**William Gilbert Founder Of Terrestrial Magnetism**

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William Gilbert of Colchester was born in 1544AD. As the founder of English experimental science, he is one of the great men of the scientific revolution. His most important single idea and enduring result was that the earth itself is a gigantic magnet. He was the eldest of five children born to a rising middle class family. Although nothing is known of his childhood, it seems clear that his interest for scientific knowledge must have been demonstrated at an early age. Aiming for a medical degree, he entered St. John's college Cambridge in 1558. Eleven years later he received his medical doctorate. It is believed that following his graduation, he attended universities on the continent. Nothing is known however until the mid 1570's when he set up a medical practice in London. His practice was extremely successful, and by 1581 he was one of the prominent physicians in London. In 1600 he was elected president of the Royal College of Physicians and appointed physician to Queen Elizabeth I. He died in 1603.

It is believed that William Gilbert spent seventeen years and £5000 pounds in the preparation of his masterpiece work on magnetism. The resulting publication of William Gilbert's treatise On The Loadstone and Magnetic Bodies and on the Great Magnet the Earth, herein referred to simply as "On the Magnet", in 1600, is a milestone in the history of science. "On the Magnet" represents the most important book ever published in the history of magnetism, and represents the beginning of the modern science of electricity. Further, it is the first scientific book of real importance published in England. It is considered the first book written in the spirit of modern science, because it breaks new ground in the use of actual observation and experiment. Gilbert's innovation is the use of experimental demonstration to validate or falsify assertions of fact. Gilbert tells us his method is superior to the usual method of philosophizing because, "Stronger reasons are obtained from sure experiments and demonstrated arguments than from probable conjectures and the opinions of philosophical speculators." Experiments were necessary because philosophy "was involved in the murkiness of errors and ignorances."

Gilbert's landmark work appears at the transition between the scientific fashion of the renaissance, which is steeped in anti-scholastic and pseudo-scientific ideas, to the mechanistic and experimentally based inductive science of the following centuries. To understand it we must remember that it appears before Galileo and Newton. There is no established science of mechanics and the concept of gravity as a universal force is unknown. The scientific revolution is just beginning. Gilbert's work is one of the leading lights of the new experimentally based method, which develops during the transition of scientific fashion from an era of natural magic to one of inductive rationalism. Culturally, the age of exploration is becoming one of colonization as Britain begins its first efforts to settle the new world. Ocean navigation is one of the most important new sciences at this time.

On The Magnet is not only innovative in its use of experimental method, but it is also daring. It appears at a time when experimentation was a risky business for natural philosophers, because it was not trusted. Rules for experimentation were entirely lacking and the typical response to a demonstration by experiment, which contravened accepted ideas, was to accuse the individual of false results, perhaps deliberately lying. This explains why quantitative measurements are rarely

published during this period. They were an invitation for an attack by an opponent. It was far better to refer to thought experiments, an approach used by Galileo. Gilbert's experimental method is not really experimental in the modern sense, because it is qualitative rather than quantitative. It is a method of reasoning by analogy of demonstration with phenomena. The idea is to demonstrate a result using a model which represents the phenomena and then argue by an analogy that the result demonstrates the desired conclusion. We see the first example of this method in Empedocles water clock experiment.

Gilbert's scientific toughmindedness is unique for his age. He is a critical thinker who resists authority and always tests the reported results of others. A steadfast Copernican, he sets out to prove the heliocentric theory of Copernicus using a new kind of physics based on magnetism. He rejects superstitious ideas and notions. He rejects the sympathetic theories of Frascatorio based on magical concepts. He is well versed in the Aristotelian and scholastic theories of the middle ages, and is familiar with the work of Petrus Peregrinus. He is also attuned to the work of the craftsmen and artisans; an important development. He is familiar with the arts of the miners, and smelters of iron. He is well versed in the practical arts of navigation and navigational instruments. This is one of the new features of the scientific revolution, a sensitivity for the knowledge and arts of the practical crafts that make experimentation possible. This is a change in fashion that Gilbert helps to bring about.

Gilbert rejects the knowledge of authority contained in books. His method is basically an extension of the approach used by Petrus Peregrinus. Gilbert believed that natural philosophers should "look for knowledge not in books but in things themselves". The magnetic knowledge at the time Gilbert wrote was as confused and contradictory as the general state of philosophy. There were no standards of scientific research, methodology, or proof. Magic, astrology, and superstitious beliefs were as widely accepted as scientifically proved truths. Gilbert had the task of reading many of the books and discovering the truth and falsity of their claims. He develops an experimental method largely borrowed from Peregrinus to discover for himself the facts. He extends these experiments adding new results and developing a rudimentary or primitive field theory to interpret the results.

"On the Magnet" is much more than an experimental treatise on magnetism and electricity. It is an attempt to found a new scientific philosophy, the magnetic philosophy, on the phenomena of terrestrial magnetism. Gilbert's fundamental idea is that magnetism is the fundamental force of the universe, which accounts for the rotation of the earth, the moon the sun and planets. It is the fundamental cosmic force that causes all heavenly motions. This approach is partly motivated by a strong desire to prove the Copernican hypothesis that the earth rotates upon its axis and that the planets revolve around the sun. "On the Magnet" introduces us to this new philosophy by establishing its foundations firmly upon the knowledge gained from magnetic experiments.

Unfortunately, Gilbert did not finish his project. He died before completing publication of his second book, De mundo nostro sublunari philosophia nova, ( On our Sublunary World, A New Philosophy) which was not published until 1651. Gilbert's magnetic philosophy was an important impetus towards the development of modern astronomy. Johanes Kepler read it and was inspired to apply its principles to the problem of the motion of the moon and planets. Although this effort failed, Kepler eventually discovered the laws of planetary motion as a result.

Gilbert's magnetic philosophy was not a successful scientific theory, it was severely criticized by Francis Bacon. Later it was completely superceded by the gravitational theory of Isaac Newton.

**Science in Elizabethan England**

Although this chapter discusses the magnetic philosophy of William Gilbert, his work is best viewed as the culmination of the magnetic science of the sixteenth century. Thus the appearance of "On the Magnet" in 1600, should be viewed as a event in magnetic history, which summarizes all of the magnetic knowledge up to the time of its publication. A study of William Gilbert's theory of magnetism and his experimental method shows that relatively few of Gilbert's experimental magnetic discoveries are original with him. It appears that most were copied from Petrus Peregrinus, Robert Norman, and William Barlowe. Gilbert's most important achievement, the claim that the source of the magnetic force is within the earth, was anticipated by others, but they didn't develops the idea as Gilbert did. There is also evidence that his discussion advocating the Copernican theory was written in collaboration with William Wright, who also wrote the introductory preface to "On the Magnet".

The view that emerges is that William Gilbert's scientific work was a synthesis of the experimental arts of the practical navigators, the metal workers and smiths, and the new scholarship of the Elizabethan age which emphasized a skepticism of the opinions of the ancient philosophers, particularly Aristotle. Gilbert's advocacy of the Copernican system of the world was another one of the ingredients in this synthesis. Hence, Gilbert's magnetic philosophy is an attempt to integrate the practical experimental methods of the artisan class, with the arts of the scholarly class. Gilbert's method is comprehensive. He examines the evidence from both worlds, and puts together a synthetic philosophy. It is a synthesis attuned to the scientific fashion of the new Elizabethan age.

The scientific attitude of the Elizabethan age is molded by the great discoveries of the new world and the far eastern world made possible by the compass and the navigational arts of sailors. It was an age that was dazzled and amazed by the large increases in wealth brought about by the world-wide empires of the Spanish and Portuguese kings. This wealth was attributed to the invention of gunpowder, which facilitated the conquests, the printing press, which disseminated a knowledge of the new discoveries, and of the magnetic compass which made worldwide navigation possible. It is not an understatement to compare the greatest discovery of the age, the compass and its use in navigation, to the computer revolution of our own era "the information age". The Elizabethan age was the product of the technical development of the compass, just as our world is the product of the development of the electronic computer. It was also an age envious of the Spanish and Portuguese wealth, which the Elizabethan English sought to achieve as well.

The during the renaissance the technical arts had also developed rapidly. So rapidly in fact, that the knowledge of the ancients contained in books no longer seemed relevant to the masters of the "high tech" arts of the Elizabethan age. The artisans had outstripped the scholars in the development of new knowledge. It was no longer to be found in books alone, it could now be obtained by the direct observation of nature by exploration and experiment. This is the new

ingredient that Gilbert adds to his synthesis which makes his work important in the history of scientific ideas.

## Contributors to Gilbert's Magnetic Experiments

Although Petrus Peregrinus letter on the magnet was written in 1259AD, it was relatively unknown before its publication in book form during the 16th century. The first edition in book form was published by Achilles P. Glasser in Augsburg in 1558AD. In 1562AD, Johannes Taisner published a plagiarized edition, as if it was his own writing. Gilbert probably knew of both editions and was aware that Taisner's version was a fake. We see from this that the magnetic knowledge contained in Peregrinus later did not become widely known until the middle of the 16th century.

Peregrinus magnetic theory was that the lodestone and other magnetic bodies derive their power to align themselves from the heavens, which explained why the compass needle always pointed in the north-south direction. By Gilbert's time, this idea was clearly untenable because the observations of the great navigators had shown that the compass needle didn't point exactly north-south but declined to the east or west depending on the navigators position on the earth. Gilbert turned Peregrinus theory backwards. Instead of deriving its magnetic power from the heavens above, Gilbert claimed that the magnetic power emanated from the earth below.

The most important contributor to magnetic science prior to Gilbert was Robert Norman. Norman was a retired professional sailor, familiar with navigation, who had taken up the profession of making navigational instruments; i.e. compasses and magnetic needles. Norman was the first to publish the discovery that the magnetic needle pointed down towards the earth, instead of in a horizontal direction. The magnetic dip had previously been discovered by George Hartmann in 1544AD. Hartmann wrote a letter describing his discovery, but it was not widely disseminated. The widespread knowledge of the magnetic dip became known only after the publication of Norman's book "The Newe Attractive" first published in 1581AD. This is the first book written in English on the subject of magnetism. In the course of making his instruments, Norman noticed that his magnetic needle did not come to rest in the horizontal plane, but inclined slightly downwards. He says that " Hereby stricken with some choller, I applied myself to seeke further into this effect." This must have been very fustrating, in trying to achieve perfect balance of the needle on its pivot, Norman discovered that this was impossible without altering the weight of the needle.

His proof, consisted of the demonstration that every effort to balance a magnetized needle in the horizontal failed. Every time he snipped off a piece of the end that inclined down (because it appeared to weigh more), in order to bring it into balance, he discovered that the needle continued to incline downwards. He achieved perfect balance, only when he added weight to the end opposite to the one that inclined downwards. But, given a perfectly balanced unmagnetized needle, when magnetized, it inclined downward. Thus the only conclusion could be that the magnetic force caused the downward inclination of the needle. From this experiment, William Gilbert deduced that the magnetic force emanated from the earth itself and not from the heavens. But, it is a surprise that Robert Norman did not feel the evidence justified this conclusion.

Robert Norman invented a second experiment which confirmed the conclusion that the cause of the dip was the directional force of the magnetic field. This experiment is described by Gilbert in Book 5, Chapter 9 of "On The Magnet". Norman eliminated the pivot balance by suspending a magnetized needle in a glass of water. The magnetized compass needle was thrust into a round cork. The material of the cork was shaved off until, when placed in a glass of water, the needle was suspended below the surface, but did not sink to the bottom. The needle was observed to dip below the horizontal in the north-south direction, which demonstrated that the magnetic force was actually directed towards the earth.

Many of Norman's demonstrations and experiments, as well as his descriptions of compasses and navigational instruments, were borrowed by Gilbert. Additionally, his method of reasoning which insisted on experimental demonstration and his rejection of the arguments of scholastic scholars was also copied by Gilbert. In a way, Norman's book "The Newe Attractive" is a prototype or model for Gilbert's "On The Magnet". Although Robert Norman discovered the magnetic dip and invented many experimental demonstrations, which Gilbert copied in his work, Norman did not develops and present a comprehensive theory of magnetism such as we find in Gilbert's book.

In 1597, William Barlowe published a book on magnetism titled "The Navigator's Supply." Barlowe, who was Archdeacon of Salisbury, is credited with being the first to use the word magnetism to describe the source of magnetic effects. He refers to "the Magnetisme of the earth" and is thought to have originated the idea that the earth is the source of the magnetic force instead of Gilbert. But since Gilbert and Barlowe were well acquainted, we can not determine which of them had this idea first. In 1616, Barlowe published a second book on magnetism, which is more widely known, titled "Magneticall Advertisements." In this book, Barlowe disagrees with Gilbert's theory that magnetism is the source of the earth's rotation. An idea which is one of the weak points of Gilbert's magnetic philosophy.

In the dedicatory letter of his 1616 book, Barlowe indicates that many of the experiments which appear in Gilbert's book were invented by Barlowe, not Gilbert. He relates the causes of the many problems he encountered in the publication of his book that delayed its appearance for many years. During this time he says "I have met with many portraitures of my magnetic implements, and divers of my propositions set abroad in print in another man's name, and yet some of them not rightly understood by the party usurping them". Clearly this is a polite reference to William Gilbert, and suggests that he borrowed many of his ideas and experimental demonstrations from William Barlowe.

Historian's investigating the sources of William Gilbert's work have concluded that most of his experiments and demonstrations were copied from the work of others. But Gilbert does not claim that these were his alone. Unfortunately, he does not acknowledge his sources, which gives the impression that he made these discoveries. A better way to view William Gilbert's book, is to think of it as a modern scientific textbook. These books do not digress to acknowledge the sources of all the scientific results described, but present the scientific theory in a logical order, along with a discussion of the supporting experiments and mathematical methods. The most useful way to interpret Gilbert's book is to understand it as a scientific treatise which presents Gilbert's magnetic philosophy. This should be understood as a systematic presentation of the

magnetic theory along with the supporting arguments and demonstrations that prove the assertions presented. Viewed this way, Gilbert's work should be interpreted as a complete and systematic account of magnetic knowledge at the close of the 16th century. This makes it the first scientific book, that presents a complete and comprehensive physical science.

## Brief Outline of On the Magnet

William Gilbert's On The Magnet is probably one of the most under-appreciated and neglected scientific works. Few historians of science appear to have read it, and even fewer modern scientists, even though it is commonly available in English translation. The result is a persistent erroneous view of its purpose and contents. The common opinion is that the main accomplishment was to debunk the many superstitions and myths of magnetism that were prevalent prior to its publication. A modern author, in his historical review of magnetism, tells us that prior to Gilbert the known facts of magnetism "were buried under a mountain of superstition", and that Gilbert's researches were important "chiefly as one of the first attempts to separate fact from fiction." A second modern misconception is that the book is only important because Gilbert establishes the modern science of electricity. While both of these ideas are true, they represent only incidental aspects of William Gilbert's accomplishment. (Bitterp26)

To fully understand Gilbert's achievement, we must appreciate that it is a comprehensive work in the science of magnetism. It is a complete compilation of the facts of magnetic science, tested by experiment, and integrated together into a theoretical structure or philosophy. It combines both the old style of scholarship in terms of a compilation of all known facts, and the old style of philosophizing about nature; with the modern criteria of experimental test and deductive proof. This approach does not yield a science in the modern sense, but it is closer to this meaning than any other work of science produced before it.

Its philosophical approach includes an historical evaluation of the theories of his predecessors, a description and justification of the experimental method, an explication of all facts which bear upon the problem, and a description of the experimental procedures and technical methods. This part is a real innovation. Gilbert, not only discusses the experiments, but discusses the technical details of the instruments and procedures used. Here he breaks with tradition, by giving due credit to the technical work of the artisans who manufactured iron, and constructed and used navigational instruments. The result is a book with a distinctly modern tone and flavor.

On the Magnet consists of six books, subdivided into chapters. Each book addresses a specific topic. Book one is an introduction and addresses the history of magnetism, explicates the nature of loadstones, and discusses the metallurgy of iron. It reviews early legends and myths and the known facts and errors regarding the loadstone. In the last chapter, Gilbert reveals his purpose is to explain all terrestrial magnetic phenomena in terms of the postulate that the earth is a giant loadstone with magnetic properties.

Book two introduces the five magnetic movements and specifically addresses the phenomena of magnetic attraction which he calls coition. In chapter two he address the amber effect because it is similar to magnetism. This discussion is regarded as the beginning of the modern science of electricity. Theories of magnetic and electric attraction are presented. These will be considered

later. This book is noteworthy because Gilbert reviews much of the lore regarding the mysterious magnetic effect. This included many of the legends and superstitions which had been promulgated over the years. These he discusses and ridicules, because they are not based on factual knowledge. Beginning with Chapter 4, Gilbert introduces the phenomenon of magnetic attraction and in Chapters 5 to 15 describes his rudimentary field theory including the key concept of the orb of virtue. Chapters 16 through 37 present demonstrations and experiments bearing upon the nature of the attractive magnetic force. Included are experiments on arming loadstones, magnetic induction, and the nature of the magnetic force. Finally, Chapters 38 and 39 consider other kinds of attractive and repulsive forces sympathies and antipathies.

Book three addresses the directive magnetic movement, and is the foundation of his theory of the variations of the compass. The orientation of the compass is conceived as the alignment of the magnetized needle with the north and south poles of the earth. This is demonstrated by experiments using loadstones as magnetic models of the earth. Chapter 1 addresses the nature of the directive force, which is the force upon the compass needle. Chapter 2 gives specific experiments and demonstrations regarding the nature of this force. The concept of verticity which is our modern concept of polarity is introduced. In Chapter 3 and 4 the directive force is discussed in terms of the effects upon the compass or versorium. Chapters 5 through 9 discuss the nature of the forces between loadstones and the directive properties of these forces. Chapters 10 through 17 are concerned with the properties of verticity and how this is changed and modified by the arrangements and locations of loadstones and iron. This establishes the ideas needed to develop GIlbert's theory of variation.

Book four address the theory of compass variations as applied to navigation. This is principally the theory of the variations of the magnetic meridians from the geographic meridians. Chapter 1 is an introduction to the known facts and opinions on variation. Chapter 2 presents Gilbert's explanation that the magnetic meridians were distorted by proximity of the masses of the earth extending beyond the spherical core and experiments to support this opinion. He Performed experiments on imperfect magnetic models of the earth in order to show that variation is due to the inequality of the earth's elevations. Gilbert noticed that, if his magnetic models were not perfect spheres and were not uniformly composed of material with the same magnetic strength, the compass needle showed a variation in its north-south orientation. This led him to propose that the variation in the mariners compass was caused by deviations in the mass of the earth from a perfect sphere. These variations were attributed to both the distribution of mass within the earth and upon its surface, as well as variation of the magnetic strength of these masses. Chapter 3 makes the erroneous assertion that the variation is constant in time. Chapters 4 through 7 give further arguments and demonstrations regarding the variation. Chapter 8 discusses the construction of compasses. Chapter 9 asserts that longitude might be found from the compass variation and Chapters 10 through 21 discuss various aspects of the magnetic variation and its measurement.

Book five address the magnetic dip and discusses it in terms of the directive force and verticity. Chapter 1 defines the nature of dip and its measurement. Chapter 2 presents a theory of the dip in terms of a field theory using the directive magnetic force. Chapters 3 and 4 discuss dip measurement methods and demonstrations. Chapter 5 presents the important result that the magnetic force on the compass needle is not an attraction. In modern terms we say that the net

magnetic force is zero, but there is a couple or turning moment, that gives direction and rotation to the needle. The theory of the dip was based on his observation that the compass needle placed on a terrella deviated from the horizontal. When placed upon the magnetic equator there was no deviation, but when moved north or south of the equator, the needle deviated from the horizontal by a greater amount when closer to a pole (increased verticity). Only when the distance from the two poles was the same, was the needle perfectly horizontal. Gilbert inferred this to be the cause of the dip observed in the mariner's compass. Chapters 6 through 10 give a theory of the dip in terms of latitude and methods of measurement and calculation. Chapter 11 gives an astonishing method to extend the field theory calculations for the surface of a sphere into the surrounding space. This is clearly the first instance of a field theory of space surrounding a magnet. Chapter 12 is the penultimate explication of Gilbert's magnetic theory. Here he presents his idea that the magnetic force is animate spiritual. He declares at the end

"Wherefore not without reason, Thales, as Aristotle reports in his book On the Soul, declares the loadstone to be animate, a part of the animate mother earth and her beloved offspring."

Book six addresses the magnetic rotation and the conception of the earth as a giant loadstone and the daily revolution of the earth as a magnetic phenomenon. Chapter 1 presents Gilbert's argument that the earth is a giant loadstone using an analogy with his experiments performed upon magnetic models of the earth. In Chapter 2 he argues, incorrectly, that the magnetic poles of the earth are invariable. The argument is that the magnetic poles are identical with the geographic poles, which are constant according to Gilbert. Chapter 3 asserts that the earth performs a daily rotation upon its axes in accordance with the theory of Copernicus. In Chapter 4, Gilbert presents his magnetic theory of the circular motion of the earth. This is followed in Chapter 5 by an argument which refutes the positions of those who deny that the earth performs a daily rotation. The remaining chapters give more detailed technical arguments based on astronomical principles. We see that this book is the foundation for Gilbert's cosmological theory based on magnetic force. It greatly impressed Kepler who adopted this approach in his early work. The theory is remarkable because it was advanced before gravity was recognized as the prime force of cosmic movements.

One criterion for the evaluation of the importance of scientific work is the concept of discovery; the first learning of a new fact or phenomenon of nature. In Gilbert's case there are few discoveries. These do not have the impact such as the discovery by William Harvey of the circulation of the blood. Gilbert discovers that a loadstone armed with iron at the poles can lift a greater weight of iron than the unarmed loadstone. He determines by measurement that larger magnets cut from the same stone have greater lifting power than smaller ones. He discovers that magnetism can be induced in iron without making physical contact with a loadstone. This seems to be the basis for his discovery that loadstones derive their magnetism from the earth's magnetic field. He discovers that when iron is heated it looses its attraction to loadstone. An iron needle which is heated and then cooled while pointing north-south becomes magnetized. He can be said to have discovered the utility of the versorium as an instrument for the investigation of electric and magnetic attraction, although he did not invent this device. Gilbert's innovation was his use of this instrument in experiments.

Another, criterion for scientific importance is the invention of new techniques and methods. This is where the importance of Gilbert's work derives its fame and importance. It is his use of instruments and procedures to demonstrate results gathered together in one place that is significant. However, we must realize that Gilbert does not attribute to others results which he presents. This is sometimes misleading, because he gathers together the results of many others, then he sometimes extends them by adding new experiments and demonstrations which clarify or extend the concept. This is the real achievement of Gilbert;s book. The comprehensive nature of its approach.

In evaluating Gilbert's work in terrestrial magnetism, it is important to remark that most of his results were not verified. His hypothesis regarding the cause of variation was disproved within a few years when it was discovered that the declination changes with time. His attempt to establish a method for determining latitude using magnetic dip also floundered when it was found that it did not correspond with his predictions.

Finally, there is one real achievement and two big mistakes. The lasting and enduring achievement is the hypothesis that the earth is a gigantic magnet. This is a result that rivals the great discoveries of the scientific age. However, this was not definitely proved by Gilbert's work. The proof remained for later scientists to follow up. The two big mistakes are the separation of electricity from magnetism and mistaking magnetism for gravity. The separation of electricity from magnetism was not corrected until 1821, while the misidentification of magnetism with gravity was corrected within a hundred years by Newton's gravitational theory.

## The Separation of Electricity and Magnetism

Gilbert's philosophical approach is best understood as the union of the new experimental method, borrowed from Peregrinus, with the older speculative philosophy. This union produces one of Gilbert's most important results. He separates or divides electricity and magnetism into completely separate phenomena. This separation was significant, because it isolated the subject areas of electricity and magnetism. This isolation was to persist until 1820, when Oerstead showed an electric current produces a magnetic field.

In the book Six Wings : Men of Science in the Renaissance, George Sarton gives the following succinct view of Gilbert's approach to the relation of electricity and magnetism.

"Though the work was devoted to magnetism, one of its chapters (III,2) included a discussion of electricity (de succini attractione). He was the first to make a clear distinction between electricity and magnetism. The basis of his distinction was erroneous, yet extremely interesting, if only because it showed that his experimental efforts had not been sufficient to overcome the scholastic tendency of his mind. He related electricity to matter and magnetism to form: thus electricity binds the particles of a body together while magnetism gives it its shape, and in the case of the earth , the tendency to rotate around a properly oriented axis. Electrical attractions are caused by effluvia; the magnetism of a body is likened to a soul. The earth and planets are endowed with a kind of life (V,12). All this was metaphysics rather than physics, and proved his own deep inculcation not only with medieval dialectics but also with Neoplatonic philosophy."

This quotation elegantly expresses Gilbert position in the history or science. He appears at the threshold of the scientific revolution, is lauded as an innovator of the experimental approach, but he uses it to advance a philosophical viewpoint which is clearly rooted in the scholastic and animistic viewpoint of the ancients. It is also interesting because Gilbert straddles the materialistic and occult viewpoints . He uses both approaches which were evident in previous philosophical systems. We see in Gilbert's approach a tension of the two systems. One uses the materialistic and mechanistic world view of explanation, while the other recognizes that the ultimate motive force of causation is essentially hidden and involves a non-materialistic cause. This tension is a theme we have been following throughout the history of electricity and magnetism as it appears again and again.

The separation of electricity from magnetism is accomplished in two parts. The first part consists of experimental demonstrations, with the second part consisting of a theoretical interpretation. The method is almost modern, but Gilbert does not attempt to prove his theory of electrical attraction using experiment. He is really presenting a hypothesis framed as an explanation of the amber effect. Right at the beginning he tells the reader that "...the causes of the loadstones movements are very different from those which give amber its properties..." His reasons are both experimental and philosophical. He takes up the experimental reasons first.

Gilbert's main contribution to electricity was experimental proof that amber was not the only material to display electrical attraction. This was not a discovery original with Gilbert. His contribution was to extend the results by showing that there was an entire class of substances which exhibited electricity. Gilbert identified a very large number of substances which could be electrified even though they were made up of quite different materials. Gilbert called the attractive power exerted by objects like amber "electricity". He called the substances that displayed electricity "electrics" from the latin word for amber. An electric is a substance which attracts in the same way as amber. Substances which did not display the electrical force were designated as "non-electrics". Based on Gilbert's definition, the word electricity acquired its original meaning which is succinctly defined in the Oxford English Dictionary as follows:

In early use, the distinctive property of "electric bodies" like amber, glass, etc., i.e. their power when excited by friction to attract light bodies placed near them; also, the state of excitation produced in such bodies by friction. Subsequently the name was given to the cause of this phenomenon and of many others which were discovered to be of common origin with it, e.g. the electric spark, lightning, the galvanic current, etc.

Gilbert is anxious to demonstrate that the electric attraction is fundamentally different from magnetic coition. After presenting an extensive list of polished substances which exhibited the amber effect, Gilbert tells us that "The loadstone, though it is susceptible of a very high polish, has not the electrical attraction." Here is a fundamental fact. Although very many substances possess an electric attraction, the loadstone does not, so its attraction for iron must be an entirely different species of action.

Gilbert's theory of electrical attraction identified it with a material cause making it a material force, while his magnetic theory made magnetic attraction an immaterial force of the form. His explanation is as follows:

"Electrical movements come from the *materia* [mater], but magnetic from the prime *forma* [form], 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 through solidest bodies or boards, or thick slabs of stone or plates of metal stand between."

Hence, we see that for Gilbert, there were very good experimental and philosophical proofs that the electrical attraction was not related in any way to magnetism.

## Gilbert's Rudimentary Field Theory

This section address the rudimentary field theory that Gilbert uses in "On The Magnet" to form the logical basis of his argument. His innovative approach is to use experimental demonstration to form the basis of a simple field theory which he borrows from Peregrinus. This field theory, like that of Peregrinus is concerned with mapping the effects on magnetism upon the surface of a magnetic model globe, and ignores for the most part, the field surrounding it, and its interactions with other magnets. Hence it is not really a field theory of space, it is a field theory which addresses the phenomena of magnetism at the surface of the earth. This being its most practical area of application and confirmation. Hence Gilbert is primarily concerned with the mapping of the surface field upon his magnetic globe which acts as a model for the earth. But Gilbert does generalize his theory so that it can be extended to interaction between magnets and the field of a non spherical magnet.

In his breathless Preface, Gilbert tells us that:

"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 treating knotty questions about which little is known in such style and in such terms as are needed to make what is said clearly intelligible. Here we sometimes employ words new and unheard or, not (as alchemists are want to do) in order to veil things with a pedantic terminology and to make them dark and obscure, but in order that hidden things with no name and up to this time unnoticed may be plainly and fully published"

This passage expresses the modern spirit of clarity of exposition which is a hallmark of Gilbert. He rejects the old methods and proceeds to invent a new one complete with a new and clear vocabulary. A difficulty for the modern reader is that Gilbert's lexicon is not modern, because it has not survived.

Gilbert recognizes five types of magnetic movements to be explained by the experiments. He conceives that:

"these movements are impulsions of homogenous parts toward one another or toward the primary conformation of the whole earth....Now five movements or differences of movement are perceived by us: COITION (commonly called attraction), an impulsion to magnetic union; DIRECTION towards the earth's poles, and verticity of the earth toward determinate points in the universe, and the standstill there; VARIATION, deflection from the meridian-this we call a perverted motion; Declination (inclination or dip), a descent of the magnetic pole beneath the horizon; and circular movement or REVOLUTION."

The field theory of magnetism arises from the necessity of understanding "by what forces the magnetic coition is regulated" and how the energy of coition "is ordered in magnetic bodies." It is based on the simple observation that:

"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."

The primary field concept that Gilbert uses to expresses his magnetic field theory is his "orbis virtutis" translated as sphere of magnetic influence, or region of power. The sphere of influence surrounded the loadstone out to a limited distance. It defined the region of activity or influence that one loadstone exerted upon another.

The orbis virtutis was not expressed in terms of lines of force or field lines as in the modern concept. Gilbert comes close to modern field theory, because he does present a method of mapping magnetic forces within the sphere of influence at the surface of the loadstone. He does not use the modern conceptions of force, so we must further explore his terminology to understand his concept.

The idea that Gilbert invented a kind of field theory requires some explanation. Gilbert doesn't use the modern idea of force. His idea translates more like our words for vigor or energy. Hence the field is described in terms of the energy or vigor of the magnetic action, which is indicated by the magnetic movements. Hence, the magnetic movements are indications of the vigor of the magnetic action. In order to make this clear in modern terms, the modern idea of a field of force will be used in the following discussion.

Gilbert employs three basic instruments for mapping the field. The first is a device he calls a "versorium", which is simply a fancy name for a compass needle, magnetized or not, suspended at its center of gravity on a vertical support, and free to move. The second device does not have a specific name. It is a piece of iron wire, which is placed with one end upon the surface of the magnet. The third instrument he uses is the "terrella" or little globe. It is a round spherical loadstone which is a magnetic model of the earth; a magnetic globe. The term "pole" is used in

the same manner as Peregrinus. The pole represents the geographical point on the terrella where the magnetic meridians meet. There are two them called north and south just like those of the earth. This concept is then extended to apply to any loadstone by the field mapping method which he borrows from Peregrinus.

Gilbert's most difficult concepts are "verticity" and "directive force". Verticity is perhaps the most confusing, because he uses it in different ways. Verticity is really a property expressed by the technique used to map the field. When the iron needle or short iron wire is placed on the loadstone, it stands up at an angle to the surface. This is a measure of its verticity. A vertical position indicates it is located at a pole. When the wire assumes a horizontal or tangential orientation, which is the dual or opposite to the vertical, it indicates the wire lies on the equator of the terella. In the first case, at the poles, there is maximum verticity, while in the second, at the equator, there is no verticity at all.

Hence Gilbert uses the term verticity to indicate the pole or polarization north or south. When a magnetized needle is divided in two parts, Gilbert says each part has verticity at its ends. Gilbert uses the word in this sense to mean that the needle is polarized at the ends. He also uses it in this sense to mean that poles have the property of verticity, the property to stand up vertically.

Gilbert also uses verticity as a descriptive measure of the magnetic power, virtue , or force. Hence, the compass needle has verticity at its poles. For Gilbert, it seems that the ability to stand up vertically was the true measure of a magnet's power. So this word is often used in this sense of meaning, to refer to the vigor of strength of the magnetic power.

The property of directive force is the property that explains the operation of the compass in navigation. The directive force turns the compass needle towards the poles so that it is in alignment with them. Gilbert uses verticity to express the directive power of the field. Since the force is directed to the poles, the force is expressed by the verticity of the location. The dual power which is the directive force towards the poles, along the horizontal direction, is measured by the versorium or compass needle. What Gilbert means when he uses verticity in the second sense of its meaning is that the directive force is greatest at the poles. So verticity is in a sense a measure of the magnetic energy or vigor. This idea seems to follow from his observation that the force of coition is greatest at the poles.

These two terms define the forces or more properly the magnetic movements at the location of measurement in a horizontal tangent plane. The verticity is a measure of the angle with which the needle stands up vertically. Hence it measures the vertical force normal to the horizontal tangent plane. The directive force is a measure of the force in the horizontal direction. The verticity is maximum at the poles, and minimum at the magnetic equator. The directive force is zero at the poles and maximum at the equator. These dual force quantities represent the magnetic movements or the impulsion to coition of Gilbert's field theory.

Gilbert uses the terms, meridian and equator in the familiar manner. However, they apply to the lines of the magnetic field not the geographic lines. Gilbert uses these ideas as a means to define concepts, like the pole. He does not utilize the lines or magnetic meridians as actual magnetic concepts. This is a step toward field theory borrowed from Peregrinus, but it is not used in the

modern manner. Meridians are the directions indicated by the directive force acting upon the versorium. These directions are mapped to form the magnetic meridians and from these the poles are located.

From the discussion above, it is clear that Gilbert conceived the idea of a magnetic force or power distributed in the space surrounding the loadstone. He tells us that:

”The terrelle sends its force aboard 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.”

Its extent is operationally defined as the extent of the attractive force. This defined the sphere of influence as the region wherein the attractive force was active. Gilbert sphere of influence was relatively close to the loadstone. It was operationally mapped using the versorium by moving it from place to place on the loadstone and noting the direction of the needle. Lines were then drawn upon the stone, forming the magnetic meridians. These measured the directive force, which urged the needle towards the poles of the loadstone, where the verticity was located.

Gilbert showed mathematically that the verticity, which was measured by noting the orientation of a short wire. Gilbert’s purpose in the filed theory was to explore the nature of the magnetic action. Hence his use of field theory is mainly descriptive in order to explore the nature of the magnetic attraction. He does not view the field as a entity, just as the scholastics, the field is the medium for the magnetic action and not the cause of it. It is really the modern conception that views the field as the primary substantive entity. For Gilbert the field is a guide to the nature of the magnetic power which resides inside Mother Earth and the loadstone which derives its power from Her.

## Gilbert's Biggest Mistake: Confusing Magnetism with Gravity

The primary thesis of Gilbert’s magnetic philosophy is his conception that magnetism is the motive force of the earth and heavens. We must remember that Gilbert’s book is published almost 100 years before Newton's concept of gravitation. Gilbert;s mistake is to confuse the force of gravity with magnetism. Since the conception of gravity was unknown in Gilbert’s era, it is easy to see why magnetism would be enlisted to account for the occult forces that controlled the earth and heavens.

Throughout “On the Magnet” Gilbert uses magnetic experiments to demonstrate this thesis experimentally. One of the most important is his demonstration that magnetism acts as the force that binds the earth into a cohesive mass. His demonstration consists of the following:

“Iron dust or iron reduced to powder, packed into 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 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."

Here Gilbert dispenses with the main objection against the diurnal rotation of the earth. He maintains that the magnetic force of cohesion holds it together, against the rotational forces that would tear it apart. Here he lays the groundwork for his theory of magnetic revolution. The unique aspect of his approach is his use of proof by demonstration experiment. He shows in an experiment how the magnetic sphere of influence of the earth causes its components to cohere into a single rigid mass. Today we interpret this cohesion as due to the gravitational field. So Gilbert mistakes or confuses the force of magnetism with gravity.

## Gilbert's Experiments in Magnetism

The purpose of this section is to review the results of Gilbert's experimental demonstrations in the study of magnetism. He borrowed heavily from Peregrinus and many of his results are confirmations of Peregrinus demonstrations published in 1269. Here we will review them in order to see in what ways Gilbert added to magnetic knowledge.

The most important innovation was the use of the versorium or compass needle to study magnetism. Using this as a measuring instrument, Gilbert was able to map the magnetic field in a crude manner. This ultimately developed into a field theory. But his interest is not the field surrounding the loadstone as much as the exploration of the field at its surface. This was accomplished by the use of a terrella, literally little earth. He used this as an instrument to demonstrate the magnetic results. The terrella was used to model the earth. An innovation based upon Peregrinus. Apparently Gilbert was the first to do this. But here we are concerned more with the experiments so lets consider them beginning with some of the more important.

There are really three main areas as follows:

1) Experiments on the polarity or as Gilbert calls it verticity these are essentially those of Peregrinus

2)Experiments on the nature of electric attraction( discussed in another section)

3)Experiments on the nature of the attractive force these involved the weighing of the loadstone and iron

"Frascatorio, in his Chapter 8, *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 is always its force; and hence the iron that is lifted ever so little above the earth by the loadstones force must needs be steadily drawn to it, and must cling to it." page 49 { this is followed immediately by}

“Bapista 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, through 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, straight away 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.”page 49

“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 fillings as from a nutritious food. Bapista Porta, having his doubts about this view, and wishing to make an experiment, took a loadstone of determinate weight and buried it in iron fillings of a weight not unknown; and after he had left it there many months, he found the stone heavier, the fillings 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 fillings are easily lost by handling.” page 49

{Gilbert’s explanation of magnetic induction page 54}

”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;...For this reason it is that magnetic bodies held pendant in air drop to the ground when the opposite pole of a loadstone is presented to them; and this is not because there is any weakening or numbing of the forces of both of the bodies before conjoined, as Bapista 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.”

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...” page 57

In book two, chapter 39, Gilbert discusses mutually repellant bodies.

“They tell us that as like things attract for conservations sake, so unlike things and opposites repel and drive each other away, as is seen in the antiperstasis (counteraction) of many bodies; but is most potent in plants and animals, which as they attract things in affinity and of kin, so do put away things extrene and disadvantageous to themselves.”

He is critical of this but says regarding loadstones.

“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."page 59

"As for Frascatorio'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." here we see that he may have anticipated dia magnetism but Gilbert dismisses this idea. page 59

**Gilbert's Magnetic Philosophy**

It is a curious aspect of Gilbert's work that he is lauded as a scientific innovator while his program is clearly not scientific in the modern sense. His method combines the modern approach with metaphysical, Scholastic, and animistic ideas. Gilbert's book "On the Magnet" is the first part of a two part presentation. His second book, which is relatively unknown, presents his magnetic philosophy without experimental demonstration. It is traditional speculative philosophy. This is the real purpose of Gilbert's work. He seeks to found a new magnetic philosophy. Gilbert sought the true substance of the earth in magnetic experiments. He tells us

"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."

What Gilbert means is that he has revealed through experimental study of the magnetism the fact that it is the ultimate substance. He asserts that the earth is a magnet and that magnetism is the primary force or source of action in the universe. We can understand this by realizing that his first book is a preliminary or foundation for the argument in his second book. The result is a curious fusion of experimental demonstration and speculative philosophy. The modern evaluation tends to emphasize the experimental results and ignore the philosophical speculation. Gilbert is lauded as a modern in the scientific spirit because of his experimental results, which are valuable contributions to magnetic and electrical science.

The puzzle of the experimental versus occult viewpoints is made clear by their presence in the acknowledged first book of experimental science. The puzzle can be partly resolved by the way Gilbert approaches the problem. To begin we must understand that Gilbert is following the philosophical tradition of a grand universal system. Gilbert's system is based on the hypothesis that magnetism is the prime mover of the world, which we call the universe. He uses the innovative approach of experimental demonstration to falsify erroneous or critical views which tended to refute this view. Hence it is imperative to show that electric attraction is distinctly different from the magnetic attraction. This Gilbert proceeds to accomplish in a brilliant manner. Reviewing his conclusions reveals the inadequate state of knowledge available to Gilbert despite his extensive experiments.

One of the major differences immediately obvious at the time is the polar nature of the magnetic force. As Gilbert says in the title to Chapter 3 of the first book ”The loadstone possesses parts differing in their natural powers, and has poles conspicuous for their properties.” This distinction is elaborated in chapter 5 which has the title summarizing its argument as follows: “One loadstone appears to attract another in the natural position; but in the opposite position repels it ...” In chapter 5 Gilbert says “The fact is trite and familiar, that the loadstone attracts iron; in the same way, too, one loadstone attracts another... 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...”

To distinguish the magnetic and electric attractions, Gilbert introduces the concept of “magnetic coition” to define the magnetic force, and opposes it to the unipolar electric attraction which does not exhibit polarity or repulsive force. Clearly this is an erroneous conclusion, but the polar nature was not known to Gilbert, and his experiments did not reveal it. He also elaborated another major difference of the electric force. It was not confined to a single class of substances. While magnetic coition was exhibited for iron and its ores found together along with loadstones in the same places, the electric attraction was revealed by a large number of widely different substances.

In the second book of “On the Loadstone” Gilbert uses this method to perform an important demonstration. He carefully weighs a magnet or loadstone, and an iron object. He demonstrates by this procedure that the hypothesis that the magnet draws material from the iron when it is attracted is false. He also shows that the prevailing opinion that a diamond or garlic destroys the force of attraction is false. Hence, Gilbert’s innovation is to oppose the authoritarian assertions of truth with factual demonstrations which are repeatable by experiment. Hence demonstration replaces authority as the criteria of proof.

This introduction to the work of Gilbert gave a brief look at the topics we will explore in detail. The main contributions to electromagnetic theory are: The initiation of the study of electricity, the formulation of a rudimentary field theory, and theories of the amber effect and magnetism. The book is also important to the fields of terrestrial magnetism and astronomy, although these topics are beyond the scope of this history. The main contribution being an explanation of the magnetic movements with a view to understanding the behavior of the compass in navigation.

**Gilbert’s Conception of the Nature Of Magnetism**

Gilbert’s conception of the nature of magnetism is not clearly stated in a succinct manner suitable for modern understanding. His concept is not as strictly Aristotelian as it seems to be at first. In many places, Gilbert explicitly criticizes Aristotelian explanations and concepts. But, on the other hand, the ideas which he uses to describe his magnetic concept have their roots in Aristotelian concepts. This makes it difficult to establish that his magnetic concept is fundamentally or essentially Aristotelian. On the other hand, his magnetic concept is clearly not materialistic. For Gilbert seems to denies that there is a material cause of magnetism. In some places his magnetic concept seems to fall into the category of animism, and in others a form of sympathy. The explanation of this is that Gilbert’s magnetic conception is fundamentally immaterial. This makes Gilbert’s magnetism similar to the modern idea of a field of force.

One of the first difficulties that we encounter with Gilbert is a fundamental conundrum of method. Since Gilbert chooses to base his philosophy on true demonstrations or experiments, it has a modern scientific flavor. However, Gilbert's experiments do not really establish the truth of Gilbert's magnetic theory. They provide only a kind of circumstantial evidence for the truth, without really proving it. This problem is compounded by the fact that Gilbert never really makes clear what his magnetic concept really is. In this we see the reason that Francis Bacon leveled severe criticism at Gilbert's magnetic philosophy.

The essence of his magnetic philosophy is Gilbert's strong identification of magnetism with mother earth. But, this is its fundamental weakness, because Gilbert's identification of magnetism as the fundamental energy or vigor contained in the earth doesn't provide a real answer at all. It is a circumstantial identification of magnetism with a vague idea that is itself undeveloped. Apparently, this concept of the earth as the source of a universal vigor or life force was to be further developed in his later writings. But Gilbert died before this could be completed.

Book 1, Chapter 17 gives the basis of Gilbert's philosophy and its method. He says "...we must formulate our new and till now unheard-of view of the earth and submit it to the judgement 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." This is followed by a long passage extolling the benefices of the earth and extolling its greatness in comparison with man's knowledge of it. Then Gilbert gives his main argument, which identifies magnetism with the fundamental "...potency of the earth's core and of its inmost viscera..." because "...the lodestone 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.... Like the earth, the lodestone 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...The lodestone derives properties from the earth...Magnetic bodies are governed and regulated by the earth, and are subject to the earth in all their movements. All the movements of the lodestone are in accord with the geometry and form of the earth and are strictly controlled thereby, as will later be proved by conclusive experiments... 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 we search diligently, manifests itself to us everywhere, in all the magnetic metals...A strong lodestone 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..Thus every separable 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." Unfortunately, none of this is a conclusive proof, because we don't really have a clear idea of what Gilbert's magnetism is, because for Gilbert, it is only a reflection of the fundamental force of the earth, which remains as unknown as it was before Gilbert wrote his book.

In the First Chapter of the second book, Gilbert addresses the magnetic movements. "Now remain the magnetic movements and their broader philosophy as developed by experiments and

demonstrations." The five movements which Gilbert describes, contradicts Aristotle, since as Gilbert says, Aristotle admits only two movements: toward and away from the center. Gilbert uses magnetic experiments to identify many more.

The second book of De Magnete addresses magnetic coition, which is our modern attractive force, and is therefore for us the main property of magnetism. After introducing the five magnetic movements, Gilbert addresses the magnetic movement, which he calls coition, in order to differentiate it from the another kind of movement known as attraction. He begins by clearly differentiating magnetic coition from electric attraction. Thus making the electric attraction a movement or force of an entirely different nature from the magnetic one. Magnetic experiments are described in order to show that the magnetic coition is a property derived form the earth's form. The approach is modern in style, using demonstration experiments. The magnetic coition is defined in terms of its descriptive qualities, with no attempt to penetrate to its essential nature. But, Gilbert makes this point essentially clear, the magnetic coition is a movement of a higher order, than the attractive movements of amber and of other attractions derived from the phenomenon lower in the natural order relative to magnetism.

In chapter 7, Gilbert gives us the clearest description of his magnetic theory. "The magnetic force is given out in all directions... around the terella it is given out spherically; around lodestones of other shapes unevenly and less regularly." This magnetic influence is then described. It is doesn't persist "...nor is the force that is diffused through the air permanent or essential; the lodestone simply excites magnetic bodies situated at convenient distance. And as light...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." Here we see that Gilbert has described magnetism in a manner consistent with a modern field theory. It is also essentially similar to the Aristotelian theory of the middle ages, but without the use of secondary qualities. The key point is the idea that the magnetic influence excites magnetic bodies but has no effect on non-magnetic ones.

How does Gilbert deal with the idea that this magnetic influence reaches across empty space to cause the motion of coition? Gilbert says that magnetism does not "...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 light impinges on whatever confronts it, so does the lodestone impinge upon a magnetic body and excites it...the magnetic ray is caught neither in air nor in water." Gilbert tells us that magnetism is similar to light in the way it seizes magnetic bodies, instantaneously, and at a distance, but unlike light, magnetism

"... is not hindered by any dense or opaque body, but goes out freely and diffuses its force every whither."

In his third book, Gilbert addresses the magnetic movement of direction. Unfortunately, he doesn't really have a theory to explain the movement of the magnetic needle into alignment with the earth's poles. After rejecting the ideas offered by previous writers, Gilbert presents his own explanation, which for the modern mind is totally inadequate. He says

“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...So hath the earth been ordered by the Supreme Artificer and by nature...”

The reason that the compass needle exhibits the directive movement is further explained as

“...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...” Hence “A rotating needle turns to conformity with the situation of the earth...”

But this is not really an explanation, it is merely a description of what is observed to occur in experiment after experiment, and this observation is a universal one “assured by the most illustrious navigators” who have sailed the earth’s oceans.

Gilbert’s forth book, addresses the variation of the compass, while his fifth book, addresses the dip of the magnetic needle. At the end of the fifth book, in chapter 12, Gilbert returns to a discussion of magnetic theory. The chapter title says “.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”. In this chapter, Gilbert gives a magnetic theory which is animistic in its character. This is the source of the idea that Gilbert’s magnetic theory is essentially animistic. In many respects, this chapter seems to contradict the ideas presented in the earlier chapters, but in others it is a continuation of them. The main reason for this is that the chapter is essentially an overview of Gilbert’s magnetic philosophy. But it is a disconnected philosophical argument that seems out of place at the end of book five which is a discussion of the magnetic dip. The reason seems to be that it is an introduction to book six, the last book, which addresses astronomical problems and Gilbert’s larger philosophical ambitions.

The chapter begins and ends with clear statements about the nature of magnetism. Gilbert begins by saying “Wonderful is the lodestone 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.” This is followed by a long discussion which explicates and criticizes the philosophy of Aristotle. Gilbert’s purpose being to show how his idea of the animate globe of the earth is superior to the older views of the Greek philosophers. Gilbert gives his view in contrast. He says

“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.... But the souls (in the interior of the globes) confined , as it were, by prison bars send forth their effused immaterial forms beyond the limits of the body...But the globes themselves remain and endure, rotate and move in orbits...But the earths magnetic force and the formate soul or animate form of the globes, ...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...Wherefore, not without reason, Thales, as Aristotle reports in his book On The Soul,

declares the lodestone to be animate, a part of the animate mother earth and her beloved offspring."

Hence the chapter ends as it begins, by declaring magnetism to be an animate force of mother earth. It is an immaterial force.

Gilbert's statements in this chapter seem to indicate a contradiction of his earlier statements. Taken out of context, as many writers have, they can be misleading. Indeed they seem to contradict that Gilbert is scientific in the modern sense. But if we combine them with the earlier statements we see that he is elaborating upon his idea that the earth is the source of all magnetic movements. The problem arises when the magnetic force is linked to the idea of animate souls in the stars and planets. This is a really profound concept that inspired Kepler, and eventually led him to the discovery of the gravitational laws. But, in terms of a theory of magnetism, this chapter adds little to our understanding, other than to make clear that for Gilbert magnetism is an immaterial force.

**Gilbert's Copernican Advocacy**

Although William Gilbert was not the first to advocate the Copernican philosophy in England, he was certainly the most famous and influential of the first English Copernicans. His book was successful, and was widely read in England as well as continental europe. Galileo read it and borrowed some of Gilbert's Copernican arguments. Gilbert's vociferous advocacy of the Copernican world system is certainly one of the reasons Gilbert's book is celebrated as one of the most important books produced during the scientific revolution.

In the last book of On The Magnet, the Sixth Book, we see how Gilbert's Copernican viewpoint influenced his theory of terrestrial magnetism. The reason is that the idea of mother earth possessing a magnetic soul justifies the Copernican movements of the earth's diurnal rotation and its revolution around the sun. These movements were caused by the earth's magnetic soul. Here we see the retrogressive aspect of Gilbert's magnetic philosophy. It is a return to the idea originally expressed by Thales two millennia before. The magnetic souls in the planets are the cause of the Copernican motions. But, this idea is really not much different from the ancient idea. What is new, is that the motion induced by the planetary souls has a physical cause which is identified as magnetism. Furthermore, Gilbert had amassed numerous magnetic experiments which he believed demonstrated the truth of his arguments.

Gilbert's Sixth Book is difficult for the modern reader to appreciate. It is difficult to read, and the arguments are complicated, arcane, obscure and confusing. This may be partly explained by the theory that the astronomical part of this book was written by Gilbert's friend and associate Edward Wright, who was certainly well educated in the details of astronomical science. This, however, seems unlikely because Gilbert's unique writing style continues to be present in this Book. Unfortunately, the astronomical details are what makes this part of Gilbert's book difficult to read. He seems to delve into arcane arguments and looses sight of the main objective. The main objective seems to be this. The motions of the celestial bodies are extremely complicated. In attempting to account for all of them, traditional astronomy invoked more and more complicated systems of spherical motions. Gilbert argues that this shows that the traditional

system must be untenable. He then asserts that an explanation of the various motions is more consistent with the motions of magnetic bodies than the traditional explanation of these motions. His elucidation of these motions in his magnetic experiments is the proof of his claim. The sixth Book is essentially a manifesto for the Copernican view of the universe based on magnetism as the physical cause of the postulated Copernican motions.

A complication which arises in chapter 4 leads Gilbert into a contradiction. Here he attempts to justify the claim that the earth rotates on its axis based on the circular motion of magnetism. The problem arises from lack of a firm foundation in mechanical principles. Gilbert asserts, based on experimental demonstrations, that the earth rotates. He tells us that magnetic terellas allowed to float in water always turn to align with the magnetic poles. He uses this circular magnetic rotation to justify his claim that the earth rotates on its poles. But this implies that there is an astral force which urges the magnetic earth to make this rotation. After refuting Peter Peregrinus claim that a magnetic terella rotates in a day because of the astral force from the heavens, Gilbert states that "the whole earth, as it moves of itself, so is propelled by the other stars...The earth moves by its primary form..." This is a contradiction. First he says the stars have no influence, then that they do, and then they do not. It is no surprise that these claims were hotly contested by Francis Bacon and others. Here it seems that Gilbert is sure only that the earth must rotate, but his explanation of why this is true is poorly given.

**What Did Gilbert Accomplish and What Is His Place In Science History?**

What did Gilbert accomplish? This is the question which this chapter has attempted to answer. The answer can be simply put as follows: Gilbert established magnetic science upon secure and firm foundations. He provides the fundamental tools to support its further progress by establishing experimental instruments and procedures for inquiry into magnetic phenomena. He supplies the foundations for a field theory which when supplied with a mathematical formulation only in the nineteenth century firmly established magnetic science. Less well known is that he also lays the foundations for the advance of astronomy during the seventeenth century. Although his magnetic philosophy is incorrect, it is the investigation of this hypothesis that leads Kepler to derive his three famous laws, which Newton uses to firmly establish the mathematical theory of gravity and the solar system. Finally, he founded the science of electricity. So what we must conclude is that Gilbert is the fundamental person who stands at the focus of developments of modern science.

The myth that Gilbert main achievement was the debunking of superstition is repeated in a contemporary history of magnetism aimed at the popular audience. The author says regarding Gilbert that

> "He was the first to confront the multitude of superstitions that surrounded this phenomenon and performed several experiments that revealed some of the properties of magnets."

We have seen that Gilbert was certainly not the first to debunk magnetic myths, but he was certainly responsible for collecting a large number of myths together and debunking them as a

category of erroneous thought. The idea that underlies this conception is that knowledge of the period was riddled with erroneous thought, and incorrect doctrine.

This is certainly a modern prejudice, and we must be on guard against it. It leads to statements such as: “In Gilbert’s time magnetism could hardly have been called a science.” Technically this is correct, but it disguises the fact that Gilbert’s magnetism was the most advanced science of the age. It also implies that science is a purely modern endeavor. This must be true only because we define science as the modern conception of it. This of course, excludes the older conception of natural inquiry, which is ruled defective because it doesn’t fit the modern fashion for truth. But, are we correct to ignore these attempts at knowledge simply because they don’t fit our conception of scientific progress? Our conception likes to style our modern world as arising out of the ignorance of the Church dominated middle ages. We must be thankful to this new knowledge that released us from the bondage of ignorance, and superstitious myth.

So only true knowledge arises in the modern age of enlightenment, an age which is scientific. But, all this is historically false and erroneous as we have seen in the previous chapters. Modern science did not spring from nothing after breaking the bonds of superstition, it actually built upon older ideas and improved them. This is how knowledge actually progresses.

Gilbert’s scientific work has never received the acclaim that it deserves. The reasons are obscure. Perhaps it is because his magnetic philosophy was a failure, despite the fact that his idea that the earth is a giant magnet has stood the test of time. In another sense, it appears that the modern historians of science were looking for a scientific method in Gilbert that followed the Galilean-Newtonian tradition, which emphasizes proof by mathematics. Today, physical science is not really experimental at its foundations but is based on mathematical theory. There is little mathematics in Gilbert, he reasons in the traditional manner of the scholastics, with a modern style that puts emphasis on the observations and experiments. Hence Gilbert’s scientific manner is not really modern, but medieval.

But, here the objective is not to trace or recognize the fully modern scientific method going back in history, but to examine the continuous flow of ideas, whether scientific in the modern sense or not. The examination of the truly modern can not proceed further back than about 1600AD, by definition of what is considered scientific, because this is when mathematical method becomes sufficiently developed to be integrated into scientific method. Gilbert’s method is scientific in the sense that it uses demonstration experiment to support its arguments as proof. He is really the first of his age to use this method in a comprehensive scientific treatise.

Gilbert’s method was imitated, and became fashionable, even if his magnetic philosophy did not become widely accepted. His criticism of Aristotle became a characteristic feature of scientific works of the age, along with the emphasis on demonstrations and empirically proved facts.

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