MAGNETISM IN THE EIGHTEENTH CENTURY

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By the eighteenth century, the separation of electricity and magnetism was so complete that these two sciences advanced along different paths. Here we will consider only magnetism in the eighteenth century. The century opens with the paradox or conundrum of magnetism at the forefront. This science had not progressed much since the brilliant work of Gilbert had set it upon a new path. The paradox is clearly expressed in the views of Sir Isaac Newton, who we will consider first as the representative for the difficulties and problems associated with magnetic science[1]. Magnetic theory was not in crisis, it was merely languishing in neglect and frustration. The great minds of the age were unable to solve its riddle. This situation continued until the end of the century when Coulomb placed magnetism upon a different path that stimulated the development of mathematical models based on the Newtonian theory at the beginning of the nineteenth century.

It is ironic that Isaac Newton was unable to resolve the riddle and adhered to the Cartesian model of magnetism[1]. This dominated the discourse upon magnetism until the middle of the century. Benjamin Franklin's discoveries in electricity stimulated interest in a Newtonian theory of magnetism based on the new idea of two magnetic fluids. In the second half of the century a new Newtonian interpretation began to emerge. This was eventually crowned by Coulomb's achievement of firmly establishing a Newtonian theory of magnetism in at the end of the century. The result is significant, but not spectacular. An entire century was required before progress in a new direction was achieved. Meanwhile field theory continued to languish.

Isaac Newton and the Paradox of Magnetism

Almost universally acknowledged as the greatest scientist of the seventeenth century[2], Isaac Newton is justly acknowledged as the founder of modern mathematical physics; an accomplishment created by his invention of the calculus. The calculus enabled him to create the new sciences of dynamics and astronomy. The main idea behind the new science of astronomy was the conception of gravity as a force acting at a distance in accordance with a mathematical law of force known as the inverse square law. This is generally what historians refer to when they use the term Newtonian theory; a theory based upon a force acting at a distance in accordance with the inverse square law.

Isaac Newton is not known for his work in magnetism. He was unable to account for the laws of magnetism in terms of a "Newtonian force" conforming to the inverse square law. Newton's almost complete silence on the topics of electricity and magnetism has been thoroughly researched, analyzed, and discussed by historians. They have ferreted out everything that Newton wrote or said upon these subjects. The result is a paradox, which reflects the situation of these sciences at the end of the seventeenth century.

Newton, like Galileo, studied magnetism but was unable to penetrate its secrets. This is surprising because Gilbert's methods were amenable to extension. It is a mystery why these methods were not exploited by Newton. Every scrap of paper, every note, draft, and revision has been carefully studied by historians for clues to Newton's true ideas on magnetism, but without any real indication that Newton had a theory of magnetism. The evidence is certain that he made the attempt, but he was unable to develop an alternative to the prevailing Cartesian formulation of magnetic theory.

Newton's crowning achievement is his theory of gravitation as a centrally acting, attractive force, which is manifestly occult. The achievement is surprising considering that the scientific fashion of the time is purely mechanical. Newton accomplishes the task by presenting the occult force of gravity in terms which are purely mechanical and mathematical. The force of gravity is presented as being mechanically determined by an inverse square law of force. The approach succeeds, but magnetism, which is historically the prime example of an occult force, does not fit into the system as expected. Newton, hoping to make it fit, needed only to discover its law of force.

Newton's ambiguous views on magnetism have been the source of debate and confusion among historians of science. This is most easily cleared up by the hypothesis that Newton simply does not know the true nature of magnetism, but he is hopeful that, in the future, it can be integrated into his system of natural philosophy. This approach has left Newtonian scholars in a state of confusion regarding magnetism. They have sought to answer the question: What did Newton believe was the cause of magnetism? Did he believe in a mechanical or a non-mechanical cause? Newton's published writings indicate he thought that it was a non-mechanical force of attraction acting at a distance like gravity, but his unpublished writings and private comments indicate he believed in a mechanical theory of Cartesian vortices.

The historical confusion has arisen partly because of the ambiguous way that Newton deals with magnetism in his greatest work Mathematical Principles Of Natural Philosophy (Principia). The book begins with a section on Definitions. In definitions V, VI, and VIII Newton mentions magnetism as being an example of a centripetal force. He is regarding it as an example of a centrally acting force; like gravity. His discussion of the magnetic force, frequently in parallel with the gravitational force, gives his readers the impression that he regards them as arising from the same physical laws. For example, in Definition V he says that magnetism is a centripetal force "by which iron tends to the loadstone". In Definition VI, he defines the absolute quantity of a centripetal force and he tells us "Thus the magnetic force is greater in one loadstone and less in another, according to their sizes and strength of intensity", and in Definition VII, regarding accelerative quantity of a centripetal force "Thus the force of the same loadstone is greater at a less distance, and less at a greater". Finally, in the discussion following definition VIII he refers to motive force

> "as an endeavor and propensity of the whole towards a center, arising from the propensities of the several parts taken together...(such as the magnet in the center of the magnetic force or the earth in the center of the gravitating force)".

These examples show that he was hoping to include the force of magnetism within his complete philosophical system of occult forces acting at a distance. It seems that he was unable to do this, but did not redact all the references in the "Principia" which implied this to be the case.

Newton's approach failed when he learned that measurements of magnetic force indicated a law of the inverse cube instead of the expected law of inverse square. In Corollary V he explained this result as follows:

"The power of gravity is of a different nature from the power of magnetism; for the magnetic attraction is not as the matter attracted. Some bodies are attracted more by the magnet; others less; most bodies not at all. The power of magnetism in one and the same body may be increased and diminished; and is sometimes far stronger for the quantity of matter, than the power of gravity; and in receding from the magnet decreases not as the square but almost as the cube of the distance, as nearly as I could judge from some rude observations."

The fact that this statement appears to contradict the earlier statements has been the cause of confusion. A modern historian tells us that "Oddly enough, the man who discovered the inverse square law believed that it did not apply to magnetic attractions." What Newton seems to be saying is that experimental measures do not support the law of the inverse square for magnetism; therefore we must consider it as different from gravity. Newton seems to be expecting that one day this might change, so he does not entirely rule out magnetism as a central acting force.

Newton's failure with magnetism leaves him open to attacks from the Courtesans. However, his public statements do not commit him to a particular theory of magnetic action. He carefully avoids making any unsupported claims that contradict the Cartesian explanation of magnetism. He even goes so far as to accept the Cartesian theory of magnetism. This is not surprising, because the evidence seems to firmly support this view. In an unpublished paper which was written in the years 1673 to 1675, Newton says :

"I believe everyone who sees iron filings arranged into curved lines like meridians by effluvia circulating from pole to pole of the [load]stone will acknowledge that these magnetic effluvia are of this kind."

Other statements in unpublished writings also indicate that Newton was persuaded by the facts of the Cartesian theory of magnetism. However, he did not endorse the Cartesian theory in his published statements. It appears that privately he admitted the superiority of the Cartesian hypothesis, but publicly he kept open the possibility of a different explanation.

In the second edition of <u>Optics</u>, which was published in 1817, Newton appears to come very close to publicly endorsing the Cartesian theory of circulating magnetic particles with his comments in Query 22. Here he requests the reader to explain the phenomena of magnetism.

"Let him tell me...how the Effluvia of a Magnet can be so rare and subtle, as to pass through a Plate of Glass without any resistance or Diminution of their Force, and yet so potent as to turn a magnetick Needle beyond the Glass."

But of course this statement is a paradox. Is Newton suggesting that the magnetic effluvia are proven by the experiment, or is he suggesting the absurdity of the effluvia passing through glass. The answer is another paradox. Newton appears to be trying to break with the Cartesian model of magnetism, but the answer is beyond his grasp.

It seems certain that he is trying to find an alternative view consistent with the Newtonian natural philosophy, because in a draft conclusion for the Optics, written sometime in the early 1690's, he says

"The particles of bodies have certain spheres of activity within which they attract or shun one another. For y^e attractive virtue of the whole magnet is composed of y^e attractive virtues of all its particles & the like is to be understood of the attractive virtues of electrical and gravitating bodies."

Here we see that Newton is trying to integrate the magnetic and electric forces into his system of central forces acting in accordance with the inverse square law. But, this effort is not successful. Several years later, he acknowledges the superiority of the Cartesian system in a conversation with David Gregory. He tells Gregory that the magnetic virtue "seems to be produced by mechanical means". Newton is trapped within the paradox of magnetic theory. Forced to accept the Cartesian views because of the prevailing fashion for scientific mechanism, yet troubled by the ability of the magnetic virtue to penetrate glass.

Newton's Invisible Hand

Magnetic theory and research in England was implicitly guided by the invisible hand of Isaac Newton until his death in 1827. His reputation, his cabal of enthusiastic supporters, and his position as president of the Royal Society were all used to influence the course of research. The primary concern during this period was the discovery of the law of magnetic action. We know that this was a top priority because Newton was also interested in the law for electricity, and other occult attractions that operated at very small distances. The queries at the end of the second edition of the Optics formed the basis of the Newtonian research program. They present a wide range of subjects for the application of Newtonian principles of natural philosophy.

Birch's History of the Royal Society records that Robert Hooke was the first to perform measurements to determine the law of magnetic force. This may have been motivated by his desire to test if the inverse square law applied. Hooke had proposed this law would apply for gravitation in a letter to Isaac Newton the previous year. The record shows:

"March 28, 1666. He [Hooke] produced a pair of scales in a box, to make experiments with upon a good loadstone for the finding out of the decrease of its attractive force upon a body, according as it is placed at greater and greater distances, in order to find out, whether gravitation be somewhat magnetical; which he said might be done by comparing the distances of the bodies made use of in the experiments from the superficies of the earth and loadstone with the diameters; it being probable, that if they hold the same proportion, they have the same cause."

On April 4, the results were reported, and measurements were performed before the society. The apparatus consisted of a balance with one pan attracted by a loadstone, with the force measured by placing weights in the opposite pan. The results were unable to demonstrate the inverse square or any other law of force versus distance. This was probably a fortunate result, because a confirmation of the inverse square law would have established that planetary motion was governed by the magnetic force. Hence demonstrating that gravity was magnetic. Fifteen years later, January 19, 1680/81, Hooke repeated the experiments, but the records of the results were lost.

Edmund Halley, namesake for the famous comet, attempted a different approach in 1687. He attempted to measure the deflection of a compass needle as a function of distance from “the Society’s great magnet”. The experiment was performed in the middle of the quadrangle of Gresham College so as to be away from the disturbing effect of any iron objects. The results were a disappointment and were never published.

In the first edition of the Principia, published in 1686, Newton merely says, in Corollary IV, that the magnetic force diminishes more rapidly than the second power of the distance. A result he probably inferred from Hooke’s measurements. However, in the second edition of 1713, the results are given (see the previous section) as following an inverse cubed law. The mystery of the “rude observations” referred to in the second edition has been the subject of extensive historical inquiry. The mystery concerns the surprising correct result for the force law. How could Newton have known that the correct force law for a dipole was the one he derives as the inverse cube? Since he does not justify his procedure for arriving at this value, we must conclude that it is simply just as he says; a rude guess based on inaccurate data. But, the fact that he guesses correctly is a mystery that demands a solution. The answer that is preferred is that the measurements that Newton used were accurate enough to give the correct result. This has prompted the search for who performed them and the method used. The result has been inconclusive.

It is certain that Francis Hauksbee, Brook Taylor, and Joseph Desaguliers were all involved in performing magnetic force law measurements at the insistence of Sir Isaac Newton. Hauksbee and Desaguliers were both employed as demonstrator to the Royal Society at a time when Newton was president. The evidence shows that the research of these men was guided by the needs and interests of Newton. We know that they performed experiments on magnetic force as well as other experiments which sought to determine laws of force for chemical phenomena.

In the early eighteenth century, after the death of Robert Hooke, Hauksbee became demonstrator to the Royal Society, with the title curator of experiments. On March 20, 1712, Newton as president of the society, proposed that Halley and Hauksbee perform measurements on magnetic force, and hinted at the result.

”Doctor Halley and Mr. Hawksbee should try the power of the Great lodestone at several distances to find the true proportion of its decrease which he believed would be nearer the cubes than the squares”.

The intent was to use Halley’s method of compass deviation. This has been interpreted to indicate that the basis for the statement in the second edition of the Principia were the requested measurements. But, this is not proved, and authorities differ regarding this conclusion. The measurement results were not published until later and there is no evidence that Newton used them as the basis for the statement in Corollary V. The author believes that Newton hoped to obtain measurements that would prove the inverse cubed law, but these were not available prior to publication. The reason is clear. If the measurements were available, then the argument in Corollary V would have been much stronger regarding the results. Newton would have been able to refer to the measurements in a specific manner. The fact that he did not shows he did not use them.

The measurements were performed by Brook Taylor with Hauksbee's assistance and reported in a letter dated June 25, 1712. Taylor measured the "Variation's of the [magnetized] needle from its natural position". There were nine measurements performed at one foot intervals over an interval from one to nine feet distant from the loadstone. The great loadstone of the Royal Society was placed with its poles directed east to west, in an end on position, pointing towards the center of a magnetic compass needle. The needle being held in the north-south meridian by the earth's magnetic field. The compass deviation from true north was measured as the distance from the compass center to the nearest pole was varied. This appears to be the only measurement performed. No attempt being made to ascertain the effect of rotating the loadstone to a different orientation. Hence no attempt to map the action of the loadstone on the needle was made.

Brook Taylor, a young newcomer to the Newtonian circle who possessed a mathematical talent, joined the Royal Society in 1712 after graduating from Saint John's College Cambridge. He was an ardent supporter of Isaac Newton's system of natural philosophy and was secretary of the Royal Society from 1715 to 1718. He was not talented experimentally and his measurements on magnetism and capillary action represent his main scientific contributions. Taylor's career was cut short by ill health, and this could explain why the results of the magnetic experiments, performed in 1712, were not published until nine years later in 1721. The results were entirely disappointing because Brook was unable to discern any law of action for magnetism. He reported

"at the distance of nine feet, the power alters faster, than as the cubes of the squares, whereas at the distances of one and two feet, the powere alters nearly as their squares... From whence it seems to appear, that the power of magnetism does not alter according to any particular power of the distances, but decreases much faster in the greater distances, than it does in the near ones."

Hence we see that Taylor's results contradict the results published by Newton in the third edition of the Principia. Ill health may not have been the only reason for the delay in publication of the results, Taylor may have feared Newton's displeasure. A modern analysis gives a different result which agrees with Newton. Using the value of 0.2 Oersted for the earths magnetic field, "At distances beyond five feet one can obtain a fairly constant inverse cube law, as a function of distance, with a magnetization of 4.4 e.m.u.g^{-1}". But Newton could not have known the value of the earth's magnetic field, and the results were not consistent with the law for distances less than five feet.

The unsatisfactory character of the results was probably immediately apparent to Hauksbee who proceeded to perform a second independent set of measurements using a smaller loadstone. The Great loadstone was judged to be of small virtue, so a different trial was attempted. Hauksbee used a disk shaped loadstone weighing approximately eight pounds that was more powerful. Measures were obtained out to about five feet with three inch intervals. But, the measurements were not sufficient to reduce them to a law of "the Proportion of the Power of the Loadstone at different distances."

In 1722 while engaged in study of terrestrial magnetism, George Graham, a London instrument maker, made a very important contribution to the measurement of magnetic force. In addition to the discovery of daily and hourly variations in magnetic declination(Still page 120), Graham discovered that the period of oscillation of a magnetic needle appeared to be directly related to the magnetic force. He put forward the suggestion that the measurement of the oscillation period was the best "method of computing the magnetic forces". This discovery was not exploited until the second half of the century when it was used by Coulomb and his predecessors to experimentally establish the inverse square law. (Feather page 61)

The Cartesian Controversies

The most significant aspect of eighteenth century science is the transition from the mechanical philosophy to a new philosophical method which is best described as the geometrical-mathematical philosophy, but is better known as Newton's natural philosophy or Newtonianism. The Cartesian controversies mark the change in scientific fashion to Newtonianaism which is to dominate the nineteenth century, after achieving acceptance towards the end of the eighteenth century. The transition is marked by fierce polemical battles which is usually expressed as a war between the Courtesans and Newtonians. This characterization is not exactly correct, because the Courtesans were not necessarily followers of Descartes, but were more properly described as mechanical philosophers of the old style. Furthermore, the mechanical philosophers violently disagreed among themselves as well as with the Newtonians.

By the eighteenth century, the deficiencies of the Cartesian system had become abundantly clear to many natural philosophers. Newton's solution appears to have been to develop a new mathematical philosophy, but its roots are Galilean. Others like Christiaan Huygens, abandoned the specifics of Descartes system while maintaining its main philosophical principles. Huygens's is the first major figure to move away from the specific aspects of the Cartesian philosophy, while maintaining the core of its mechanical basis. Another important figure in the battles is Wilhelm Leibnitz. He took the position of the mechanical philosophy against the Newtonians, but like Huygens rejected the mechanical principles advocated by the orthodox followers of Descartes. Both Huygens and Liebnitz advanced alternative theories of planetary motion and had a history of controversies with Isaac Newton.

Newton's new method of philosophy was bound to result in conflict with the old mechanical philosophy which it sought to replace. The transition was not as rapid and decisive as the transition from the Scholastic to the mechanical philosophy. The war was marked by bitter controversy, and personal mean spiritedness that has been the subject of considerable historical inquiry. The main issue involved Newton's universal gravitational attraction. Magnetism enters the debate as an example of an attractive force. The death of the major participants Newton, Huygens, and Leibnitz did not end the struggles. The fierce debates continued unabated through most of the first half of the eighteenth century, and only abated towards the end of the century as the proponents of Cartesianism died off. Only towards the end of the century do we see that Cartesian theories of the magnet begin to lose ground. An important aspect of the conflicts is the inability of the Newtonian proponents to establish a credible alternative to the Cartesian theory of magnetism.

Historians generally portray Newton, Huygens, and Leibnitz as natural philosophers who had all been trained in the ideas and methods of Descartes, but who had learned to grow beyond them each in a different way. However, Huygens and Leibnitz remained faithful to the old idea of mechanical philosophy that all physical explanations must be expressed in terms of contact between particles of matter. Newton is seen as transcending that limited and confining view by introducing the notions of attractive and repulsive forces acting at a distance without material contact. This decisive insight is what made Newton a great scientist. The inability of Huygens and Liebnitz to concede this insight explains their failure to make the great discovery of gravity.

This view is perhaps a little too contrived to be accurate. Newton's philosophy is a radical change from the older Cartesian approach. Newton introduces a new style of scientific philosophy, makes some specific assertions about the reality of attractive force, and introduces a new hypothesis concerning the motion of the moon, planets and tides of the earth. The battles between the Courtesans and Newtonians involve the differences in viewpoints that arise because of Newton's innovations in these areas.

"Hypothesis Non Fingo" The Nature of Newton's Hypothesis

Newton's objective in the "Principia" is to present an alternative philosophical system contrary to that of Descartes, by moving beyond his hypothetical physics and implementing mathematical certitude.The new system is intended to do more than superceed Descartes, it is designed to firmly establish beyond reproach the truth of the hypothetical system of Copernicus. The new system is based upon a belief in the certitude of mathematical proof. This presents the difficulty that mathematical certitude is not identical with physical truth. Newton's approach is to deduce the mathematical principles inductively from experiments, then by a mathematical deductive method, derive the proof of physical phenomena with mathematical certainty. The system did not make use of hypothesis as a starting point for the derivation of conclusions as in the Cartesian method. Newton's famous statement "hypothesis non fingo", I feign no hypothesis, was a clear effort to distinguish his approach from that of Descartes in a way that clearly demonstrated its superiority. This was a claim designed to appeal to disenchantment with the Cartesian system. The longing for a new method was fulfilled by Newton's new and modern system of mathematical certitude and its avoidance of hypothesis. Surely this would be a system worthy of the name natural philosophy. A system which would lead to the truth of the physical world a true philosophy.

The deficiencies of the Cartesian method were readily apparent by the end of the seventeenth century. In 1695 Andrien Baillet published a book entitled De la vie de Monsieur Descartes (Life Of Descartes). It included some harsh criticism. Balliet called Descartes' Principles of Philosophy a "romance" and described his physical explanations as conjectures, fictions and chimeras. He said that Descartes

"gave out conjectures as truths, which can be seen in the grooved particles that he used for the explanation of the magnet, the circle of ice suspended in the air that he used for the parhelia at Rome, and a hundred other things, without which he would relieve himself of a great deal of absurdities that these hypotheses drag along with them."

Both Newton and Huygens objected to the hypothetical absurdities which resulted from Descartes method. Newton rejected hypothesis and sought truth in mathematical certitude, while Huygens took a more realistic and pragmatic approach. Where Newton sought certitude in mathematics leading to a true philosophy, Huygens sought only probable and conditional truth.

Newton's method provoked a spirited controversy between Huygens and Newton. The essential nature of the debate disguised the fact that it revealed a significant difference in viewpoint between the Courtesans and Newton. In asserting that he was not making an hypothesis regarding the nature of the gravitational force, Newton was inviting trouble. The Courtesans correctly saw his gravitational force as an hypothesis. That Newton denied this by adhering to a restricted concept of hypothesis deepened the confusion. For Newton believed that his philosophical system gave certain truth, hence the term hypothesis had no place within it since an hypothesis was a mere assumption used to establish a probable truth. In explaining why he rejects the use of hypothesis Newton says

"...and the reason of my making exception to the word, was to prevent the prevalence of a term, which might be prejudicial to true philosophy."

Huygens rejected this notion of a "true philosophy" interpreted as the philosophy leading to an absolute certain truth. For Huygens an hypothesis demonstrated by induction and deduction was a probable truth, but for Newton, an hypothesis was an absurd notion. He dealt only in truth itself, so an hypothesis was a notion he rejected.

Newton's method of philosophy is usually either not clearly stated, or when clearly stated, inconsistent with his practice. It purports to derive principles from experiments rendered general by induction, but we never explicitly find this procedure in his work. The method was to perform experiments and then formulate hypothesis or preliminary causes from the experiments. After a suitable mathematical proof was obtained with its apparent certainty, the theory was restructured and all references to the specific details of the experiments were removed. This accounts for the ambiguous references to magnetic experiments which we find in the Principia. The method had the major flaw that with the experiments removed and the physical model suppressed the resulting theory lost its intelligibility as a physical explanation. Hence it became merely a set of geometrical propositions.

Examples of this occur in his use of magnetic principles in the Principia. He mentions magnetism and magnetic phenomena, but he never describes magnetic experiments in detail. This is typical. Newton often appeals to experiment, but he does not present an experimental philosophy. His distrust of experiment reminds us of Galileo who appeals to experiments to support his arguments, but never presents an experiment in sufficient detail to actually perform it. Newton's physical experiments are similar to this. In his experiments with the solar spectrum, he describes how light consists of different rays of colors with different refrangibility. He describes his experiment but attempts by others to perform it fail completely. Newton does not give the needed information to repeat the experiment. This may explain why he distrusts the use of experiment in his physical system.

The initial Cartesian reaction to Newton's Mathematical Principles of Natural Philosophy appeared in the first printed review in 1688. The author of the review, who is unknown, characterizes the work in a very accurate and precise manner. He says

"The work of M. Newton is a mechanics...it is not possible to make demonstrations more precise or more exact than those that he gives...But one has to confess that one cannot regard these demonstrations otherwise than as only mechanical...he has not considered their Principles as a Physicist, but as a mere Geometer.

This is followed by the essence of the authors criticism

"In order to make an *opus* as perfect as possible, M. Newton has only to give us a Physics as exact as is his Mechanics. He will give it when he substitutes true motions for those that he has supposed."

It is hard to disagree with the reviewer's first criticism, after all, the title of Newton's work announces it as Mathematical Principles for natural philosophy. Newton's physics is hidden throughout the work, and this is the major cause of criticisms arguments and confusion that has come down through history. Newton's method is unclear and ambiguously presented in the Principia. He uses induction from experiments to arrive at the laws he supposes. But he hides this procedure of induction from real phenomena and presents his physics as a purely deductive system based on Geometry. The result is a purely mathematical mechanics without contact with the physics of the real world. The substance of the Cartesian criticism is that Newton's system is a mechanical philosophy only in the sense of mathematical or geometrical description, but not with regard to the physics of the real world.

Newton's distrust of hypothesis and the resulting obscurity of his theories has provoked volumes of historical discussion. Newton's famous statement, hypothesis non fingo, was written after considerable criticism from the Courtesans. The famous statement appears in the General Scholium at the end of the "Principia". It appears in the context of a discussion regarding the cause of gravity. Newton says

"But hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I feign no hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction."

Presumably, this statement was designed to satisfy his critics regarding his use of hypothesis. His only concession is to change his reference to true philosophy and refer instead to experimental philosophy. But, his response is still a challenge, he doesn't back down or concede anything else.

Historians have extensively debated what Newton meant by his statement, but have neglected to consider how competing natural philosophers reacted to the statement. Newton claims to have achieved the true philosophy. A claim that is matched only by Descartes egotistic system. The use of the word feign, is surely designed to imply that only Newton has achieved truth in philosophy. It is an egotism that can not avoid offense. Others who employ the use of the term hypothesis properly face the absurd situation that they are labeling their own system false by doing so, because Newton claims all hypotheses are feigned or pretended truths. The result is insulting, since Newton characterizes all systems other than his own as false, and merely pretending to seek the truth, while being fundamentally incapable of ever achieving it.

His bullheaded response has been debated as to its meaning for many years. Yet, it is difficult to see how it can be construed otherwise than as an insult. Newton seems to be saying that all of his hypotheses are true, because he does not present false ones. Further, because he only deals in truth, he has no need of the concept of an hypothesis, which is a false assumption. Thus for Newton all hypotheses in his system are true, because he never presents a false one. But, being true, they are no longer hypotheses, so they are no longer needed. This certainly agrees with his claim of the certitude of truth within his philosophy, but this claim has further implications. Newton is claiming superiority over the truth of the church; a claim which caused Galileo much grief. This certainly was a slap in the face of many Courtesans who were French Catholics, as well as an insult to their Christian faith. The bitterness that followed explains one reason for the resistance to Newtonian ideas and a reluctance to give up the Cartesian theory of magnetism.

The Concept Of Attraction

Throughout this history, the descriptive verb to attract has been used in the sense of a noun to describe the action of electricity and magnetism as an attraction. During the seventeenth century beginning with Beeckman and then Descartes, this descriptive term was banished from natural philosophy along with the associated notions of occult quality and hidden virtue. These descriptive notions were supposed to have no place in the new mechanical philosophy, which demanded that physical actions have a material cause. All forces were conceived as resulting from direct physical contact and exchange of quantities of motion. The notion of an attractive force had no place within the fundamental metaphysics of the mechanical philosophy of Descartes. The physical theories which were advanced utilized material effluvia consisting of different types of particles and mechanisms to account for the apparent attractions manifested by magnetism and electricity.

Newton’s invention of the concept of gravity was certainly motivated by the ideas of Gilbert, Kepler, and Robertval which had attempted to explain the motions of the earth, and planets revolving around the sun and the moon around the earth using the attractive force of magnetism. We see this in the very beginning of the Principia where magnetism is used in the fundamental definitions of a centripetal force. Newton’s invention of the concept of gravity is founded upon the idea of a mutual attraction between two material bodies. The primary example of this type of force was the magnetic attraction. But, as we have seen, the Courtesans banished this force from natural philosophy. Newton faced a dilemma. His solution was to introduce the notion of a mathematically demonstrable action not dependent upon the action of a known physical process. While Newton does not tell us how he arrived at his invention, we can surmise that he arrived at it inductively form the discovery that the Cartesian gravitational theory of vortex motion was inconsistent with Kepler’s laws. Then having determined that an inverse square force law gave the correct results, Newton constructed his theory deductively.

Histories of mechanics make the point that Newton's Principia completed the science of mechanics. This means that all the essential laws or fundamental principles of mechanics were enunciated by Newton. But only two of Newton's three principal laws of motion were known. The key law which Newton invented and added to mechanics was his third law. This turns out to be the crucial new law which was needed to complete the science of mechanics.

The third law of motion is a crucial element of Newton's theory of gravitation. He gives it as follows:

"To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contract parts."

This is followed by a explanation which ends with the important statement that

"This law takes place also in attractions, as will be proved in the next Scholium."

Newton is certainly not highlighting the role that the third law plays in attractions. Perhaps because it a new concept that requires a more complete and extensive discussion. In the Scholium, Newton presents the following deductive argument which relies upon the first law

"In attractions, I briefly demonstrate the thing after this manner. Suppose an obstacle is interposed to hinder the meeting of any two bodies A, B, attracting one the other: then if either body, as A, is more attracted towards the other body B, than that other body B is towards the first body A, the obstacle will be more strongly urged by the pressure of the body A than by the pressure of the body B, and therefore will not remain in equilibrium: but the stronger pressure will prevail, and will make the system of the two bodies, together with the obstacle, to move directly towards the parts on which B lies; and in free spaces, to go forwards *in infinitum* with a motion continually accelerated; which is absurd and contrary to the first law."

To conclude the argument by experimental demonstration he says that

"I made the experiment on the loadstone and iron. If these, placed apart in proper vessels are made to float by one another in standing water, neither of them will propel the other; but, by being equally attracted, they will sustain each other's pressure, and rest at last in an equilibrium."

These statements lead to the conclusion that Newton's third law of motion as applied to attractions derives from experiments in magnetism. While it is tempting to conclude that Newton discovered this law by experimenting with magnets, a conclusion which is supported by his method of experimenting and then forming deductive proofs, we do have not have direct evidence to prove this assertion.

It is also tempting to surmise that Newton derived these ideas from reading William Gilbert's On The Magnet. There the concept of magnetic attraction is described as a mutual action, or "coition" as Gilbert calls it. Unfortunately, there is no direct historical evidence that he obtained his ideas from Gilbert, since he does not attribute sources for them. Nevertheless, the Scholium proceeds to explain that the gravitation between the earth and its parts is mutual. An idea that appeared in Gilbert's explanation of how magnetism held the earth together, and prevented its matter from flying into space due to its rotation.

Newton's argument does not demonstrate the existence of an attractive force in magnetism but assumes it a priori. Since the Cartesians deny that attraction is a valid conception in physics, a controversy was bound to erupt. It is clear that if magnetic action is explained by an occult force, then Newton's experimental demonstration falls to the ground, because occult forces are prohibited from physics.

The Cartesians immediately recognized that Newton's gravity relied on the principle of action and reaction with the new conception that the action occurred at a distance. So for them the new gravitational force was merely the old concept of occult force and hidden qualities in a new form. While the principle of action and reaction was not vulnerable, because the Cartesian vortex relied upon the notion of a communication of motion, through action and reaction of impact. The idea of action at a distance by attraction, however, was a vulnerable idea.

If you are wondering, dear reader, what all this has to do with magnetism, the answer is as follows. Newton's experimental basis for his principal of universal gravitation is magnetism. Where Gilbert saw magnetism as the universal force of nature, Newton substituted gravity. He sees magnetic attraction as a force analogous to gravity. His procedure is inductive. He performs experiments, and then inductively derives laws of mechanical action. But, he does not reveal this in the final presentation of the Principia. The inductive procedure is suppressed, leaving only the mathematical laws and the deductions derived from them. This leads to the Cartesian criticism that his system has no physics.

Newton's use of magnetism as a template for gravitational attraction presented him with a dilemma. Both concepts were occult forces, but magnetism was explained within the Cartesian system using vortices of circulating magnetic particles. In the case of gravity, Newton was able to prove mathematically that vortices of a subtle gravitational aether did not yield the known laws of planetary motion discovered by Kepler. His appeal to magnetism therefore needed to be muted and suppressed. We saw previously how this led to a paradox regarding Newton's views on magnetism. The Courtesans had successfully banished the idea of attraction from magnetism, and Newton was faced with the problem of reviving it for gravity. This he did, but only as a law of universal attraction that was presented mathematically using geometry.

The rouse did not succeed initially, because the Cartesian reaction identified it immediately. Huygens commented to a friend in a letter that

"I have nothing against His not being a Cartesian, provided he does not give us suppositions like that of attraction".

Huygens correctly surmised that Newton's gravitational force was merely an occult force of attraction in a different guise. In a letter to Leibnitz written in 1690 he says

"Concerning the cause of the flux given by M. Newton, I am by no means satisfied [by it], nor by all the other theories that he builds upon his principle of attraction, which to me seems absurd, as I have already mentioned in the addition to the *Discourse on Gravity*. And I have often wondered how he could have given himself all the trouble of making such a number of investigations and difficult calculations that have no other foundation than this very principle.

The basic argument that surrounded the Cartesian denial of attraction. As we saw previously, the Courtesans beginning with Beeckman, denied that any attractive force existed in nature. This was clearly in conflict with all the evidence presented by Gilbert to support his magnetic philosophy. The result was not an advancement of magnetic science, but a fundamental denial of its foundations. The Courtesans rectified this by establishing a mechanical theory of magnetism which was not successful and ultimately harmful because it suppressed magnetic research based on Gilbert's field concepts.

From the point of view of magnetic science, the transition from the Cartesian to the Newtonian philosophies demanded a strictly Newtonian or geometrical philosophical interpretation of the magnetic action. This was not achieved in the eighteenth century. The main activity was the attempt to supplant the Cartesian theories by the Newtonian. But as we have seen the Newtonian program failed miserably and decisively. However, at the same time the Newtonians were winning victories in the field of universal gravity. This convinced them of the ultimate truth of their system.

Magnetism featured prominently in the Newtonian system although Newton's style tended to downplay its significance. Newton dynamics was based upon three laws of motion. The third law was a source of considerable controversy, and this forced Newton to point to his explanation in which he states that the third law is proved experimentally by experiments using a magnet and an iron body floating on wood in a tub of water. Newton says that the magnet and iron come to rest in the water after coming together, proves the correctness of his third law.

The crux of the controversies between the Newtonians and Courtesans was Newton's concept of a universal gravitational attraction which assumed as an hypothesis that all matter attracted other matter in accordance with an inverse square law of force versus distance. The Courtesans felt that this was a physically absurd hypothesis, because it violated the principles of the mechanical philosophy which asserted that all force was effected by physical contact of material bodies. In their eyes Newton was merely postulating an occult force, which as we know was completely unacceptable to the Courtesans, as well as being outside the accepted fashion of a modern natural philosophy. The Courtesans rejected attraction as a concept outside physics. Clearly, one possible answer was to appeal to magnetism as a well established example of an occult force that was a real force of nature which obeyed mechanical laws of nature. This is what Newton intended, but the use of magnetism in this way was a trap, and Newton understood this fact. The prevailing interpretation of magnetism was Descartes theory of magnetic particles flowing in a vortices through and around the magnet. Thus magnetism had a mechanical explanation in the Cartesian system. Newton could not very well use it as an example of a force similar to gravity, because he deigned that gravity was caused by Cartesian vortices of subtle matter. This created problems particularly since, Newton had no really good alternative to the Cartesian theory to put forward in its place. Hence, Newton was reticent about pointing to magnetism as a centrally acting force without a visible explanation of force resulting from direct contact.

The conclusion of this section ends with an ironic twist. It is clear from the evidence that Newton's third law was inspired by experiments on magnetic force. As an experimental law it is less valid than a deductive proof. However, this stands or falls by experiment. Only one experiment being needed to refute the validity of the law. The ironic twist is that the third law is violated by moving charged particles. In this case, the magnetic fields produced by moving charged particles violate Newton;s law of action and reaction. That magnetic forces violate the law which they were responsible for creating is a really ironic aspect of modern physics.

When we examine the criticisms of William Libnitz we recognize the problem very clearly. Leibnitz correctly saw that Newton's gravitation was an occult quality. In 1690 he expressed this view in a letter to Huygens. He said that he was astonished that Newton considered gravity to be an incorporeal and inexplicable virtue that could not be explained mechanically. Later he became more specific and explicit. In 1703 in his Nouveaux essais he says regarding Newton's gravitation that

"This is, in effect, to return to occult qualities, and even worse, to inexplicable ones."

He goes on to says in a rather scathing tone that he would rather "renounce Philosophy and reason, opening an asylum for ignorance and laziness." than accept Newton's attraction as well the ideas of occult qualities, which he considered miraculous. In later years he made the attacks more specific and pointed.

The Nature of Gravitational Attraction

Leibnitz certainly understood, probably better than any other critics of Newton's theory, that the Newtonian gravity was a form of magnetic attraction described in terms of a mathematical law. His own theory of gravity clearly shows the role of magnetism in the conception of gravity. Leibnitz did not hide the connection, he made it explicit. In the first version of his theory of planetary orbits, which was published in an essay know as the Tentamen, he tells us that

"The harmonic circulation having been explained, we must first consider the paracentric motion of the planets, which originates from the extruding impression [excussorius] of the circulation [centrifugal force] and the solar attraction combined together. We may call it attraction, though in truth it should be impulse; indeed the sun can, with some reason, be regarded as a magnet; however, its magnetic actions derive, doubtless, from the impulses of fluids. Therefore we shall call it also Solicitation of Gravity, considering the planet as a heavy body tending towards the center, that is, the sun. But the shape of the orb depends on the special law of attraction. "

Here Leibnitz says that the solar attraction is analogous to magnetic attraction which he interprets in terms of the Cartesian theory of vortices.

In a later revised version of the Tentamen, Leibnitz again makes the connection with magnetism, even clearer than before, and brings in William Gilbert's ideas to emphasize the point.

"From the considerations of the famous Gilbert it is clear that every larger body of the world insofar as it is known to us, has the nature of a magnet, and that, besides the directing power (vis directiva) [in virtue of which] it looks at certain poles, it has a force of attracting the parent [similar] bodies placed inside its sphere [of force], which [force] in things terrestrial we call gravity, and which, by a certain analogy, we attribute to the stars. But it is not sufficiently clear, what is the true cause of this very obvious phenomenon, and whether this cause is the same as in the magnet."

Towards A Newtonian Theory Of Magnetism:The Failings of Musschenbroek

We have seen that Isaac Newton himself was reluctant to publicly reject or criticize the Cartesian theory of magnetism, which employed the concept of circulating streams of subtle matter to account for the action of magnets. Newton was probably reluctant to reject this notion because he harbored hopes that the attractive actions of electricity and magnetism could be explained via his conception of "...a certain most subtle spirit which pervades and lies hid in all gross bodies, by the force and action of which spirit the particles of bodies attract one another at near distance, and cohere, if contiguous..." The first newtonian natural philosopher to explicitly reject the circulating streams proposed by Descartes was a Dutchman Pieter van Musschenbroek.

Musschenbroek is an important, yet curiously unheralded early proponent of newtonian methods, who discovered the very important phenomena of the Leyden Jar and conducted some of the earliest quantitative measurements of magnetic force.

Unfortunately, Musschenbroek's magnetic researches were unable to establish a definitive law of magnetic force, and his work has consequently been neglected as well as criticized by modern historians.

Modern historians, who implicitly accept the validity of the inverse square law of magnetism, have not learned to appreciate the pioneering experiments in magnetism conducted by Musschenbroek. J. L. Heilbron, the author of a definitive history of electricity, opens his description of Musschenbroek's magnetic experiments by saying: "Consider next the failings of Musschenbroek..." Heilbron then proceeds to describe Musschenbroek's attempts to discover the law of magnetic attraction from the point of view that Musschenbroek had failed to understand the foundations of Newtonian doctrine. He implies that as a disciple of Newton, Musschenbroek had failed to fully comprehend the real meaning of the inverse square law, and that his failure in comprehension was responsible for the inability to establish the inverse square law for magnetism. This is a harsh criticism considering the difficulties and problems involved. But the main difficulty seems to be that the inverse square law of magnetism is not the universal law that many believe it to be. Modern textbooks avoid the concept and substitute the concept of an inverse square law for current elements as the foundation of magnetism. The difficulty lies in the way that magnetic materials respond to magnetic forces in unpredictable ways. This is a problem that Musschenbroek and the other early experimenters faced, and which eventually thwarted their hopes to discover the magnetic law of force.

Although Musschenbroek's attempts to determine the law of magnetic force had failed, by 1725 he had derived sufficient experience from magnetic experiments to become convinced of the falsity of the Cartesian theory of circulating magnetic matter. That year a letter from Musschenbroek to Desaguliers was published in The Philosophical Transactions of the Royal

Society. The letter detailed a case against the Cartesian theory, by arguing the experiments showed that magnets do not act by means of corporeal effluvia. Musschenbroek took the newtonian position that the cause of magnetism was unknown and that it might even be non-corporeal. A result consistent with Gilbert's conclusions obtained more than one hundred years earlier.

His case against the Cartesian vortex theory was definitively presented in his treatise on magnetism, Dissertatio physicia expermentalis de magnete, published in Leyden in the year 1729. Musscehbroek's dissertation concerning the magnet, written in terms of the newtonian fashion, confesses at the opening that: "You may well be amazed at an author who writes about a phenomenon [magnetic attraction] of whose cause he confesses himself ignorant." He goes on to criticize the Cartesian vortex theory: "I would say that I have never observed an Hypothesis more opposed to Experiments and truth than this one...I am of the opinion that there does not exist a magnetic Fluid save in the mind of one imagining it." Here we see that the circulating vortex of magnetic particles has transformed into a magnetic fluid. This is a significant development because it marks a shift in emphasis from the corporeal effluvia viewpoint towards the conception of a magnetic fluid. This is an idea that develops into a mature form towards the second half of the century.

Conceiving the Cartesian theory in terms of the circulation of a magnetic fluid, Musschenbroek was able to demonstrate that this conception was incompatible with magnetic force measurements. Probably the most telling result was his observation that the attractive strengths of the north and south magnetic poles were different. This is a surprising result. Today, we recognize that it is false. But the reasons for this incorrect conclusion are instructive. It reveals that magnetic force experiments were extremely difficult. The newtonian method made no hypothesis concerning the cause of magnetic force, it sought to discover the law mathematically describing this action. So when Musschenbroek discovered that the force of the magnetic poles was unequal, it became a clear refutation of the Cartesian vortex theory. If the magnetic flow behaved according to the known laws of fluid flow, the flow at the opposite poles was required to be the same. Hence the attractive forces must also be the same. The fact that this was not the case disproved the Cartesian circulation theory.

A second observation was that material bodies interposed between magnets failed to alter the magnetic forces. Only ferrous bodies effected the forces. This suggested to Musschenbroek that a circulating magnetic fluid was not responsible. His reasoning was that surely the interposition of a dense body must effect the magnetic forces in some way , even if only slightly. Conceiving the passage of the magnetic fluid as analogous to the passage of light particles through glass, there should have been some diminution or refraction of the magnetic particles as they passed through the interposed bodies. But, Musschenbroek's measurements revealed absolutely no effect upon the measured forces. Only when iron was present was there a change in the forces. This was a result that could not be readily explained by the Cartesian theory that relied upon the passage of magnetic particles in order to account for its magnetization, yet these particles were completely unaffected by their travel through bodies other than iron or steel.

Musschenbroek also performed two other experiments which he believed demonstrated the falsity of the theory of circulating magnetic effluvia. He subjected the region between a magnet and a compass needle to blasts of air and to a current of heat rising from a stove. Neither of these disturbances had an effect upon the compass needle. These demonstrations were offered as additional proof that circulating streams of magnetic particles were not responsible for magnetic forces.

Musschenbroek's detailed measurements of the magnetic force between magnets were an important source of detailed magnetic experiments that guided magnetic science in the following years. Unfortunately, the detailed series of measurements, presented in tables of distance versus force did not reveal the presence of a systematic force law as expected form the newtonian approach to scientific endeavor. Following the Newtonian fashion in science, Musschenbroek expected to uncover the law for magnetic action, just as Newton's methods had discovered the law for gravitational action. As we have seen, the endeavors of Musschenbroek failed as miserably as those of Newton, Halley, Hauksbee, and Taylor. The general opinion of historians has been that these experimenters failed because they were unable to apply the principles discovered by Newton in a proper manner. As J. L. Heilbron tells the story, the failure of these experimenters "...reveals that these Newtonian hierophants had failed to understand the foundations of their doctrine." This is a harsh comment and it deserves examination.

Musschenbroek's apparatus has designed to measure the force between magnets as the separation distance was changed. He used loadstones, an important source of difficulty because of the wide differences in force which were available. Another difficulty was the inability to accurately define the magnetic power or attractive force exerted by a particular loadstone. The usual method was to measure the lifting power by placing weights on the magnet. This procedure depended on the size and shape of the weights, as well as the type of iron used. There also was no appreciation of the environmental effects of the apparatus used to perform the measurements. Were there any iron objects nearby which could effect the results? Even if we assume that all these problems were solved, others which were more fundamental remained.

When Musschenbroek measured the force between two spherical loadstones, an experiment he performed Christmas eve 1724, he suspended one magnet above the other and used a counterbalance to measure the force. Changing the distance between the loadstones, he derived a table of force versus separation distance. But this table revealed no simple force law. This was certainly a puzzle to Musschenbroek. Newton had obtained a force law which found that magnetic attraction varied as the cube of the separation distance.

"Would that the experiments from which Newton gathered this result had been recorded! For perhaps that man of stupendous subtlety in mathematics found a way to segregate attractions and repulsions, the proportion of which he found to decrease as the third power of the distance."

This was Musschenbroek's lamentable comment on his own failure to reproduce the law which Newton had so deftly obtained. But, as we saw above, others had also obtained this result, but only for a limited range of distances. Seeking a law which applied for all distances from near to far was the problem. No one realized that the inverse square law of Newton was valid for only larger distances, while for really close distances the effects of magnetic induction disturbed the results.

Musschenbroek's experiments demonstrate an ironic and instructive episode in experimental science. It appears that Musschenbroek's detailed and varied experiments did reveal the laws of magnetic attraction, but the results did not conform with the theoretical expectations. Here is an example where the failings of exact science become apparent. Musschenbroek's methodology derived at least three different laws. The first giving the first power of the distance, a second giving a 2/3 power of the distance, and finally a third of the fourth power of distance. In addition to these disparate results, he also found that the action of the magnet "is not equal on diverse bodies; is subject to changes in the weather; [and] varies in intensity." Results that demonstrate the extreme difficulty of conducting experiments in exact science in the early eighteenth century.

Musschenbroek's different magnetic laws were not the result of large errors, they reflected his philosophy of experimentation as applied to different measurements. His approach was to discover a law of magnetic action between magnets and magnetic bodies, not a law of action between magnetic poles. Heilbron aims his criticism at Musschenbroek for this approach. As a good Newtonian, he should have known that it was the action between the poles which was important. Hadn't Sir Isaac led the way to establishing this point? But, Musschenbroek is a through experimenter, and he sought the law of total magnetic action between different kinds of bodies with different shapes. He tried different shapes of magnets, with variously shaped and types of attracted iron bodies, and obtained different laws of force. He subjected different shapes of bodies to the magnetic action. These were not always based on the separation distance. He also tried to identify the law of action with some measure of the space or volume between his objects subjected to the magnetic force.

When he used a cylindrical magnet, and an identically shaped piece of unmagnetized iron, Musschenbroek found that the total force varied inversely as the first power of the space between the bases of the cylinders. When he used a spherical magnet and a cylindrical magnet, he found that the force varied inversely as the sesquiplicate or 3/2 ratio of the "empty space enclosed in a cylinder bounded by the base of the cylindrical magnet and a mid-plane through the spherical one." Finally, when a spherical magnet was used to attract an iron sphere, he determined the force law to be the inverse fourth power of space between them.

The measurements revealed the phenomena correctly, but the theory was unable to account for the results. It is a case where qualitative study could have been applied more successfully. Why? At this stage, the phenomena of magnetic induction were not recognized. There were a number of ways that induction effected the results. At sufficiently close distances, magnetic induction acts to increase the attractive force between different magnetic poles. This effect depends on the intrinsic magnetic potential of a particular magnet. At some distance, the attraction of opposite poles becomes overwhelmed by the inductive effect. Hence we no longer measure the force exerted between the two magnets, but only the attractive force of the stronger magnet. This effect is more pronounced when like poles face each other. In this case, the magnetic repulsion becomes an attraction when the separation distance is sufficiently small. Further, at larger distances the effect lessens the repulsive force when directly compared with the attractive force for the same magnets and distance separation. This causes the poles strengths to appear different. A result that Musschenbroek was the first to clearly identify and measure. All of these effects also depended upon the intrinsic strength of the magnets used. A factor which could not be quantified exactly.

All of these difficulties led Musschenbroek to conclude that:

“the magnet was composed of quite heterogenous parts; some of these attracted, some repelled, in such a manner that, when two of these forces were opposed, they disturbed the proportion of simple repulsion or attraction.”

Musschenbroek was certainly on the trail of subtle and complicated magnetic phenomena. But, he was looking for a simple power law, not a complicated set of multiple forces that were extremely difficult to unscramble. For this reason, Heilbron and other historians have been critical of his efforts. Musschenbroek was the main source of experimental date on magnetism until near the end of the century. Although he was unable to discover a law of magnetic, his experiments helped point the way by illuminating the difficulties and pitfalls.

Servington Savery’s Magnetic Studies

In the year 1730, an English savant, Servington Savery of Shilston published an essay on magnetism in the Philosophical Transactions. His main achievement was to describe his method for making artificial magnets; an enterprise that would change the nature of magnetic studies. The essay is significant because it included a contempory summary of the state of magnetic knowledge as Savery understood it. This has been reduced to eleven principles. Of these, only four can be considered new or important when compared with the magnetic knowledge of William Gilbert. These new principles or magnetic facts are as follows:

Steel is more retentive of magnetism than iron
The forces of attraction and repulsion in a magnet or loadstone are equal
The magnetic poles of the earth are different from its geographic poles
The magnetic force is different from that of electricity or gravitation

The first is the most significant new fact resulting from the studies on artificial magnets. It resulted from the observation that in artificial magnets, steel could be made to retain a stronger magnetism than iron. This discovery was important in the development of the new artificial magnets. The second conclusion that the forces of attraction and repulsion are equal is an important quantitative conclusion. But, as we have seen, Musschenbroek’s studies did not agree with it. The discovery that the magnetic and geographic poles do not coincide was one of the major discoveries in geomagnetism of the seventeenth century. The final point is Newton’s great discovery that the force of gravity is a unique force different from magnetism.

Considering these new facts of magnetic science, it is apparent that considerable progress had not been achieved during the 130 years between the publication of Gilbert’s work and that of Servington Savery. This illustrates that the slow pace of magnetic discovery continued through the first half of the eighteenth century. When in 1747 Benjamin Martin published a summary of magnetical knowledge, the list of magnetic properties was almost identical to Servington Savery’s compilation of 1730. This illustrates that the slow pace of magnetic discovery continued up to the middle of the century. When compared with the dramatic pace of discovery in electrical science, the results were disappointing. But, the advances in electricity, the continuing efforts to discover the law of magnetic action, and the new studies of artificial magnets were stimulating researches that would cause a change in the pace of magnetic discovery in the second half of the century.

Calandrini Experimentally Establishes The Inverse Cube Law Of Magnetic Force

In the years 1739, 1740, and 1742 a new three volume edition of Newton's Principia with notes and commentary was published in Geneva under the authorship of two French members of the Franciscan order of Minims. Known as the Geneva or the Le Seur-Jaccquier edition, in honor of its editors, this version of the Principia was filled with many notes and comments prepared by various authors. A long note to Newton's Corollary 5, Proposition VI, of Book III gave a detailed mathematical discussion and experimental proof of Newton's supposition of the inverse cube law of magnetic force. The experimental results and theoretical discussion gave the final definitive proof of the law which had eluded the efforts of Halley, Hauksbee, and Taylor.

The author of the note is believed to be J. L. Calandrini professor of mathematics and philosophy at the University Of Geneva. After reviewing Musschenbroek's experiments he tells the reader that:

"When virtually everything required for the estimation of the forces had been duly noted, I observed, by experiments conducted with all possible care, that the diminution of magnetic force proceeds according to the ratio of the cube".

He then continues on in the modern manner with a mathematical presentation of theory, followed by experimental measurements and analysis of the results. His results convincingly demonstrated the supposition by Newton that the force law varies with distance as the inverse cubed. The method used is essentially the same as previous ones which measured the force of a magnet on a magnetized needle. The result cleared up the confusion over the nature of the force law and Newton's cryptic comment in his Corollary 5, thereby ending a long series of attempts to establish Newton's assertion.

The publication of Calandrini's note cleared away the confusion by presenting the mathematical justification for the supposed law as well as experiments to demonstrate its validity. Curiously, Calandrini did not base his mathematical arguments on the inverse square law of force between magnetic poles, but proceeded by a different method. Calandrini ended his note with a definitive statement that Newton's law of magnetic force had been sufficiently proved. Following this, there were no longer any attempts to prove this supposition and the efforts shifted to attempts to prove the inverse square law between magnetic poles.

John Mitchell Proposes The Inverse Square Law For Magnetic Poles

It is curious that until the publication in 1750 of A Treatise of Artificial Magnets by Reverend John Mitchell, a Fellow of Queens College, that no one, not even Newton himself, had seriously attempted to establish the inverse square law of force between magnetic poles. In retrospect it seems that this was an obvious route to pursue in light of the importance of that law in gravitational actions. But no one attempted it until Mitchell made the definitive statement. Regarding magnetic action Mitchell explains that:

“Whenever any Magnetism is found, whether in the Magnet itself, or any piece of Iron, etc., excited by the Magnet there are always found two poles, which are generally called North and South; and the North pole of one Magnet always attracts the South pole, and repels the North pole of another: and vice versa.”

This is followed by the statement that:

“Each pole attracts or repels exactly equally, at equal distances, in every direction”.

In contradiction to the results of Musschenbroek, he states definitively that:

“The Magnetical Attraction and Repulsion are exactly equal to each other”,

and asserts that this overthrows the theory of Cartesian vortices because “those who imagine Magnetism to depend upon a subtle fluid” do not admit this conclusion. Continuing on he remarks that:

“Most people, who have mentioned any thing relating to this property of the Magnet, have agreed, not only that the Attraction and Repulsion of Magnets are not equal to each other, but that also, they do not observe the same rule of increase and decrease.”

Now arriving at the most important point of this discussion he states that:

“The Attraction and Repulsion of Magnets decrease, as the squares of the distances from the respective Poles increase”.

We see here that Mitchell’s statement of the inverse square law was based on his assertion that each pole of a magnet uniformly attracts or repels equally in all directions at the same distance, a principle that has the status of an unproved postulate or axiom. The axiom surely arises from his intuition that all the problems in establishing magnetic force laws can be cleared up once this principle is appreciated.

Mitchell presents his assertions regarding the magnetic force law while reviewing the experimental results of his predecessors. In commenting upon their efforts he says:

“The conclusions of these Gentlemen were drawn from their experiments, without their being aware of the third property of magnets, just mentioned [namely, each pole attracts or repels exactly, at equal distances, in every direction]; which if they had made proper allowances for, together with the increase and diminution of power in the Magnets they tried their experiments with, all the irregularities, they complained of , (as far as appears from their relations of them) might very well be accounted for, and the whole of their experiments coincide with the Squares of the distances inversely.”

Mitchell's inference that the equality of magnetic action leads to the inverse square law is not justified in his work. In modern terms we can understand the law by requiring a diminution of magnetic flux that spreads out equally in all directions from a central source. The flux density decreases as the inverse square of the distance from the center. Mitchell may have based his conclusion on this approach, but he does not explicitly present a mathematical derivation of it.

While some authors credit Mitchell with "This great discovery, which is the basis of the mathematical theory Magnetism", it is clear that he did not provide proof of his assertions, hence we most recognize him as the first to propose this law deduced partly from his own observations and partly from those of previous investigators. He regards his conclusions as very probable, but he does not

"pretend to lay it down as certain, not having made experiments enough yet to determine it with sufficient exactness."

Mitchell's assertion of the inverse square law for magnetism sets a new agenda for magnetic investigations. Following his pronouncement of this law, efforts are primarily directed towards establishing this law experimentally.

The Poor Old Loadstone Is Put Quite Out Of Countenance

In 1744, Dr. Gowan Knight, an English physician, made an important advance in the technology of magnetism. He invented a secret method to make artificial magnets and became the founder of the art and science of making artificial magnets more powerful than loadstones. The invention was important commercially because loadstones were expensive. Loadstones commanded high values in commerce, because of their use in navigation, medicine, and jewelry. They were needed aboard ships to magnetize the compass needles, which lost their magnetic properties over time. Loadstones were used as precious stones in jewelry. Isaac Newton possessed one mounted in a ring that was reported to be capable of carrying 250 times its own weight. In medicine loadstones were ground up and used in various ways to treat ailments. As a rule of thumb, a typical loadstone was valued about the same as an equivalent weight of silver. The value of an individual loadstone depended on its magnetic power and size. Obviously, more powerful and larger stones commanded higher prices in trade. The Reverend John Mitchell assures us that the justification for making artificial magnets is that "lodestones are very expensive when they are good".

Artificial magnets were not a new invention. The idea was as old as the compass. The action of stroking or rubbing an iron or steel needle to magnetize it makes it into an artificial magnet. The technical term used to describe this is "touching" by the loadstone. There was an art to the procedure which was commercially valuable. The primary method used was the single touch method. The procedure was to stroke the needle a number of times by placing or touching the pole of a loadstone at one end of the needle and drawing it along the length of the needle to the opposite end. The loadstone was then withdrawn and returned to the tip of the needle for the next stroke along its length. The process was repeated until the needle was magnetized.

Dr. Gowan Knight's invention was a new procedure for making artificial magnets called the "divided touch". These new magnets were demonstrated before the Royal Society at a meeting in 1746, but Dr. Knight did not reveal the secret of their construction. The invention is important for a number of reasons. It resulted in creating artificial magnets more powerful than loadstones that could be used to make even more powerful magnets. The procedure also provided a new insight into magnetism that became a stimulus for theory. Finally, because Dr. Knight failed to divulge his secret procedure, he challenged the scientific community to discover his secret. The challenge stimulated a new field of magnetic research that was to bear fruit in the form of new theories of magnetism. Simply put, the invention renewed a flagging interest in experimental magnetism.

The artificial magnets invented by Knight had three major advantages over natural stones. They were more powerful, retained their magnetism, and were less expensive. The divided touch method was basically performed in the following way. Two bar magnets were placed end-to-end with opposite poles together. An unmagnetized steel bar was then placed on top of the two magnetized bars with the middle of the unmagnetized bar over the junctions of the magnetized bars. The magnetized bars were then separated by sliding them apart in opposite directions along the length of the unmagnetized bar. The procedure was then repeated by turning the unmagnetized steel bar over in order to magnetized the opposite side. The procedure was repeated until the bar was sufficiently magnetized.

Here the concept of magnetic saturation can be appreciated. Experience showed that the process of magnetization eventually reached a point where repetition of the procedure did not yield an increase in magnetic power of the bar. This saturation of magnetism indicated that the bar was magnetized to the maximum extent possible. Different materials gave different results. Knight used soft iron, but later experimenters found steel to give the best results.

In 1745 at meeting of the Paris Academy in February, Henri-Louis Duhamel and Pierre Le Maire presented the discovery of a method as good as Knight's. The method which was due to Le Maire, resulted in artificial magnets as strong as those produced by Gowan Knight. They placed the unmagnetized bar on top of a previously magnetized bar and then used the single touch method to stroke the upper surface of the unmagnetized bar. This was repeated after rotating the unmagnetized and continued until the bar was completely magnetized.

Later in 1750, Duhamel, Antheaulme and Le Maire developed an improved method, after learning that Knight was producing even stronger magnets. The new approach successfully produced magnets stronger than Knight's and became the basis of the methods later developed by John Mitchell and John Canton. The unmagnetized steel bar was placed end to end with two previously magnetized bars, such that unlike poles were facing.The north pole of one facing one end and the south pole of another facing the opposite end. This procedure created a magnet circuit through the unmagnetized bar. The unmagnetized bar was then stroked by two additional magnetized bars which were held vertically facing down towards the unmagnetized bar. Each stroke was begun in the middle, with an each moving away from the center towards a pole of like magnetization. Hence the north pole moved from the center towards the north pole of the adjacent magnet, while the other pole moved towards its counterpart.

The publication of John Mitchell's Treatise on Artificial Magnets in 1750 was crowned by his announcement of his double touch method of creating artificial magnets, which he described as an "easy and expeditious method of making them, superior to the best natural ones." The method was independently developed by John Canton, and is known today as the double touch method. The procedure was based on the layout used by Duhamel, Antheaulme, and Le Maire. The unmagnetized bar was placed end-to-end between two unmagnetized bars. These bars were termed the supporters. Magnetization was accomplished by a pair of magnets separated by a small distance and bound together so that opposite poles were side by side. These two poles were then used to stroke the unmagnetized bar in order to magnetize it. The innovation in this case was that the stroking occurred with the two poles side-by-side as they were moved back and forth along the unmagnetized bar. Mitchell claimed that his method produced magnets that were superior to those made by Knight's secret method. One of the reasons for the success of the new method was emphasized by Mitchell. The magnets should be made from high-quality hardened steel,

"instead of the soft or spring-tempered, which was most commonly used, from the notion, I suppose, that such bars would receive the most virtue; whereas they only receive it with more ease, but will not retain it to so great a degree."

This became an important part of the new technology. Hardened steel was harder to magnetize, but once magnetization was achieved, much stronger magnets and longer lasting magnets could be obtained. The process was self-reinforcing. As stronger magnets were produced, they could be used to magnetize harder steel and create even stronger magnets.

Franz Aepinus's Newtonian Magnetism

By the middle of the eighteenth century, Newtonian physics was rising rapidly toward ascendancy, mainly as a result of its success in celestial mechanics. The new science was based on an empirical philosophy backed up by the deductive logic of mathematics. Meanwhile, the new science of electricity "the wonder of the age", had achieved stunning success in the hands of a new breed of natural philosophers. But this development was not the exclusive province of the Newtonians. The success of electrical science introduced a unique phenomena; science became a form of popular entertainment. This rise of demonstration science as a popular entertainment was an indication that the intellectual pursuit of science had achieved fashionable status in european society. This was largely due to the efforts of French courtesans who made science accessible to the aristocratic elite. Their method was inductive. They demonstrated science through its wonders in the form of demonstration experiments, structured in the form of an entertainment. One of the most telling aspects of their success was the patronage provided by the feminine elites of the aristocratic french cartesians. Cartesian demonstration science became fashionable in an age that craved entertainment. The most successful practioner was the Abbe Jean Antoine Nollet (1700-1770), who espoused a cartesian theory of electricity based on a circular motion of electricity.

The Cartesian explanation of magnetism attributed attraction and repulsion to the circulation of a subtle magnetic matter in the surrounding space. Clearly this should be interpreted as a form of field theory, because the action takes place in the region of space surrounding the magnet. The

Newtonian view was that the action of the force of attraction occurred within the bodies themselves with the action of matter in one body acting on the matter of the other body through intervening empty space. Hence the Newtonian theory was not a field theory because the active forces did not occur in the space surrounding the interacting bodies. The rise of electrical science had the peculiar effect that the Newtonians began advocating a field theory for electrical action. Prominent among them was the American scientist Benjamin Franklin (1706-1790).

Franklin achieved world wide fame and acclaim for his experiments in electricity which led him to the bold conclusion that lightning was a giant spark of electricity, the same as the discharge of a Leyden Jar. In 1752, Franklin's speculation was confirmed. Lightning was a form of electricity. It was the most dramatic physical discovery of the century. It marked a new phase in the march toward Newtonian ascendancy in physics. An ascendancy coincident with the new age of enlightenment. An age created by the discoveries of natural philosophy.

Franklin's theory of electricity was based on the concept of an electric fluid which pervaded all common matter. He explained electrical actions as the result of an excess of this fluid beyond the normal amount and a deficiency of the normal amount. In some cases the pressure of electric actions could cause the electric fluid to surround the empty space of an electrified body. When this occurred, it was said that the body had an electric atmosphere. Although this concept was vague, it was clearly meant to explain the effects of electric induction, which were incomprehensible in terms of the action-at-a -distance concept. The significant fact was that this theory was a field theory because it posited that the action occurred within a region surrounding the electrified body due to electric matter in the surrounding space. The new theory was a combination of both Newtonian and Cartesian concepts regarding the nature of electricity.

In the year 1759 Franz Aepinus completed a revolutionary theory of magnetism that was completely Newtonian in its methods and approach. Aepinus's <u>Essay on The Theory Of Electricity and Magnetism</u> was the first truly Newtonian theory of electricity and magnetism as well as the first attempt to present a combined theory of electricity and magnetism using the same methods. Its newtonian character is revealed in its use of quantitative mathematical methods and the existence of hypothetical forces acting at a distance. It is unique because of its apparent unification of electricity and magnetism. This unification, however, was only an apparent similarity of the laws governing the forces of electricity and magnetism. Because Aepinus did not assert the unity of electric and magnetic forces, he postulated completely different causes for them. The similarity was in the way the forces acted at a distance in accordance with the newtonian concept of mathematical force laws.

Franz Aepinus (1724-1802) was born in Rostock, Germany into a traditionally academic family of university professors. Aepinus who had a talent for mathematics and experimental methods choose physics as his profession. He learned cartesian physics from Georg Erhard Hamberger at Gottingen, and at Jena studied with the legendary mathematician Leonhard Euler. Aepinus' theories of electricity and magnetism have a curious origin. In 1756, he noticed that the mineral tourmaline produced positive and negative electricity when heated. Aepinus tells us that this behavior was marked "by the utmost similarity between this stone and a magnet. This is so obvious that I doubt that anyone who has read what I then wrote about the tourmaline has thought it without prompting. So, spurred on by this opportunity and by a brighter gleam of hope, I began a fresh, and more diligently, to explore the similarity of magnetic and electrical forces...For after I had examined the analogy of electricity and magnetism...I clearly perceived at last there is a fundamental analogy which is not open to doubt. Indeed after I had begun to transfer the Franklinian theory of electricity, emended on certain heads,to magnetism, I soon became convinced that a theory of magnetic phenomena could be constructed quite similar to Franklin's theory of electricity...". Aepinus seems to be leaping beyond the thought of the times. His imagination is bold, but there is more than just this alone.

Aepinus is a through-going Newtonian. He announces his preference for this method as follows: "I do not however inquire into the source of these primitive forces of attraction and repulsion...I leave that to the further discussion of those happy to spend time in investigations of that kind." Aepinus announces that he prefers to follow in the custom of the geometers. The method he espouses is unfortunately obscure, but it is a statement of the Newtonian method. " If they have to solve a problem depending upon the quadrature of the circle, they are satisfied to reduce it to this quardature and to show how the problem depends on it. They do not require that the qradrature of the circle be taught at the same time." Aepinus goes on to say "The eminent Newton proceeded by this method. He demonstrated how the motion of the heavenly bodies depends on universal gravity; but he did not spend energy on rooting out the source of this universal gravity."

This statement of method is clearly deductive based on mathematical principles. It is distinguished from the Cartesian method which is principally based upon induction, which Aepinus dismisses. The difference is one of principle and method. The argument centers upon the nature of scientific proof. The view of the Cartesoams is that the proof is clearly evident from induction through experiment, while the Newtonian view is that the deductive method through mathematical proof is the preferred method. It is a curious situation. The Cartesians point to the patterns of iron filings produced by a magnet as proof of the circulating magnetic fluid, here the proof is the experimental evidence. It leads in the direction of a field theory. Aepinus tells us that this type of evidence is not really relevant, it is the deductive method of the geometers that constitutes real proof. He says: "I would conjecture that the primitive and fundamental forces, whose assistance nature uses, are much the same thing in physics as transcendental quantities in geometry. The eminent Newton proceeded by this method." The Newtonian viewpoint is not a field theory, which Aepinus clearly rejects. When Aepinus refers to his modifications of Franklin's theory, it is the theory of the electric atmosphere which he has removed; the part which is a primitive field theory.

The significance of Aepinis' essay was that he demonstrated the applicability of mathematical methods to the analysis of electricity and magnetism. These methods were not received with universal approval in an era where the emphasis was on the methods of philosophizing. The mathematical approach was not universally appreciated.

Coulomb's Laws- The Triumph of Newtonian Physics

In 1785 Charles-Augustin Coulomb (1736-1806) published a series of six papers which stand as the foundation of the modern science of electricity and magnetism. In many histories, these papers serve as the starting point for the history of this science. They are famous not only because they serve as the foundation of electromagnetic science, but because they are a perfect model for the ideal of modern scientific method. They combine theory and experiment with mathematical analysis into a perfect experimental program which conclusively demonstrated that the laws of force for electric and magnetic action obey Newton's inverse square law. Coulomb's accomplishment in terms of the Newtonian ideal of method provides the capstone which finalizes the Newtonian effort to integrate electric and magnetic physics under the aegis of the Newtonian paradigm.

Before proceeding to Coulomb's experiments, lets return to the attempts to prove the inverse square law. The middle of the eighteenth century marked a revival of attempts to establish Newtonian magnetism by experimental proofs of the inverse square law. These attempts resume following the publication of John Mitchell's Treatise on Artificial Magnets in 1750. Mitchell's arguments were not based on experiments but the proofs offered by Tobias Mayer in 1760, Lambert in 1766 and finally Coulomb in 1786 were. These attempts were all directed by the effort to simplify the geometric relation of the magnetic forces as advocated by Mitchell since "Each pole attracts or repels exactly equally, at equal distances, in every direction" Mitchell's hint of a solution directed efforts to remove the geometrically complex problem that the opposite poles of a magnet both exert a force in opposite directions; creating a magnetic dipole. Newtonian theory achieved its success because the geometric center of a planet corresponds with the center of action for the inverse square force. The simplification makes it possible to analyze revolving planets as geometric points in empty space. Newtonian magnetism needed to be established by a similar geometric simplification of the magnetic forces, so that the center of action can be resolved in geometric pointlike poles of force.

On June 7, 1760 and again on January 16, 1762, Tobias Mayer (1723-1762) set out the results of his magnetic research, with the purpose of establishing a mathematical theory of the terrestrial declination and dip, in two papers read before the Royal Society of Sciences in Göttingen. Mayer, who is better known for his Lunar Tables published in 1753 which were used in navigation, died only a month after reading the second paper, before the complete papers could be prepared for publication, and the full results of his work were not published. Summaries of his presentations were published instead. Mayer's work is based on two assumptions regarding the distribution of the magnetic intensity in thin artificial bar magnets. The first was that the geometric center of the magnet corresponded with the zero point of magnetic force, and that the intensity increased in direct proportion to distance from this neutral point. The second, was that "the power, with which each particle of the one magnet acts on a particle of the other magnet, is in conformity with the distance between the two particles in such fashion that it is inversely proportional to the square of the distance". On the basis of these assumptions the summary reported that "he finds the most perfect accord between his calculation and experiments". Of course the details are not included in the published summaries.

The results of the published summaries were severely criticized by Aepinus who could not examine the details of Mayer's proof. Aepinus, who was a very experienced magnetician, immediately saw from the published summaries that Mayer's experimental proof was defective. Aepinus criticism went straight to the essence of Mayer's proof. Aepinus pointed out that, in his experience in making artificial magnets, it was certainly not always true that the geometric center of a magnet corresponded with the magnetic center, or that the magnetization varied linearly from this supposed center. Further, there were consequent poles to consider. These were poles in addition to the usual poles at the ends. It was simply not true that there are only two poles in an artificial magnet. Sometimes many more were present as well. Finally, anyone familiar with the effects of magnetic induction must know that the position of the poles and the distribution of magnetic intensity changes when one magnet is brought close to another. Hence the assumed distribution of magnetism in the two magnets can not be assured once two magnets are placed near to one another. Since the mathematical method depended upon the calculation of force using the assumed distribution of magnetism, and this distribution was certainly not established as fixed, the method could not be relied upon.

In 1972, Mayer's unpublished papers appeared as part of a collection of his unpublished work. They reveal that Mayer's experimental proof consisted of two parts. In the first experiments, Mayer measured the relative intensity of the magnetic force using Graham's method; by placing a magnetic needle at different distances from the end of a bar magnet along the extension of the magnetic axis. The oscillation period of the needle was measured for each distance and used as a measure of the force. The results were encouraging. Next, he attempted to measure the force between two different bar magnets separated by different distances. Using the assumption that "Each part [of a magnet] is thought of as attracted not... by all the unlike parts of the other magnet, but by one only, and similarly repelled by one only of the like parts; and the parts which thus act on one another are those which in similar magnets are the same distance from their centers or whose distance from their centers is proportional to the distance between their poles." (Home page 206)

Here we see that Mayer's proof depended upon the geometric simplification that the forces of the entire magnet can be reduced to forces acting between the poles conceived as geometric points. This is the essential process that made proof of the inverse square law experimentally feasible. Historian J. L. Heilbron, who concludes that Mayer's experiments did successfully prove the inverse square law, tells us that "Mayer found a good fit when he assumed that only 'symmetrical' parts of the magnet interacted...". Mayer's method reduced to its essentials was as follows. Assume the inverse law of force and then deduce consequences based on this assumption. The measured agreement between the experiments and theory proved the force law. The method was uniquely Newtonian. The same method was used by Newton prove his force law for gravity. The law of force was assumed true. Calculations were performed for the lunar and planetary orbits. The successful comparison with measured positions in the heavens was proof of the law used for the calculation of the gravitational force.

In 1766, Johann Heinrich Lambert (1728-1777) published "Analyze de Quelques Experiences Faiter sur l'Aiman" in Mémories of the Berlin Academy of Sciences. Lambert's purpose was to develop a method for the mathematical description of the interaction between two magnets. He does not entertain the ultimate causes, but concerns himself with mathematical description. While it is generally believed that he attempts to experimentally prove the inverse square law for magnetism, this conclusion is not universally accepted. Lambert uses the assumption that the force between two magnets depends on the force between the magnetic particles, which varies as the inverse square of the distance between them. Lambert was a mathematical physicist who is famous for his studies in optics, the unit of optical flux bears his name, astronomy, metrology, and non-Euclidean geometry. His foray into magnetic science is generally regarded as unsuccessful because he was unable to experimentally establish the inverse square law for magnetism.

Historians generally agree that Lambert did not successfully prove the inverse square law for magnetism. But, they do not agree on what Lambert's paper actually accomplishes. Lambert's method was essentially the same as used by the earlier investigators in the eighteenth century; the deviation exerted upon a magnetic needle placed at a distance from the magnet. Hence the force which he measures is not the magnetic force, but the dipole moment or turning couple exerted upon the magnetic needle. An examination of the data seems to show that Lambert's method demonstrates the dipole field of a magnet, a conclusion which is supported by an analysis of his data. Lambert's near discovery of the dipole field is an historical footnote, which shows the inherent difficulties present in the methods used in the eighteenth century. Lambert's contribution seems to be similar to Mayer's; the idea that the total force depends upon the summation of the force elements due to the integration of the forces from the interacting particles of both magnets. A problem which was clearly unsolvable at that time.

From the foregoing discussions, we see that Coulomb's accomplishment did not stand alone. It was the culmination of a century of efforts to prove the law of the inverse square. It built upon the mistakes of the failed experimental methods and upon the new theoretical foundations of Newtonian magnetism. It owed much of its success to the theoretical methods of Franz Aepinus one fluid Newtonian theory of Electricity and Magnetism. Coulomb however modified this by adopting the two fluid theory which had largely supplanted Aepinus pioneering effort. The two fluid theory posited two different magnetic fluids the austrial and boreal, which accounted for the north and south magnetic poles. Coulomb further posited that these fluids were confined to magnetic particles distributed throughout the magnetic material. Hence the effect of the magnetic force was to polarize the magnetic particles forcing the tow different fluids into opposite ends of the magnetic particles. When there was no magnetic force, the fluids were equally mixed, and there was no magnetic force. But, in the presence of a magnetic force, the fluids separated and created magnetic poles. This theory became the standard model for magnetic materials throughout almost all of the nineteenth century.

Coulomb's accomplishment built on the discoveries of the eighteenth century in other ways. His method used artificial magnets created using Mitchell's double touch method as improved and developed by Aepinus and others. These consisted of long thin iron wires two feet long. Magnets of this type had the advantage that the magnetic poles were located far apart at the opposite ends of the long wire. This isolated the effect of a single pole, and reduced the error caused by the action of the opposite pole.

Coulomb's success has been attributed to his invention and use of a new instrument, the torsion balance, but this neglects to consider that his success was due to avoiding the mistakes of others. From the examination of Coulomb's method, it is clear that he had carefully examined the prior art, then developed a method to avoid the known pitfalls. We are certain that he carefully read Aepinus essay, because he incorporates its methods for making artificial magnets. Coulomb was also successful in further developing the experimental techniques of Mayer and Lambert. This continued the program of geometric simplification of the magnetic forces. Where Mayer and Lambert sought to derive mathematical descriptions that resulted in a simplification of the forces acting between the poles, Coulomb took a different approach. Instead of assuming a distribution of magnetic force, Coulomb designed and built his magnets so that the assumptions regarding the concentration of force at the poles was always true. Coulomb proved this by paying attention to Aepinus. He measured the distribution of magnetism in his magnets. To assure that magnetic induction had negligible effect, he made his magnets out of long thin iron wires which yielded widely separated magnetic poles. Hence, the change in pole location contributed little to the experimental error. Coulomb's method produced magnets with all of the magnetic intensity concentrated into widely separated geometric point poles. Then using both Graham's method of the oscillating needle, and the torsion balance, Coulomb demonstrated that the magnetic force varied according to the inverse square of distance between the isolated poles.

The Century In Review

When we look back across the eighteenth century and try to evaluate its accomplishments in magnetic science, it is apparent that the most important accomplishments can be outlined as follows:

- The separation of magnetism from electricity and gravity
- The development of artificial magnets
- The demonstration of the inverse cubed and inverse squared laws of force
- The discovery that different magnetic materials varied in their susceptibility to magnetization.
- The development the magnetic fluid theory of magnetism by Aepinus in analogy with electricity.

In the standard accounts of science history, the triumph of Newtonian science is interpreted as a positive development. It completes the emergence of the modern ideal of scientific method, from out of the false methods of the Greek and Catholic Church dominated middle ages. By restricting the viewpoint to science since 1600, we see only positive progress towards enlightened science which reaches the pinnacle of perfection in the eighteenth century with the success of Newtonian method. Then building upon this success, modern science finally emerges during the nineteenth century.

This viewpoint is highly selective. It is based upon a scientific history that sees astronomy and celestial mechanics as primary to scientific development. From the viewpoint of magnetic science, the story is not as benign. Magnetic science at the end of the eighteenth century has rejected field theory in favor of action-at-a distance. This is not a progressive development. The nascent field theories of the Greeks, and the scholastic philosophers which finds tentative expression in Gilbert is nonexistent by the end of the century. Two hundred years after Gilbert's ground breaking work, magnetic theory has progressed very little. The progress in technical achievement is certainly impressive. The development of artificial magnets and the increased knowledge of terrestrial magnetism are certainly impressive, but they pale in comparison with the fact that the understanding of magnetism as a force of nature has improved very little.

The standard account of science history confuses technology and engineering with science. The progress in knowledge obtained by the Newtonian method is purely the knowledge of the engineer, the artificer, and the mathematician. Progress in natural philosophy had been neglected and languished during the eighteenth century. The Newtonians seemed to believe, once the law of magnetic force was established to be the same as gravity, then its application would solve all problems in magnetic science, just as easily as the law of gravity transformed celestial mechanics and knowledge of the solar system. This dream was never fulfilled for the electric and magnetic sciences. The steady progress towards understanding under the aegis of Newtonian method was not what happened as the eighteenth century faded into the nineteenth.

Next Chapter **Exit**

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