he explains that by means of the needle the content of iron can be diagnosed in ores. The needle is the main part in the compass, which is, as it were, "the finger of God," and has made possible the Spanish and English circumnavigations of the globe. By means of the magnetic needle veins of iron ore can be discovered, subterranean galleries can be driven in sieges, guns can be pointed at night, territories can be surveyed, and subterranean water-conduits can be constructed.³⁴

Altogether, the impression of Gilbert's originality is considerably impaired, when he is confronted with his sources and especially with Norman. In spite of that, Norman is virtually unknown today, whereas Gilbert is counted among the pioneers of natural science. But this proves to be less unjust when the rise of science is viewed as a sociological process. Unfortunately we can only give a sketchy and simplified exposition of that view here and, of necessity, must omit a part of the evidence bearing on the point.³⁵

³³ He reproaches them (pref. fol. iij) with "veiling things in darkness and obscurity by means of silly words." They are called (I, 3 p. 19) "cruel masters of metals who torture and harass them by many inventions." They are "delirious" (p. 20) and their doctrine that metals can be changed into gold is "futile" (p. 24).

³⁴ The considerable part played by military engineering in this enumeration might be striking. We have already met with gun-making in Gilbert's discussion of metallurgy (I, 7 pp. 23f.), have been forced to mention naval warfare and privateering several times, and should meet with military engineering even more frequently if we discussed the investigations of Leonardo da Vinci, Tartaglia, Duerer, and Galileo. Military technology has contributed considerably to the rise of the experimental spirit and natural science. Its influence on Gilbert is comparatively rather slight.

³⁵ On the following cf.: Leonard Olschki, *Geschichte der neu sprachlichen wissenschaftlichen Literatur* (vol. 1: *Die Literatur der Technik und der angewandten Wissenschaften vom Mittelalter bis zur Renaissance*, Heidelberg 1918; vol. 2: *Bildung und Wissenschaft im Zeitalter der Renaissance in Italien*, Leipzig-Roma-Firenze-Geneva 1922; vol. 3: *Galilei und seine Zeit*, Halle 1927). All these volumes abound in valuable information on the scholar-literature and the craftsman-literature of the period and contain many sociological aspects. The third volume contains statements, until now scarcely used, on the influence of contemporary technology on Galileo (on the relations of the artists to handicraft, mechanics, military engineering and mathematics cf. I, 30-447; on mathematics and mechanics III, 72-110; on Galileo III, 117-469). On a later period cf. Robert K. Merton: *Science and Tech-*

From antiquity until about 1600 a sharp dividing-line existed between liberal and mechanical arts, *i.e.*, in the final analysis, between arts needing heads and tongues only and others needing the use of hands also. The former were considered as worthy of well-bred men, the latter were left to lower-class people. Thus the contempt for manual labor tended to exclude experiment (and dissection) from respectable science. The prejudice against manual labor, however, did not prevent the experiments of the alchemists. Alchemy is not an occupation as carpentering, or forging; it is made respectable by the charm of both magic and gold, and even well-bred people may practise it as a hobby. But no respectable scholar who was proud of his position as a representative of the liberal arts even thought of using the methods of the mechanical arts. The case of those craftsmen who aspired to a higher social level is different; they—*e.g.* the Italian artists of the fifteenth century—discussed the social qualifications of manual work again and again, and stressed that they were connected with mathematics, *i.e.* with science.

The social background and the professional conditions of the scholars of the fifteenth and sixteenth centuries can not be discussed here. Nearly all of them had academic degrees and were consequently more or less linked to the universities, or they were humanists. Though several humanists had obtained academic chairs, generally speaking the universities of the period were still dominated by the spirit of Scholasticism. Both the university-scholars and the humanistic literati were accustomed to deal with natural phenomena chiefly in so far as they had been treated before by the authorities of Scholasticism and humanism respectively. On the other hand, since the decay of the guilds and their traditionalism real observation of natural phenomena, and even some experimentation, were to be found among skilled manual workers. Very little, however, is known of their intellectual interests.

nology in the 17th Century, *Osiris* vol. 4 (1938) pp. 360–630. On the prejudice against manual labor and its intellectual implications *cf.* Edgar Zilsel: *Die Entstehung des Geniebegriffes*, Tuebingen 1926 (pp. 112–130 the humanistic literati, 130–143 the inventors and discoverers, 143–154 the artists and artist-engineers, 310–15 two strata of intellectual activities). On the effects of the prejudice against manual labor on astronomy *cf.* Edgar Zilsel: *Copernicus and Mechanics*, in *Journal of the History of Ideas* vol. I (1940) pp. 113–118. On the effects on anatomy *cf.* Benjamin Farrington: *Vesalio and the Ruin of Ancient Medicine*, in *Modern Quarterly*, London, vol. 1 (1938) pp. 23 ff.

Since they got no education but the practical one in the workshops of their masters, their observations and experiments must have proceeded rather unmethodically.

With the advancement of early capitalistic society two major intellectual developments occurred: on the one hand, by virtue of technological inventions, geographical discoveries, and economic changes, the contrast between present times and the past became so obvious, that in the second half of the sixteenth century rebellion against both Scholasticism and humanism began among the scholars themselves. Representatives of the learned upper ranks, such as Telesio, Patrizzi, Bruno, and Campanella, vehemently attacked Aristotle and the belief in "words," felt enthusiastic about nature and physical experience, but did not experiment. Merely speculative metaphysics was, as it were, the older brother rather than the father of modern experimental science (*cf.* above § 4).

On the other hand, among the ranks of manual laborers a few groups of superior craftsmen formed connections with respectable scholars. During the fifteenth century Italian painters, sculptors and architects had slowly separated from whitewashers, stone-dressers and masons. As the division of labor was still only slightly developed, the same artist usually worked in several fields of art, and often in engineering too. The technical problems of their occupations led them more and more to experimentation. Many of them made contacts with humanistic literati, were told of Vitruvius, Euclid, and Archimedes, and a few of them, such as Brunelleschi (1377-1446), Ghiberti, Leone Battista Alberti, Leonardo da Vinci, Benvenuto Cellini (1500-1571), started writing diaries and papers on their achievements. Biringuccio's treatise on metallurgy, *Della Pirotechnia* (1540), Duerer's two treatises on descriptive geometry and fortification, of 1525 and 1527, in some respect even the papers of Stevin, belong to this literature of the artist-engineers. Another group of superior manual workers were the surgeons, who practised dissection and made contacts on the one hand with artists interested in anatomy, and on the other with medical doctors. Others were the navigators, who formed connections with mathematicians, astronomers, and cosmographers and published treatises on navigation; and, finally, the makers of nautical and of musical instruments. These superior craftsmen were the predecessors of modern experimental science,

though they were not regarded as respectable scientists by contemporary public opinion. So far as papers were composed by them, they were written in the vernacular, not in Latin, and were not read by most of the respectable scholars, even if they were printed. By their colleagues, however, the books, especially those on navigation, were diligently read, as is proved by the five editions of Norman's and Borough's treatises between 1581 and 1614. One has only to recall the humble apologies in Norman's preface to realize the barrier between craftsmen-literature and scholar-literature at the end of the sixteenth century. Experimental science could not have come into existence before this barrier was demolished.

But a few learned authors, very few, comparatively, already showed an understanding of mechanical arts before 1600. The German physician George Agricola published Latin treatises on mining and metallurgy (1544 and 1556); the chaplain at the royal court of Madrid, Peter Martyr, wrote two Latin books on the great geographical discoveries of the period (1511 and 1530); the learned secretary of the Senate of Venice, Ramusio, did the same in Italian (1550); a few Portuguese and Spanish cosmographers, such as Nuñez and Pedro de Medina, wrote mostly vernacular books on navigation. But especially in England, and in the period of Gilbert, similar studies increased. The Oxford B.A. Richard Hakluyt (1552-1616) edited Peter Martyr and published his own widely read books on the great English voyages and discoveries; the prebendary of Winchester, William Barlowe, wrote an English treatise on navigation (1597). The East India Company engaged the Cambridge graduate William Wright as a lecturer on navigation to their master-mariners. Wright and two more mathematicians, the Oxford graduates Thomas Harriot and Robert Hues, published Latin and English books in the same field (1588, 1594, 1599).

All these half-technical, half-learned activities show that some branches of the mechanical arts had become so important economically that they began to engage and to interest a few scholars. But they dealt with metallurgy and mostly with navigation rather than with experiments. The first academically trained scholar who dared to adopt the experimental method from the superior craftsmen and to communicate the results in a book not to helmsmen and mechanics but to the learned public was William Gilbert,

who was a personal friend of most of these English authors. This is Gilbert's achievement in history. It might have been as difficult for the physician in ordinary to Queen Elizabeth to overcome the prejudice against manual labor as it was for the craftsman Norman to raise and answer his theoretical problems—though the two achievements are of a rather different kind. By his understanding of the scientific importance of experiment Gilbert made it—or helped to make it—respectable among the ranks of the educated. A few years later two other scholars likewise followed the method of the superior craftsmen: Francis Bacon, who ranked the great inventors and navigators above the scholars of his period, and Galileo, who started from military engineering.³⁶

But we must deal with an objection. Is it true that experimental science could not come into existence so long as liberal and mechanical arts were kept separate by the contempt for manual labor? The fact that Pierre de Maricourt had already performed experiments does not seem to fit in with our exposition. Yet it is significant that Pierre tries to come to terms with the prejudice against manual work. In chapter 2 of his treatise he emphasizes that the investigator of magnetic phenomena must not only know “the nature of things” and celestial motions, but that he must also be “industrious in manual work” (*industriosum in opere manuum*); only by “manual industry” will he be able to correct errors which by mere reason and mathematics cannot be avoided. Obviously Pierre can not stress the value of experimentation without immediately speaking of and defending manual labor.

Pierre, no doubt, was the best experimentalist of the Middle

³⁶ Galileo had already experimented a few years before *De Magnete* appeared. He became acquainted with Gilbert's book rather soon. We have a letter from Gilbert to William Barlowe, telling that Gilbert met with the Venetian ambassador who brought him a Latin letter of Joannes Franciscus Sagredus. Gilbert continues: “Sagredo is a great Magnetical man and writeth that he has conferred with . . . the Readers of Padua and reported wonderful liking of my booke” (Barlowe, *Magneticall Advertisement*, London 1616). The letter must have been written between 1600 and 1603. Sagredo was a friend of Galileo and later figures as one of the persons of the discourse in Galileo's great dialogues. No doubt, Galileo himself, who was then lecturer on mathematics at the University of Padua, is the “Reader of Padua.” Thirty years later, Galileo praises Gilbert highly because of his new and true observations and his habit of examining all statements of authorities by his own experiments. The only thing he misses in him is a little more mathematical knowledge (*Discorsi, Opere*, Edizione nazionale, VII, 432).

Ages.³⁷ He probably was not a monk but a nobleman and might have been in the Orient as a pilgrim or crusader as his surname *Peregrinus* suggests. In 1269 he took part in the siege of Lucera in Apulia, probably as a kind of military engineer. Most probably he is identical with the *magister Petrus*, the *dominus experimentorum*, often mentioned in Roger Bacon. If this assumption is correct, we know a little of his scientific and social attitude. This Petrus was, as Roger Bacon puts it, keen for the experiences even of "laymen, old women, and country bumpkins"; he was interested in metal founding, the working of gold and silver, mining, arms and military engineering, the chase, surveying, earthworks, the devices of magicians, and the tricks of jugglers.³⁸ In short, he was interested in all branches of technology that his period had developed and was hampered in his interest by the social prejudices of neither clergy nor nobility. It is significant that in the report of Bacon himself some social scruples still are hinted at ("country bumpkins, old women, jugglers"). Unfortunately we do not know where Petrus' freedom from bias originates. Altogether Pierre's attitude rather confirms than disproves the importance of manual labor and the mechanical arts for the history of science. The extremely rare medieval experimentalists would need an extensive and careful sociological investigation. We have, however, to return to Gilbert.

The social rise of the experimental method from the class of manual laborers to the ranks of university scholars in the early seventeenth century was a decisive event in the history of science. Natural science needs theory and mathematics as well as experiments and observations. Only theoretically educated men with rationally trained intellects were able to supply that other half of its method to science. With Gilbert, however, not much of the superiority of academic training as to the theoretical side of science can be noticed: his general speculations have not proved to be fruitful. It is different with Francis Bacon and Galileo. Bacon's far-reaching ideas on the advancement of learning and scientific coöperation could scarcely have been formed by craftsmen, though they were nothing but generalizations of their own practice. Galileo, on the other hand, joined mathematics with experiment.

Why did Gilbert himself never reckon, why did he come to a

³⁷ On the following, cf. the papers on Petrus Peregrinus quoted in footnote 14.

³⁸ *Roger Bacon, Opus tertium*, cap. 12, p. 46 (ed. Brewer).

standstill at the first beginnings of quantitative inquiry? Certainly that deficiency is connected with his subject matter. Magnetic and electric processes can be measured only by complicated methods and, in consequence, were first measured almost two hundred years after Gilbert by Coulomb. It is mechanics that was the birthplace of quantitative research, since mechanical processes can be measured comparatively easily. Therefore, authors dealing with mechanics, such as Stevin and Galileo—and centuries before them Archimedes—were the first mathematical physicists. Gilbert on the other hand, as we have seen, is remarkably little interested in mechanics. He almost appears to have been biased against it. In *De Mundo* (II, 10 p. 154) he criticizes mechanistic astronomers who think Ptolemy's spheres to be material. He objects to their hypothesis on the ground that by it the universe is made a great wheelwork and God a mechanic. In the eighteenth century a comparison like this scarcely could have served as an objection to a theory; on the contrary, similar comparisons were commonplaces in the period of mechanistic physics and deism.

Gilbert's pre-mechanical way of thinking and his predilection for a field where measurements are so difficult may be due to his individual characteristics. But they are connected also with the special conditions of his native country. Practically all quantitative investigations in *De Magnete* originate in nautical technique and the work of the compass-maker Norman; Gilbert's interest in iron-making and iron-foundries, on the other hand, does not result in any quantitative inquiry. It was English iron-making and English iron-manufacture, however, that were advancing fast in the late sixteenth century. Instructive inferences can be drawn from the rapid rise of iron-manufacture.³⁹ Blast-furnaces were introduced in England in the middle of the sixteenth century; the first English wire-mill was built in 1568; iron cannon, which had previously been imported from abroad, began to be exported from England in the same period; in 1581 and 1585 two laws were passed forbidding the construction of more blast-furnaces, in order to prevent devastation of the forests, since blast-furnaces were heated with wood. Certainly these laws show that iron-manufacture was not yet the leading industry of England; wool-trade and cloth-making still were much more important. Altogether, in the six-

³⁹ Ludwig Beck: *Geschichte des Eisens*, Braunschweig 1893-95, vol. II, pp. 892 and 896.

teenth century iron had not yet reached its dominant part in technology. It still was used in making weapons and simple tools rather than in machinery. And just this point leads us back again to our problem.

The first machines were made of wood and the first mechanical insights, therefore, were acquired from wooden devices—levers, reels, windlasses, inclined planes. There the Italian artist-engineers and Stevin made their studies and found quantitative relations and laws. Galileo, when experimenting on the law of falling bodies, made brass balls roll down an inclined wooden groove. Not before the eighteenth century did iron machines, and not before the nineteenth did metallurgy become subjects of calculation. In the preceding centuries, therefore, predilection for iron prevented rather than promoted application of mathematical methods. Thus England's natural, economic, and social conditions might form, not a sufficient, but a necessary condition for the characteristics of Gilbert's method. When reading *De Magnete* we must never forget that twelve years before its publication English ships and English iron guns annihilated the Spanish Armada, then the most powerful fleet in the world. England, the country of iron mines and advancing navigation, produced the first learned book on experimental physics. It dealt with the mariner's compass, magnets, and iron. And for that very reason it did not introduce mathematical methods into natural science.

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