Yoshitaka Yamamoto, *The Pull of History：Human Understanding of Magnetism and Gravity through the Ages*, World Scientific Publishing Co. Pte. Ltd. 2018/2/28（All 944pages）

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本書は、山本義隆『磁力と重力の発見』全 3 巻（みすず書房、2003 年 5 月 22 日）の翻訳書である。とは言っても、英語版にする際、かなりの内容の改訂をおこなっているので、事実上の改訂版である。

本書はシンガポールの出版社から 2018 年 2 月 28 日に刊行された。長らく待望されていた英語版であるが、それまで 15 年の歳月を要した。刊行当時、日本語版は読書界に大きな反響をもたらした。2003 年度の大仏次郎賞、毎日出版文化賞、パルピス賞を同時受賞した作品である。

今回、事実上の改訂英語版を読了した。Preface、Introduction、全 22 章の各章を音読したあと、そのつど、各章（chapter）の目次（contents）と各章の最後にある総括的な文章（Brief Summary と私が命名）を書き写し、再現することに努めた。あくまでも、私的学習の備忘録である。これで待望の英語版を多少でも俯瞰することができるのではなかろうか、と思っている。私は本書には特別の思い入れあり、この学習メモを掲載することにする。（猪野修治）

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Preface

This book was originally published in 2003 in Japanese as *Jiryoku to juryoku no hakken* (Discovering magnetism and gravity). For the English edition, however, I have updated and substantially rewritten certain sections. To that extent, the present work represents a revised edition rather a faithful translation of the original.

In this work, I trace the evolution of man's understanding of action at a distance (also known as noncontact force) from antiquity to the modern era and consider how this intellectual evolution shaped the rise of modern science. From ancient times through the Middle Ages, magnetic force was identified as the primary example of action at a distance. In modern times, universal gravitation was added to the category of action at a distance, a step that in many respects marks the birth of modern physics.

My investigation of this theme began almost thirty years ago when I first began studying the history of science. It struck me as curious that Johannes Kepler frequently described gravitational force as magnetic. Although I searched a variety of sources, nowhere could I find a clear, satisfactory answer to the question of why he identified gravitation with magnetic force. My curiosity was further piqued by the fact that, whereas it precisely Kepler's and Newton's positing of gravitational force that laid the foundation of modern cosmology, continental thinkers, particularly Cartesians and other mechanists, emphatically rejected the Newtonian idea of gravitation on the ground that it was "occult."

As I pursued answer to such questions, I gradually came to see that the key concept in the formation of modern physics was force—above all, force in the form of action at a distance. Histories of physics, and especially histories of mechanics, have mainly traced the construction and development of the law of motion. I believe, however, that by shifting the focus to changes and transitions in concept of force, it is possible to gain to new insight into the birth of modern physics. This conviction is what motivated me to write this book.

Several points are developed in this work that, to the best of my knowledge, have never before been discussed in scientific histories. Marbode's discovery in the
twelfth century of the electrostatic force of chalcedony is one example, but others involve more than pointing out specific facts. My perspective on Thomas Aquinas, for example, no doubt differs from the mainstream view. Nonetheless, I believe the argument can be made that Thomas's theory of astrological causality, according to which celestial bodies exert force on terrestrial bodies, may have derived from the discovery around that time of the directionality of the loadstone. As I discuss at the end of Part 1, the first scientific experiments on magnets were conducted by one of Thomas's

contemporaries, Petrus Peregrinus.

Part 2 opens with an account of Nicolaus Cusanus and his proposal for the quantitative measurement of magnetic force in the mid-fifteenth century. This represented a decisive turning point in the development of the concept of physical force. It is also underlined that the Renaissance concept of magic change significantly from the fifteenth century to the sixteenth century to the sixteenth century. On religious grounds, Marsilio Ficino and other fifteenth-century thinkers rejected demonic magic (black magic), which called upon the power of demons, and differentiated it from natural magic (white magic), which made use of natural forces. Yet they did not deny the existence of black magic. In the sixteenth century, however, Pietro Pomponazzi and some other scholars no longer believed that demonic magic existed. The main focus of scientific inquiry during the latter half of the sixteenth century was natural magic. Natural magic, particularly as practiced by Giambattista della Porta, was essentially experimental, an approach that opened one of the doors to modern science. Natural magic viewed the natural world as a network of sympathy and antipathy, that is as occult actions between natural things. The remarkable properties of magnets—namely, their powers of attraction and repulsion coupled with their peculiar directionality—were considered typical of these occult actions and were the central focus of study. Thus, action at s distance was explored mainly from the perspective of magic.

This brings us to William Gilbert, a figure who plays a leading role in conventional histories of magnetic science. Studies of Gilbert, however, rarely discuss the connection between his discovery that the Earth is a large magnet and subsequent changes in the prevailing view of the universe—specifically, the rise of the heliocentric model. While Gilbert's experimental methods and his Earth-magnet discovery are recognized as a milestone in the history of modern science, his argument that the Earth is a living entity with a "soul" has generally been either downplayed or entirely overlooked. Yet his view of the Earth as a living, self-moving entity is precisely what hastened the downfall of Aristotelian natural physics (which viewed the Earth as inanimate and immovable) and opened the way to Keplerian gravitational theory. The main theme of Part 3 is the development of such theory—specifically, how the magnetic philosophy of Gilbert and Kepler led to Hooke's and Newton's elucidation of the "system of the world."

In writing this book, I was able to find answer the question that had troubled me for so long. The result, I believe, is in its own way a new and original account of the birth of modern science.

The research necessary for this work required access to a vast amount of literature. I was able to find more sources at the Japan Diet Library, but to access others I was assisted by many my friends, colleagues, and students. I am also indebted to many people for their invaluable assistance in the preparation of the manuscript. I particularly wish to express my gratitude to Ms.Masae Hayashi, Mr.Shuji Ino, Ms.Satsuki Hayakawa, Ms.Miho Kanno, Ms.Katsumi Kawanishi, Ms.Keiko Kimura, Mr.Takahiro Miyake, Mr.Noritoshi Morinaga, Dr.koichi Nakamura, Dr.Masao Nomura, Mr.Yasuhiko Oshima, Ms.Ikuko OKai, Dr.Shigeo Sawai, Ms.Mizue Taguchi, Mr.Yoshihiro Takata, Mr. kazuki Yoshimoto, and my brother, Shigenobu Yamamoto.

With regards to the English translation, I am exceedingly grateful to Mr. Dean Robson,Ms.Cathy Hirano, and Ms.Esther Sanders. Finally, I wish to thank Misuzu Shobo, the publisher of the original Japanese edition; Mr. Shogo Morita, Ms. Ayako Ishigami, Ms. Misako Nakagawa, and Mr.Takeshi Arai of the Misuzu Shobo editorial ataff; and World Scientific, the publisher of the present English edition. (Yoshitaka Yamamoto)

Introduction

As a physicist and a historian of physics, I am constantly reminded that modern physics, and indeed modern natural science in general, arose mainly in Europe. The late twentieth century saw much controversy over the way in which the development of natural science unfolded on that continent during the sixteenth and seventeenth centuries. Some focused on the revival of Platonism, others on technological achievements from the late medieval period onward, and still others on the magical beliefs prevalent during the Renaissance. In particular, the contribution of magic to the formation of modern science was the subject of much interest and controversy among scholars. There are some excellent books on science and magic, including those by such eminent scholars as Frances A. Yates and Paolo Rossi. Their writings interpret the methodology, logic, and views of nature of early scientists, philosophers, and so-called magicians and weave all of this into the fabric of science history. But they neither examine the development of individual concepts nor seek answers to specific questions.

The concept for this book arose from my conviction that historical inquiry precisely such case studies. Questions about the contribution of magic or technology, if discussed only in general terms, become mired in differing interpretations of historical documents, and definitive conclusions fail to emerge. The sheer vastness of the question "what made the birth of modern science possible?" Precludes a simple answer. To develop deeper, we need to focus on key concepts and examine their development in concrete terms.

In physics, the key concept is *force*, and more specifically *gravitational force.*

The shift from a geocentric (Ptolemaic) to a heliocentric (Copernican) model was a watershed in the development of modern astronomy. From the point of view of physics, however, merely placing the sun at the center of things was not sufficient to establish an accurate understanding of the solar system. This understanding came only with the discovery of universal gravitation as the force that enabled our sun to keep its planets in their respective orbits. As one scholar puts it, "the clear comprehension of mechanical force and the conscious incorporation of it into the basic structure of physics can be regarded as the beginning of modern science."

Very Briefly, the history of physics can be summarized as beginning with the atomic theories of ancient Greek scholars, who created the notions of the atom and void space. Two thousand years later, in the seventeenth century, came the discovery of universal gravitation, the quintessential example of *action at a distance*. Then, in the nineteenth century, the concept of field was born, and finally this led to the physics of the present day by way of the discovery of the quantum. In modern physics, the notion of action at a distance has been reduced to the concept of field, but it is indisputably true that the introduction of this notion—in the specific form of universal gravitation –marked the starting point of modern physics and played a crucial role in the history of science during the seventeenth and eighteenth centuries.

To fill in some of the details: Nicolaus Copernicus introduced a revolutionary way of understanding the cosmos; Johannes Kepler further refined Copernican thinking with his three laws, which included the statement that orbits are elliptical: and then Isaac Newton introduced the law of universal gravitation as a mathematical explanation of the physical order of the solar system. The shift posed by Copernicus was geometric, but it took Kepler and Newton to establish a basis for this shift on principles of physics and dynamics, relying on gravitational force between celestial bodies as a key concept. In 1600, William Gilbert became the first to say that the Earth was an active magnet rather than an inert limp of soil. Kepler took this idea and carried it further, arguing that the sun exerted on the planets some kind of force analogous to magnetic force. Newton's theory replaced the Aristotelian –Ptolemaic view of the universe and became the point of departure for modern physics, with the concept of gravitational force as the cornerstone of our understanding of the cosmos.

From ancient times, people recognized matter and motion, but this recognition in itself did not lead to the birth of physics. We owe a lot to Rene Descartes and Galileo Galilei for establishing a mechanistic way of viewing matter and for establishing principles of mechanics However, Descartes's system of mechanics was inadequate in that it allowed for motion to be transmitted only by collision and in no other way. For Galileo's part, he did not have the notion of force, and so he failed to view the solar system dynamically. Moreover, neither man was able to understand the significance of Kepler's discovery. It was only when Robert Hook and Newton linked the idea of force to the achievements of Copernicus and Kepler that the solar system became a subject of the study of dynamics, and with this the true meaning of Kepler's law was finally recognized. Thus, the formation and development of the concept of force was the key to the way in which the heliocentric model was completed as part of the discipline of physics and modern physics advanced with its first step toward triumph.

We can assume that People first developed the concept of force through the sensation of exertion and resistance when they lifted or carried heavy loads or when they pushed or pulled one another. The concept of force was thus anthropomorphic, and therefore it was only natural for people to believe that the intervention of some physical intermediary, comparable to an outstretched arm or hand, was required to exert on a distant object.

Even as far back as ancient Greece, Plato noted that

> as to flowing of water, the fall of the thunderbolt, and the marvels that are observed about the attraction of amber and the Heraclean stones [i.e., magnets],--in none of these cases is there any attraction.

He asserted that what appeared to be attraction must somehow be explained by contiguous action of one kind or another. Aristotle, too, thought it obvious that

that which primarily is moved locally and corporeally must be either in contact with or continuous with that which moves it… That which is the first movement of a thing….is always together with which is moved by it (by "together" I mean that there is nothing intermediate between them). This is universally true wherever one thing is moved by another.

In the thirteenth century, Roger Bacon affirmed the idea that "proximity is required as a necessary of action." Later, at the dawn of the modern age, Gilbert claimed that "no action can take place by means of matter unless by contact." In the seventeenth century, Walter Charleton, in a tone typical of the mechanists and atomists of his day, postulated as follows:

When we see a piece [sic] of Amber, Jet, hard Wax, or other Electrique, after sufficient friction, to attract straws, shavings of wood, quils, and other festucous bodies of the same lightness, objected within the orbe of their Alliciency ; and that with a cleanly and quick motion: Why should we not conceive, that this Electricity or Attraction may hold a very neer Analogy to that attraction of Gnats, by the exserted and nimbly retracted tongue of a Chamaeleon.

Charleton wrote this in 1654, just a few decades before Newton published his laws of gravity. It is "general law of nature," said Charleton, that "Nothing can act upon a Distance subject." Thus, even into the early modern period it was considered self-evident that an intermediary agent was required for any force to act on a distant object.

During the first half of the seventeenth century, Descartes and Pierre Gassendi, also mechanistic-atomistic theorists, competed with chemical philosophers of the Paraclesian school, both sides seeking to occupy the position of supremacy long held by the Aristotelians. One heavily disputed issue was weapon salve, which followers of Paracelsus believed could cure injured soldiers when applied not their wounds, but to the swords that had injured them: "Paracelsus saith," wrote one British Aristotelian critic of the notion in 1631, “if the weapon be annoynted, the wounded partie may be cured, though 20miles absent.” The use of weapon slave was derided no only, of course, by mechanists and atomists, but also by physicians who adhered to the teachings of Aristotle and Galen. The practice was rejected outright as either nonsense or magic. The refusal to accept this magical therapy can be traced back to one of the conventional belief of the times: that action without an intermediary agent is impossible. The same British Aristotelian summed up the position succinctly: “Nullum agebs agit in distans” [No action can operate at a distance] .

But the logic that rejected weapon salve also repudiated the possibility that the sun could exert a gravitational force on the Earth, or the Earth on the moon. Even Galileo denied the influence of the moon upon the tidal movements on the Earth. As a result, when Newton introduced his law of universal gravitation, he was subjected to unimaginably harsh criticism at the hands of both progressive scientists, including Cartesian epigones and Gottfried Leibnitz, and old-guard Aristotelians. Leibniz wrote : “A body is never moved naturally, except by another body which touches it and pushes it ; after that it continues until it is prevented by another body which touches it. Any other kind of operation on bodies is either miraculous or imaginary.” It was simply beyond thinkers of both the new and old school to consider tat Newton’s ideas could represent anything other than magic or astrology.

It was none other than magnetism that provided the logic to defend the notion of action at a distance. Even as early as the second century A.D., Alexander of Aphrodisias acknowledged magnetism to be the sole instance of action occurring at a distance. And in the fourteenth century, William of Ockham (most famous for Ockham’s Razor, a maxim now often paraphrased as “Entities should not be multiplied beyond necessity”) asserted that “the lodestone acts at a distance immediately and not through a medium.” Gilbert, too, who denied action at a distance in general terms, accepted it in the case of magnets. These thinkers were alike in reaching a com-sense conclusion based on the premise that direct experience is to be accepted at face value as an accurate reflection of reality.

Many shared this conception of magnetism as the singular example of action at a distance. Paracelsus, thought to be the originator of weapon-salve, gave credence to the idea that celestial bodies can influence the Earth. In his treatise “*The Diseases that Deprive Man of His Reason*”, he puts it thus:

The stars have the power to hurt and weaken our body and to influence health and illness. They do not fall into us materially or substantially, but influence reason invisibly and insensibly, like a magnet attracting iron.

A century later Francis Bacon called magnetism "an instance of divergence" and designated the motion caused by action at a distance "magnetic motion"

Because of its capacity to act without direct contact, magnetism had, since ancient times, appeared miraculous or enigmatic and was often considered to be a living, spiritual, or even magical force. In the sixteenth century, Georgius Agricola, a German physician known for his discourses on mining and mineralogy, explained that

Theologians attribute the powers this mineral [i.e., lodestone] possesses to divine origin, scientists to natural origins, the nature of which cannot be interpreted.

In 1600 Gilbert made similar observation :

Loadstone and also amber do some philosophers invoke when in explaining many secrets their senses become dim and reasoning cannot go further. Inquisitive theologians also would throw light on the divine mysteries set beyond the range of human sense, by means of loadstone and amber.

And even in fairly recent times, several renowned thinkers have associated this force of nature with the inexplicable. In the eighteenth century, for example, Scottish economist Adam Smith wrote that

when we observe the motion of the iron, in consequence of that of the loadstone, we gaze and hesitate, and feel a want of connection betwixt two events which follow one another in so unusual a train.

Even today, for those who have no knowledge of how it works, magnetism can appear nothing short of wonderful. Twentieth-century physicist Albert Einstein related the following experience from his childhood:

The development of [our] thought world is in a certain sense a continuous flight from "wonder." A wonder of such nature I experienced as child of 4or5years, when my father showed me a compass. That this needle behaved in such a determined way did not at all into the nature of events, which could find a place in the unconscious world of concepts (effect connected with direct "touch")

Were it not for our conditioning to the idea through education, motion occurring without direct contact would remain incomprehensible even today.

The story of how we have come to our present level of understanding of magnetism, historically perhaps the most incomprehensible of all nature phenomena, is a source of endless fascination . Ancient people had long used the lodestone in religious ceremonies, medical treatment, and rites of exorcism. Then Greek civilization, and with it the beginning of natural philosophy, came onto the scene, and two types of explanation for magnetism emerged: on the hand, mechanists and reductionists believed emerged : on the one hand, mechanists and reductionists believed that invisible particles or some imponderable fluid acted as an intermediary agent to effect the attraction of one object by another: on the other hand, hylozoists believed that magnetism was a living or soul-like force that defied further explanation.

In the Middle Ages, the hylozoistic view became dominant, and magnetism became a symbol for the network of "occult forces" or the working of "sympathy and antipathy." In the thirteenth century, Saint Thomas Aquinas remarked that

> in the physical order things have certain occult forces, the reason of which man is unable to assign; for instance that the magnet attract iron.

An organic view of nature, together with belief in an occult force, persisted into the Renaissance and was the basis for the magical philosophy that held sway in certain circles. Expressing ideas that were typical at the time was sixteenth-century philosopher Pietro Pomponazzi :

> The magnet attracts iron, and diamond repels it. Sapphire cures ulcers and improves eyesight. There are a number of other examples of this kind of occult force.

Magnetism was not only typical of occult force but also virtually the only manifestation of such force in the material world.

As if the lodestone's power to attract were not enough to inspire wonder, thinkers of bygone centuries also had to grapple with the observed facts that lodestones pointed north and imparted to iron needles both attractive force and northward directionality. At one time it was believed that lodestones were attracted to the North Star or to a celestial pole and that this property was bestowed upon them by the heavens. It was therefore believed that lodestones embodied some sort of sympathetic relationship between the Earth and the heavens and even offered proof of the validity of astrology. We see an early example of this viewpoint in Thomas Aquinas :

The magnet, for instance, attracts iron .....because it shares in the powers of the heavens.

An even more specific statement is offered by the fifteenth-century Renaissance humanist Marsilio Ficino :

A balanced needle influenced on its end by a lodestone points towards the Bear: this happens because the lodestone draws it in that direction, since the power of the Bear prevails in this stone; and from there it is transferred into the iron and pulls both toward the Bear. Moreover this sort of power both was infused from the beginning and also grows continually by the rays of the Bear.

Once sailors began making use of magnets in the form of compasses for navigation, the way was paved for the discovery of the Earth's magnetic field, which in turn led to the novel idea that the Earth was active and no mere lump of dirt. In 1600, Gilbert published *On the Magnet*, in which he revealed his discovery that the Earth was a giant magnet. He described our planet as a living, soul-like being, and thereafter it became possible to think of the Earth as a moving planet, a premise that was essential to the viability of heliocentrism. Soon after that, in 1605, Flemish engineer Simon Stevin wrote the following about the Earth's movement as proposed by Copernicus :

Since this motion is simply described by him [i.e., Copernicus] without any natural argument or proof, this supposition long troubled me in my mind .... But thereafter there was published the book about the great terrestrial magnet, described by *Guilelmus Gilbertus* [William Gilbert], in which the natural cause of this notion in my opinion is hit off and revealed.

Kepler shared Gilbert's view of the Earth as a magnet, and by association he conceived of the idea of a gravitational force between astronomical bodies:

> Just as the kinship of their bodies makes the loadstone attract loadstone or iron; so also in the case of the moon it is not unbelievable that she should be moved by the terrestrial body which is akin, although neither in that case nor in this case is there any contact between the bodies.

Although this association between magnetism and gravity has been almost entirely forgotten and strikes us today as rather odd, centuries ago it was crucial in inspiring scientists with the idea that celestial bodies might be exerting a force upon one another. Gilbert himself wrote, in a work published posthumously :

> The Moon is drawn to the earth by magnetism.

Robert Hook, who was one of the first to state in the form of conjecture what Newton later proved mathematically as the law of universal gravitation, explained in 1666 the part that magnetism played in the drama of the discovery of gravity:

> GILBERT began to imagine [gravity] a magical attractive power, Inherent in the parts of the terrestrial globe: the noble VERULAM [Francis Bacon] also, in part, embraced this opinion: and KEPLER (not without good reason) makes it a property inherent in all celestial bodies, sun, stars, planets.

It was none other than the magnetism-related magical discourses and practices of the era preceding modern science that enabled the concept of force—universal gravitation—to take shape and gain acceptance. Without knowing this, we might all too easily explain the birth of modern physics as merely the result of some stroke of genius by Kepler or Newton.

My writing of this book is an attempt to fill what I see as a serious gap in science history. I have sought to explain the genesis and development of modern science, placing importance on the evolution of the concept of force in Europe from antiquity to the beginning of modern times. I have focused especially on magnetic force and gravitational pull, emphasizing the contributions of both magic and technology to their discovery.

This is not to say that there is any lack of books on the history of either magnetism or gravity; on the contrary, there have been many tomes written about these subjects. Most, however, regard Greek philosophy as containing the seeds of modern science and then kip straight to the Renaissance, ignoring an entire millennium. Typically, they then state that modern science was formed during the period from the Renaissance to the early modern era through struggles against Aristotelian philosophy. In the area of mechanics, this type of neglect has been redressed somewhat since the time of French physicist Pierre Duhem, but the history of electromagnetics remains largely unstudied to this day. A case in point is Edmund T. Whittaker's *History of the Theories of Aether and Electricity*: beginning in the thirteenth century, it describes how Aristotelianism spread throughout Western Europe during this period under the influence of Thomas Aquinas, and then how William of Ockham's struggle for liberation from Thomist philosophy in the next century prepared ground for the flowering of the Renaissance and the successes of Copernicus and Kepler.

Physics is not the only subject where we see this tendency to ignore what is essentially most of the Middle Ages, Thomas Steele Hall's *Idea of Life and Matter*, for example, is s scholarly study of the history of biology and medicine, a meticulous (for the most part) genealogy of theories of life from ancient Greece to modern times. But following a discussion of Galen, a physician of the second century A.D., the camera fades and the scene suddenly cuts to the Renaissance.

Science history tends to pay only scant attention to anything that has been labeled "absurd" or "reactionary" or has otherwise drawn contempt from the perspective of modern science, such as superstition, conjecture, folklore, and religious discourse. In the eleventh century, for instance, Marbode (the Bishop of Rennes) mentioned in a poem extolling the supernatural powers of precious stones that a type of quartz called chalcedony possessed an attractive force. This discovery of a third substance, following amber and jet, capable of drawing other objects with static electricity has to my knowledge been completely overlooked by historians writing about electromagnetics. Consider also Thomas Aquinas's claim that lodestones were grated their power by the heavens Despite the importance of this idea in terms of its historical influence, few documents record how it was passed down to the Renaissance. And the contribution of Giambattista Della Porta's Natural magick to the study of magnets during the sixteenth century may not have been totally neglected but it was certainly underestimated.

So persistent has this type of thinking been that in a detailed treatise on magnetism published in the 1940s, author A. Crichton Mitchell leaves out any and all discussion of Saint Augustine, whose philosophy had an enormous and tangible impact on the understanding of magnetism for some one thousand years. Mitchell explains that he does not mention "legendary matter with the history of the subject has been diluted"; and further that

> It has also been decided to omit most of those references, chiefly from the early Church Fathers, in which magnet's attraction for iron is only used as an illustration of some doctrinal theme, and are obviously not intended as serious contributions to the science of Magnetism.

If Mitchell belittles some contributions as "not serious", it is because he is looking at them with modern eyes. We must remember that in their time these contributions were indeed very serious, and that without acknowledging the contributions and influence of key figures such as Saint Augustine, far too much is missed.

To close this introduction, I'd like to draw attention to the words of a scholar who eloquently points would-be historians toward a better way. In his preface to a work about superstitions in medieval Europe, Jean-Claude Schmitt, a contemporary historian of the Annales school, offers the following advice:

> For a long time, students of the history of Christianity, especially those who were clerics, believed that they could study Church tradition by using concepts passed down by the Church. We need, however, to reexamine the concepts most prominent in the Christian heritage, especially such deep-seated concepts as magic, superstition, and even religion. In order to be objective about Christian culture in historical terms, one must be critically distanced from Christian terminology. In other words, historians need to distinguish between the technical terms that they establish for their study and the existing terms of Christian culture, the very subject of this scholarly exercise.

Here, Schmitt is cautioning Christian historians to remember that among the lower strata of medieval European society Christianity coexisted and competed with indigenous beliefs and other religions known since antiquity. Although Christianity came out the winner and eventually dominated all other forms of religion, the history of the Middle Ages, when this contest was ongoing, cannot be well understood by passive judgements from a contemporary perspective. I believe that by replacing "Christianity" with a particular science such as "physics", "the Church" with "academia", and "clerics" with "scholars", Schmitt's warning applies with equal validity to the history of medieval science.

Schmitt adds that, "undaunted by the prospect of sounding paradoxical, I daresay that in the long period where devotion to region was domination, a true 'history of religion' did not exist". The same caveat applies in case where the yardstick of modern science is used to measure the scientific development of an era rife with an assortment of religious and magical beliefs. Again, "history of religion" can be replaced with "history of science." Scholars of the Middle Ages, after all, knew nothing of the fixed notion that we, in hindsight, have come to designate the "history of physics." If wish to truly learn about the birth of science, we must examine premodern writings about force within the context of their own times.

I am, both by training and by profession, a physicist. I know full well that venturing outside my specialty to wrote a work of history goes beyond audacity, almost to the point of recklessness—as though I were an unlicensed driver barreling through an unfamiliar neighborhood. Nonetheless, I could not resist the urge to shed light on facts that physics historians have, if not misread, at least ignored or undervalued. It is my sincere hope that this challenge will contribute to a redefining of the foundation of modern physics and, by extension, of modern science in general. It is this, the secret of the birth of science, that remains to unlocked.

Part 1 Antiquity and the Middle Age

● chapter1―Ancient Greece :The Science of magnetism is Born (3-38)

Contents

5 Theophrastus and Later Aristotelians (32)

Brief Summary (36-38)

The ancient Greeks were the first to attempt to explain magnetism. Some, such as the atomists and Plato, attempted to explain the magnet's action in terms of an invisible substance providing contact as an intermediary agent, while others attributed it to the work of a living soul. Although they diverged onto these two separate roads, they were alike in being the original pathfinders in the discovery of the concept of force.

Let's jump ahead for a moment to Gilbert, who discovered at the end of the sixteenth century that the Earth itself is a magnet. Two thousand years after the time of Aristotle, Gilbert maintained that "magnetick force is animate, or imitates life," and that "Thales, not without cause, held that the loadstone was animate." It is really not surprising that Gilbert thought the Earth, as a magnet, to be a living, active entity rather than an inert lump of soil, because he was essentially an Aristotelian, and as such he hearkened to the ancient Greek master's assertion that "what has soul in it differs from what has not, in that the former displays life." Soul, Aristotle had added, was "the essential whatness' of a body" that has the "power of setting itself in movement and arresting itself." Ironically, this belief of Gilbert's in the lifelike qualities of our planet was at loggerheads with another of Aristotle's beliefs: that the heavens revolved around the Earth.

I have already discussed Aristotle's conception of four Earthly elements and a fifth element, the ether, and their arrangement within a spatial hierarchy. Aristotle also posited a hierarchy of value corresponding to this spatial order, with the ether, as a divine substance, being ranked most highly and soil, the element forming the Earth, being accorded the lowest status and considered the most distant from any relation to living things. This way of thinking was actually not new: recall that the Milesian monists selected either water, air, or fire—never earth –as their candidates for the single original substance forming all of matter. Plato, too, singled out earth as the only one of the four elements that, because of its shape, could not transform itself. So it seems that from the very beginning of Greek philosophy, only earth is relegated to this, shall we say, base position, possessing no soul and no life, and leading inevitably to a definition of the Earth as something dull and inert. This line of reasoning lent a naturalistic basis to geocentric theory—a model of the universe in which the celestial bodies orbited a motionless Earth—and was ingrained deep in the psyches of generations of scholars and scientists.

But then along came Gilbert, who audaciously suggested that this very same Earth was a large magnet, might actually have a soul, and hence could move. Although historians generally have not dwelled upon this, part of the great significance of Gilbert's discovery is that it established a foundation, in terms of natural philosophy, for the shift from a geocentric to a heliocentric (sun-centered) model of the universe. Indeed, it offered for the first time a physical basis for the Earth's movement—however misguided that basis may seem to present-day sensibilities. In short, the focus of a number of controversies about Copernicus's heliocentric theory shifted so that discussion now centered not on astronomy but on physics. Then came Kepler, who under the influence of Gilbert developed a concept of gravitational force between celestial bodies. The details of how all of this unfolded form a major theme of his book, so I will be returning to this topic in later chapters.

Aristotle, the greatest of the ancient Greek philosophers, died in 322 B.C. His passing marked the end of the first of three periods, each lasting approximately three hundred years, into which the history of science in ancient Greece is generally divided. Politically as well, great change was in the wind. Just a short time earlier, in 338 B.C., the allied troops of Athens and Thebes were defeated by King Philip II of Macedonia (356-323 B.C.) resulting in the absorption of Greece into Macedonian empire. Philip II died just one year later, leaving his throne to Alexander III (356-323B.C.). The new king, better known as Alexander the Great, had in his youth studied under Aristotle, and died just one year before the great master. Alexander the Great is famous for his conquests, which extended across Asia Minor, Egypt, and central Asia into India. His eastern expedition widened Greek hegemony in one great sweep, but after his death the empire was divided among Ptolemy I of Egypt, Seleucus I of Asia, and Antigonus I of Macedonia, at the dawning of the Hellenistic age. The Greek city-states lost much of their power and came under the thumb of Macedonia. It was around that time that the first stage of Greek science came to an end.

●chapter2—The Hellenistic Age (39-71)

Contents

Brief Summary (68-71)
Before we leave our discussion of antiquity, let's step back from the trees and take a look at the forest. Broadly speaking, the Great philosophers fell into two camps concerning the mysterious and wonderful power known as magnetism. First were atomists (principally Democritus, Epicurus and Lucretius) and the micro-mechanists (principally Empedocles, Diogenes, Plato in his later years, and Plutarch).

These reductionists rested their theory on the premise of local action. Second were those who saw magnetism as divine and soul-like (principally Thales, Plato in his earlier years, and Aristotle) and those who subscribed to organic and holistic theories, arguing that magnetism was somehow akin to life (principally Galen and Alexander.) All those in the latter camp were alike in seeing magnetism as a form of action at a distance that could be explained no further.

Later in this book, we will see how this intellectual rift repeated itself in early modern times, when thinkers inquiring into the nature of gravity divided themselves unto mechanists on the one hand and Newtonians on the other. In the first group were those who revived the reductionist (mechanistic and atomistic) theories of the ancients in fundamentally the same form, with the premise that all action had to take place through some intermediary.

In the second group were Newton and his adherents, who championed the idea that gravitational force between the planets and other celestial bodies was simply a fact of nature. Newton considered the mechanistic models constructed by Descartes to be fantastic and dismissed them,, criticizing Decartes for "feigning hypotheses." The Cartesians, for their part, criticized the Newtonian theory of gravity whereby bodies (i.e., the planets and so on) exerted force on one another through the void of empty space. They argued that Newton had done no more than to restate the very phenomenon that they demanded be explained.

All of this was where the debates that played out in ancient Greece eventually led, but this revival of those earlier struggles took well over a thousand years to surface. After the criticism by Galen and Alexander that appeared in the late second and early third centuries, Europe seemed to lose sight of the mechanistic-reductionist view of magnetism almost completely. I say "almost" because in the twelfth century the philosopher William of Conches (c.1100-1154) made reference to Lucretius's *On the Nature of Things* in his treatise *Philosophical mundi* (philosophical of the world). But until an almost complete manuscript of Lucretius's poem was discovered in 1417 by the Italian humanist Poggio Bracciolini and then printed in 1473, this perspective was essentially gone from the intellectual landscape. Plato's *Timaeus* was one of the very few works of Greek philosophy that continued to be read in medieval Europe, but we do not see references to its mechanistic theory of magnetism in the scholarship of the Middle Ages. We do not see a revival of Platonism in the third century, but according to On *Abstinence from Killing Animals*, written by the neo-Platonist Porphyry (c.233-c.304),

a magnet gives soul to iron placed near it, and the heaviest iron become light as it rushes up to the breath of the magnet.

This, clearly, is an extension of the arguments espoused by Thales and Aristotle. And in medieval period, the influence of mysticism (with its traces of the orient) overlapped with the organic and holistic theories of Galen and Alexander.

Notice that until this point we have been considering only the attraction between magnets and iron. Interestingly, it seems that the ancient Greek were not aware of the force that magnets exert on one another.

A further sidenote is that the ancient Greeks apparently did not realize that lodestone and magnetized needles pointed north, and mariners of that time therefore did not enjoy the advantages of navigation by magnetic compass. In his 1590 work *Natural and Moral History of the Indies*, Spanish Jesuit Jose de Acosta, who had been engaged in missionary activity in the New World, noted that "there is no world in Latin or Greek or Hebrew for such a remarkable object as the compass," and asserted that the "ancients did not know of the lodestone or its "properties and remarkable virtue ….in navigation."

And further, Timoteo Bertelli, a nineteenth-century Italian historian, conducted a study of over seventy related works written in Greek and Latin between the sixth century B.C.

and the tenth century A.D. and found not even a single reference to magnets pointing northward, much less to the application of this phenomenon in navigation, astronomy, or geodetic surveying.*

We have noted that ancient attempts at explaining magnetism were neglected by Europeans for about a thousand years, as were efforts to study magnets in a scientific manner. But this does not mean that interest in the subject wanted. The mysterious phenomenon of magnetic attraction continued to be a much-talked-about source of fascination. This interest, however, was pursued from a very different perspective from that which was to emerge later with the birth of modern physics. What sort of perspective this was we shall soon see.

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*Albert the Great states in his Book of Minerals that "Aristotle in his Lapidary says "the corner of a certain kind of magnet has the power of attracting iron towards zoron, that is, the North ; and mariners make use of this. But another corner of this magnet attracts in the opposite direction, towards aphron, that is, the South Pole" (Book of Minerals,148).

This attribution of the Lapidary to Aristotle, however, is spurious; the work likely originated in Byzantium, Syria, or Persia, and was then added to and revised numerous times before being translated into Latin. The words zoron and aphron appear to be from Hebrew, and we can do no more than conjecture about when and where this isolated reference to the north-finding property of magnetized iron might have been appended.

●Chapter 3—The Days of the Roman Empire (72-102)

Contents

Brief Summary (101-102)

And so in ancient Rome we see the formation of the prototype for the way in which the magnet and magnetism, as well as the forces of nature in general, were understood in the Christian medieval period. The view that magnets were in some way alive ; the notion that magnets had not only physical but also physiological characteristics and, moreover, supernatural powers ; and the idea that all of nature operated through a mesh of interlocking relationship based on either sympathy or antipathy – this entire perspective was formed in ancient Rome.

“The science of the Dark Ages,” points out one historian,

> had a spiritual kinship with Roman science from its very beginnings. The symptoms are clearly seen in Pliny: inability to comprehend Greek science or to distinguish between absurd anecdote and sober theory, between ungrounded opinion and brilliant original thinking.

As this suggests, Roman “science,” led by Pliny, played a huge part in shaping the Middle Ages. Indeed, it is significant in this regard that Lynn Thorndike, the well-known investigator into the history of medieval science, begins his voluminous *A History of Magic and Experimental Science* with Pliny, not Aristotele.The departure represented by Pliny is likewise my reason for treating Rome separately rather than follow the example of most science historians, who lump Roman and Hellenistic civilization together under the rubric “Greco-Roman era.”

The fact is that the Roman view of nature, and in particular the web of relationships the Roman called sympathy and antipathy, had a huge influence on medieval European thought all the way up until the Renaissance. In general, that is, natural objects came to be valued for their supposed supernatural powers affecting human fate and , more specifically, for their purported physiological, psychological, and pharmacological effects on the human body and soul. The power of magnets was a typical case in point : magnetism was considered and debated primarily as something with medical effects and more broadly as a phenomenon that influenced the body, the soul, and , ultimately, even destiny itself.

But with the Middle Ages came Christianity, new thread woven into the intellectual web, and one that requires a new chapter in our story.

●Chapter 4—Christianity in the Middle Ages (103-133)

Contents

Brief Summary (132-133)

According to Kunz's *The Curious Lore of precious Stones*, the beliefs that spirits reside in stones and that gems are endowed with magical powers are found in folklore from every part of the world. In ancient Rome such ideas had probably been transmitted from Egypt or Asia, and they were certainly not compatible with Christian doctrine. It is known that the penchant for gemstones that pervaded the Roman upper classes was condemned by the early Christian church. This was not simply because it represented extravagance but precisely because gemstones were associated with magic. Far from dying out with the spread of Christianity, however, magical and pagan beliefs concerning the powers of stones actually became more firmly rooted. Zircon (jacinth) and emerald (smaragd), for example, were reportedly worn as protection against infection during outbreaks of the bubonic plague in the fourteenth century.

Nor was such lore restricted to the Middle Ages. Oral traditions concerning the inherent powers of gemstones continued into the seventeenth century in Europe. Anselmus Boetius de Broodt, regarded as the originator of modern geology, asserted in 1609 that "it is very necessary to observe that many virtues not possessed by gems are falsely ascribed to them". Nonetheless, half a century later, in a long treatise written from the then new mechanist perspective and titled *An Essay about the origin and Virtues of Gems,* even Robert Boyle, the English natural philosopher who, along with Galileo in Italy and Descartes in France, was at the vanguard of the seventeenth-century scientific revolution, wrote: "I will not indiscriminately reject all the medicinal virtues that traditions and the writers about precious stones have ascribed to those noble minerals."

Thus, the perception that gemstones and magnets were magical persisted unabated in Europe. In fact, Christianity never completely supplanted indigenous folk religion. Instead, it close for the most part to quietly tolerate and coexist with pagan elements and folklore by cloaking them in Christian doctrine, though occasionally branding one or another for rejection as heretical or magical. Although medieval Europe was ostensibly dominated by Christian ideology, at a deeper level pre-Christian, pagan, indigenous, and folk spiritually lingered on and, in its own way, continued to arouse people's interest in nature.

This trend was particularly conspicuous in the field of medicine and healing. In the Middle Ages, medical treatment had a strong indigenous, magical, and pagan character. Interest in magnetism during this period was predominantly focused on its supposed medicinal properties, understood in a broad sense that included mental healing and psychi or spiritual effects. For this reason, it was intimately tried to the study of pagan and magical arts, despite the fact that European society was dominated by Christianity. Even leading scholars of the medieval Christian world—Marbode in eleventh-century France; Bartholomew in thirteenth-century England, and the illustrious thirteenth –century philosopher Albert the great of Germany—openly proclaimed the magnet's supernatural, magical powers. This alone is a striking testament to magnetism's unique hold on the imaginations of the people of that time.

●Chapter 5—The Discovery of Magnetic Directionality (134-164)

Contents

Brief Summary (164)

Let us review the shift covered in this chapter. Two key developments occurring mainly in the twelfth and thirteenth centuries revolutionized Latin Europe's understanding of nature and precipitated a philosophical and social transformation. These included, first, the discovery of Aristotelian Philosophy—the greatest legacy of the ancient Greek world— and of the works of then-contemporary Islamic philosopher Averroes ; second, the development of towns and cities and the emergence of universities.

In terms of magnetism in particular, the discovery of directionality in magnetic needs and magnet set the stage for the subsequent discovery of magnetic poles. Moreover, the fact that the phenomenon of directionality was also perceived as a straightforward example of the influence of the heavens on terrestrial bodies precipitated a momentous change in the concept of force. The various phases of this philosophical and social transformation were expressed at roughly the same time, beginning in the late 1260s, in the philosophies of Thomas Aquinas, Roger Bacon, and Petrus Peregrinus. And here is where we begin to glimpse the embryo of modern physics.

●Chapter6—Thomas Aquinas and his Understanding of Magnetism (165-194)

Contents

Brief Summary (192-194)

In his writings, Thomas was constantly discussing one or another issue of natural science. At bottom, these wide-ranging references were united by a single viewpoint: the idea that the attributes and behaviors of any given thing could be deduced through a process of logical reasoning as long as one began with a correct understanding of the natures of things. In other words, a fact could be considered proven if it were deduced from a general principle. This idea, which formed the basis for the rational ideologies of Scholasticism, from came into being in an ancient Greece and was then transported into the Europe of the thirteen century as part and parcel of the work of Aristotle. In On Being and Essence, written something between 1250 and 1260, Thomas assert that "a thing is intelligible only through its definition and essence" and that "essence" is that which is signified by the definition of thing." For him, truth was to be found in the world of words: "When I desire to grasp the essence of a stone, I must arrive at it through a process of reasoning." Accordingly, he placed little emphasis on observation and experimentation, even within the realm of natural science. In fact, we cannot find anywhere in Thomas's writings a single observation about the natural world that goes beyond what was left to history by Aristotle.

To begin with, Thomas—unlike his mentor Albert the Great – had never had much interest in natural philosophy per se. Instead, his interest lay in the principles of theology and metaphysics, and he discussed natural philosophy, which he considered to be one of the "lower" branches of learning, only to the extent that it contributed to an understanding of those principles. In his *Commentary On the Metaphysics of Aristotle*, for example, he includes a very long, drawn-out treatment of Aristotle's model of the cosmos whose sole purpose is to offer a proof of the existence of God : "Hence it follows that the whole universe is like one principality and one kingdom, and must therefore be governed by one ruler. Aristotle's conclusion is that there in one ruler of the whole universe, the first mover….whom above he called God , who is blessed for ever and ever." And in Thomas's view, this "one ruler," God, does more than to merely keep the celestial spheres in motion: "The intention of the First Mover and Orderer, namely God, must extend not only to certain beings but even to the very last ones. Therefore all thing are subject to His providence." This "executors" of this divine providence are the "lower separate intellects …that we call angels." It is not only that these being move the heavenly bodies, but also that these bodies—for example, the fixed stars, planets, and the moon—have souls of varying levels and impart the power of the angels to the minerals, plants .animals, and human of the Earth.

In all probability, however, Thomas's theory of magnetism as a power imparted to lodestones by heavenly bodies was not founded on his metaphysical basis alone. It seems quite clear that his beliefs were also based on empirical knowledge of magnetic polarity and of the fact that magnetized needle pointed northward. In this sense, Thomas embodied Scholasticism and all the significance and limitations that that philosophy was to have for the formation of modern natural science.

●Chapter7—Roger Bacon and the Propagation of Magnetic Force (195-225)

Contents

As we have seen, Bacon proposed that magnetic force, like light, was propagated through the medium of air within a finite amount of time. Moreover, he explained this phenomenon within Aristotle's schema of causality, using the framework of potentiality and actuality. Here, let us recall that the term "species" was also called "likeness" and consider together with this Bacon's statement in *Opus majus* that the magnet attracts the iron "because of the similar nature" of the two (OMJ,631). It seems clear that Bacon used Arisotle's theories to reinterpret and demonstrate a new basis for idea that like attracts like –a proposition that had been around since the time of Democritus and Plato, But to the extent that Bacon took this approach, magnetic force remained mysteriously cloaked in the shadows cast by the limitations of Aristotelian natural philosophy. Bacon advocated experiential science, stressed the importance of experimentation and mathematics in natural philosophy, and proposed the technological application of natural force as the ideal purpose of intellectual endeavor. In the case of magnetism, however, he did not practice what he preached. As we will see in the next chapter, this was left up to Petrus Peregrinus. (pp.224-225)

●Chapter8—Petrus Peregrinus and his Letter concerning the Magnet (226—260)

Contents

Brief Summary (259-260)

In the history of experimental research concerning the magnet, Peregrinus was a pioneer, the first to demonstrate that magnets were north-south dipoles and that like poles repelled each other while oppsite poles were mutually attracted. The late thirteenth century was a time of transition, a period when Europeans seemed ready to shed the old, medieval ideas about magnetism, ideas fraught with mystery and superstition, that had prevailed since the time of Dioscorides and Pliny. This shift started with Thomas Aquinas, who restored the influence of Aristotelian philosophy and gave his sanction to the idea that the rational study of nature did not necessarily violate the teaching of the Bible, it continued with Roger Bacon and his advocacy of experimental science and emphasis on the practical application of natural philosophy; and it was taken still further by Petrus Peregrinus and trailblazing work in experimental research. And so, as one scholar points out, the thirteenth century came to a close with signs of reform to come. Nonetheless, in the fourteenth centuries at least, there was no further expansion in the study of magnetism stemming directly from these developments —with the sole exception of the work of Nicolaus Cusanus, as we will see in the next chapter.

Despite, having theorized about the north-pointing property of magnets, Peregrinus was completely unaware of the role that the Earth played with respect to this phenomenon. But his ignorance here is quite understandable. After all, in order to see the effect that the Earth had on magnets, people first had to discover the Earth itself. This had to wait for the age of discover and exploration and for a time when people were ready to dispose of the long-unquestioned assumption that the Earth was an inert, motionless lump of soil. It had to wait for the long, slow passing of the entire fourteenth century and the first half of the fifteenth, during which period Europe wallowed in poverty and stagnation due to waves of famine brought on by adverse climate as well as to repeated epidemics of plaque. Eventually, however, much of this hardship passed, and the Middle Ages gave way to the Renaissance.

Part 2 Renaissance

●Chapter9—Nicolaus Cusanus and the Quantification of Magnetic Force (263-283)

Contents

Brief Summary (282-283)
And so Nicolaus Cusanus, who asserted that quantitative measurement was the foundation for understanding nature, was the earliest known thinker to point out the importance of measuring force—for our purposes, gravity and magnetism. If this line of inquiry had been diligently pursued at the time, there would have ensued a shift from

ontological questions concerning why magnetism existed to functional questions concerning how it operated, and that point begun its metamorphosis into the modern, quantitative science of physics. As it happened, however, that evolution was not to occur for quite some time.

Instead, as the renaissance unfolded, ideas about magnetism shifted to a Hermetic view of magnetic force as type of magic. The, in 1600, Gilbert revived the Aristotelian idea of magnetic having a kind of "soul." Meanwhile, Della Porta took up Cusanu's novel proposal of measuring magnetic force as part of the practice of "natural magic." It was from that point on that thinkers and scholars gradually moved toward modern understanding of magnetic force.

The road to modern science was, however, neither straight nor simple. The modern scientific concepts and methods familiar to us today had to be incubated within a climate of diverse premodern ideas that now seem distinctly unscientific. (pp.282-283)

●Chapter10—The Rediscovery of Thing Ancient: Magic in the Early Renaissance Period (.284-316)

Contents

Brief Summary (314-316)

For people of the Renaissance, nature was an aggregate of symbols and metaphors, the universe was a gigantic network of power, and magic was nothing less than a profound philosophy and sacred technology that gave man the ability to sense and decipher the meaning hidden within all natural things by becoming one with universe and to manipulate this network of power, which extended to all things. Most importantly, the magical thought of Ficino and Agrippa became vehicles for open discussion of the conviction that man could, by studying nature, harness the power of the universe and nature's energy. In this way, Renaissance magical thought was to become one of the driving force behind the subsequent development of scientific technology.

But modern science did not sprint out of the starting block from that point in time. Ficino and Agrippa ended their work one step before natural magic approached empirical science. They, and especially Agrippa remained medieval thinkers, not because they believed in and discoursed on magic but rather because they regarded texts and oral folklore from ancient times on with an uncritical eye, believing these sources to have absolute authority. Although Agrippa wrote repeatedly on the lodestone, all of his statements on that topic were copied from Pliny or others, and it is unlikely that he ever took a lodestone in his hand and conducted experiments on it. One can only concur with the observation that the great enemy of scientific progress was not speculation and experiments in natural magic, but the old fossilizes bookish learning.

It was to take a great thinker of the 1500s to transcend this limitation

Most historical surveys make no distinction between the magic of the 1400s and the 1500s, but in fact the magic of these two periods should be viewed as qualitatively different, or at least representing two distinct stages. As we have, neo –Platonism and Hermetism had a significant impact on the former, but the latter, as we will discuss later, was inspired by Roger Bacon and greatly influenced by Aristotle. For this reason, whereas the magic of the 1400s tended to be more religious and speculative, enmeshed in a world of words, the magic of the 1500s was empirical, mathematical, and practical in nature, and it tended to be paired with technology passed down by craftsmen. It is from this later type of magic that modern science, with its experimental methods, mathematical reasoning, and pursuit of technical application, is thought to have arisen—a subject that will be discussed in detail in later chapters.

At any rate, magical thought –the conception of nature as full of things that mutually interacted and of man as able, through observation, to understand nature's powers—was to prepare the way for the discovery of the law of universal gravitation, the key concept of the modern physics eventually initiated by Johannes Kepler, Robert Hooke and Isaac Newton . The idea that distant celestial bodies could influence terrestrial bodies, originally an astrological concept, was a part of Renaissance magical thought concerning the interaction between the macrocosm and the microcosm.

However, before European could become aware that this idea also pertained to the existence of a physical power acting between the Earth and the sun or the moon, they first had to reexamine and rediscover the Earth itself, and this required the expeditions of discovery and exploration that came with the age of great ocean voyages. In the next chapter, therefore, we turn our gaze to the events of this era and to the discovery of the Earth's magnetic field.

●Chapter11—The Age of Exploration and Discovery of Magnetic Declination (.317—356)

Contents

Brief Summary (355-356)

The use of the nautical compass during the age of exploration brought about the discovery of magnetic declination, which, together with the discovery of inclination, had huge implications for our understanding of the Earth. (W will discuss inclination in the next chapter.) As knowledge unfolded, the ancient and medieval notions of a "magnetic mountain" in a place vaguely referred to as India gave way to the sixteenth-century idea that such a mountain existed in the Arctic Circle, which in turn led to the concept of a "magnetic pole." This discovery made it possible for Gilbert to realize that Earth itself constituted a single gigantic magnet. Late in the sixteenth century, Giordano Bruno remarked as follows in *Essay on Magic*:

> It is not easy to explain why magnetic attraction occurs at the pole of the earth, especially if what some say is not true, namely, that in that region there are many large magnetic mountains.

Although this excerpt implies skepticism about the existence of magnetic mountains per se, it nonetheless makes clear that by this point in history the shift to an understanding that magnets got their power from a terrestrial pole was more or less complete. In other word, some thinkers who came just before Gilbert were a hair's breadth away from anticipating his understanding of the Earth itself as a magnet.

Moreover, this entire intellectual process entailed a movement away from the medieval view of science as an exercise in textual interpretation— a kind of exegesis – to a view of science as an exercise in the observation and measurement of actual natural phenomena, with mariners and craftsmen and soldiers now participating in scientific activities. And shift was to take even clear shape with work of the man we are about to meet, the British mariner and compass maker Robert Norman. (pp.355-356)

●Chapter12—Robert Norman and The Newe Attractive (357—384)

Contents

Brief Summary (383-384)

The discovery of magnetic dip by the sundial maker Hartmann and mariner and instrument maker Norman, which followed on the heels of the discovery of declination, set the stage for the realization that the Earth itself was a magnet. These discoveries were clearly by-product of the remarkable development of long-distance travel, with its use of the magnetic compass. At the same time, the discovery of dip heralded the emergence of craftsmen and mariners as the new agents of progress in natural science.

The voyages of exploration went hand in hand with a shift from the former preoccupation with book learning to a zeal for knowledge based on experience. Above all, this had the effect of increasing man's understanding, particularly of the magnet's relationship to the Earth, but it also led to the emergence of a new type of scholar. Within this context, both technology and magic underwent a metamorphosis that would lead to their convergence in modern science. Through the efforts of such unique men as John Dee, the road to modern science would be paved by, on one hand, the reconciliation of an emerging experimental science practiced by craftsmen and engineers and, on the other, revived magical thought. In deed Dee and other believers in magic had a very strong interest in technology. The nature of the reconciliation they helped to effect will become clearer in subsequent chapters when we examine Girolamo Cardano's research into static electricity and Della Porta's study of the magnet.

●Chapter13—Mining and the Continued Peculiarity of Magnetism (385-417)

Contents

Brief Summary (419)

Technologies related to mining, to navigation, and to warfare expanded rapidly from the second half of fifteenth century and on into the sixteenth. In the sixteenth century, mining engineers an seamen, as well as soldiers and military surgeons, began to engage in substantive inquiry into and discourse about these technologies and to take up questions that expressed related theoretical problems. Moreover, such discourse took place in the native languages of the participants rather than in Latin. The emerging book-printing and publishing industries accelerated this trend and broadened the urban population's intellectual interest in the natural world and technology. The seismic shift this effected in the world of knowledge was nothing short of a cultural revolution. Among the university-educated as well, there now began to appear those who took up as topics of scholarly research the very issues of technology that academics had previously ignored.

Biringuccio's *The Pirotechnica and Agricola's De re metallica* were two products of this trend. In both works, the authors present consistently empirical discussions based on real-life experience, marking a clear departure from the argument-based scholarship of the universities, which was dependent on past authority and literature. Yet, when it came to the magnet, even these two comparatively modern figures unquestioningly repeated the superstitious tales passed down in Europe over several millennia. Despite their empiricism and positivism, these thinkers appeared to suddenly take a giant step backward when dealing with the subject of magnetic force.

As things thus stood in the mid-sixteenth century, the puzzle of action at a distance as manifested by magnetic force remained a major impediment to the advancement of modern science.

●Chapter14—Paracelsus and Magnet Therapy (420-446)

Contents

Brief Summary (445-446)

The sixteenth century saw much technological development coupled with a widening chasm between Scholasticism and the facts of reality. Out of these changes emerged the modern approach to scientific research, which values experience and is informed by the productive labors of engineers and tradesmen. Yet the road to empirical modern science war far from straightforward. Some form of theoretical framework was needed in order to judge, articulate, and systematize observed facts and experiences and make them more readily comprehensible. As people's experience expanded and Scholasticism's lack of usefulness became apparent, an intellectual vacuum developed and was soon filled by astrology and alchemy, as well as magical thought, all of which together provided the logic for understanding nature based on experience and practical activity. For a time, these disciplines served in place of a new foundation for scientific endeavor. "To the sixteenth century world at large," indeed, the scientist was mage rather than sage.

This magical view of nature nonetheless engendered a perspective that defeated the Scholastic view. The alchemist saw the Earth as a living, productive entity with the power to grow metals un its womb, and this led to the view that the Earth was an agent that moved of itself and could influence other things. This perspective ultimately destroyed the Aristotelian model of the cosmos in which the Earth was a lowly, inert lump of soil and the superior celestial spheres revolved independently of it. Coupled with the astrological view that celestial bodies affect object on Earth, this new view of the Earth made possible the concept that the planets influenced each other. Certain key modern scientific concepts, including that the Earth is a magnet and that gravitational pull exists between planets, were, in fact, discovered within this context. We will soon see how that process unfold through the ideas of Gilbert and Kepler, but in preparation, let us first take a brief look at the changes in magical thought that occurred in the sixteenth century.

●Chapter 15—Changes in Magical Thought during the Late Renaissance (447-490)

Contents

Brief Summary (489-490)
When the Platonic of Florence, influenced by both neo-Platonism and Hermeticism, revived magic in the 1400s, they recognized two types of magic-demonic and natural. For religious reasons, Marsilio ficino and others hesitated to discuss demonic magic at all, although they did believe in its existence. But the thinkers of the 1500s, influenced by Roger Bacon and by Aristotle, dismissed demonic magic on philosophical grounds. They rejected the transcendental perspective, which held that magic and miracles occurred at the whim of demons and angels, and therefore thought demonic magic to b bogues.

With this philosophical orientation, in the 1500s experience, observation, and experimentation led the way, shedding light on occult forces that were understood to be amenable to manipulation in accordance with natural laws. Natural magic practiced in this manner took on the form of what we can call premodern physics, evolving into something both secular and technological. John Dee imbued natural magic with a mathematical and technological character, and others used it to develop experimental techniques and to inform their observations of real-world phenomena. And because magnetism and state electricity were seen as exemplars of the so-called occult forces that were at the heart of magical thought, these two phenomena in particular became the subject of much observation and experimentation in the field of natural magic.

But the most important development for our purposes here was the realization that mathematical reasoning and experimental technique were not in themselves incompatible with magic. Moreover, the demand arose for rational explanations of unseen forces once figures such as Cardano and Bruno had smuggled the reductionist theories of mechanism and atomism into the arena of magical thought. "In early modern Europe," notes Paolo Rossi, "magic and formed a web not so easily unraveled." Driven by seafarers, tradesmen, and military men on the hand and by magicians, astrologers, and alchemists on the other, during the latter half of the sixteenth century, research into magnetic force was on the verge of a momentous confluence with the intellectual streams of experimental physics and rational reasoning.

●Chapter16—Della Porta's Investigations into Magnetism (491-532)

contents

Brief Summary (531-532)

In *Natural Magic*, Della Porta shows that both the iron-attracting power of magnets and their magnetizing effect are cases of action at a distance, and observes that these forces diminish with distance. By proposing, as Cusanus had done, that magnetic force can be quantitatively measured, and furthermore by developing the concept of "sphere of virtue". Della porta helps pave the way toward the understanding of force expressed in modern physics as mathematical functions.

Moreover, by experimentally testing and thereby refuting many long-standing myths about magnets, Della Porta relegates many magnet-related superstitions to the past and facilitates the shift from textual magic to experimental magic. *Natural Magick* further prepares the ground for modern science by breaking away from the medieval

esoteric approach to understanding nature and by encouraging the demystification and popularization of magic.

Thus, through Della porta, Renaissance magical thought reached the threshold of modern scientific and technological thought. Although his writing on magnetism remained hylozoistic, Della Porta freed the discourse on magnets from many superstitions and misconceptions, thereby illuminating the path toward a more scientific understanding. What he lacked, crucially, was the broad perspective and theory necessary for articulating and systematizing the many separate empirical phenomena that he investigated.

Part3　The Dawn of the Modern Age

●Chapter17—William Gilbert's On the Magnet (535-590)

Contents

Brief Summary (595-598)

Gibert's achievements were significant. First, he distinguished the science of electricity from that of magnetics. In doing so, he laid the foundation for experimental study of electricity by conceiving the "electric versorium" namely electroscope, and with his model of electric force as action through a medium of effluvia he provided both the experimental and theoretical starting point for subsequent studies on static electricity. Second, by discerning that the Earth was a giant magnet, he founded the science of geomagnetism. And third, through a "magnetic philosophy" positing the Earth as an active entity endowed with magnetism as its primary form, he provided, albeit imperfectly, a natural-philosophical and metaphysical explanation for the Earth's self-motion as demanded by the heliocentric theory that had emerged half a century earlier. This last achievement has received scant recognition in science historiography because it is so alien to subsequent scientific thinking. But in the early seventeenth century, when modern physics and modern view of the universe were just emerging, this was the point that had the greatest impact, because it also dispelled the ideological underpinning of the geocentric model—specifically, the notion that the Earth being inferior to other astronomical bodies, was inert and unable to move on its own. The influence of Gilbert's idea is clearly evident in Galileo's comment, made ten years later, that the Earth is "movable and surpasses the Moon in brightness, and …. is not the dump heap of the fifth and dregs of the universe." Gilbert's magnets philosophy was carried on by Kepler in Germany and John Wilkins and Robert Hooke in England and become a major driving force in the formulation of a new cosmology. It thus served as a vital bridge from the geometrical Copernican hypothesis developed in the mid-sixteenth century to the modern physics-and dynamics-based cosmology that emerged in the second half of the seventeenth century.

On the other hand, Gilbert's arguments themselves were far from modern in character. By this I mean more than simply that he engaged in metaphysics and slipped into a species of hylozoism. More importantly, whereas the laws of modern physics must be founded on quantitative measurement and expressed mathematically, Gilbert showed no inclination whatsoever for such an approach. Rather, in the interpretation of experiments his theory followed Aristotelian natural philosophy, a *qualitative* physics. Although this thinking proved useful on the qualitative side—such as in distinguishing electricks from non-electricks—it was completely devoid of aspiration toward precise quantitative measurement. There is also Gilbert's remark near the beginning of *On the Magnet* that "after the magnetick nature shall have been discloed" by his teatise, "all darkness [i.e. in thought on the subject] will disappear"(OM 1.1:7), a claim that betrays a thoroughly Scholastic outlook. In short,the purpose of his inquiries was to exhaustively explore the essential nature of magnets, not to establish laws of magnetic force. Gilbert in fact appears not to have made any quantitative measurements; despite attaching great importance to magnetic dip, in *On the Magnet* he cites not a single measurement concerning that phenomenon, not even one of Norman's, nor, indeed, concerning anything.

Zilsel points out that, whereas Gilbert referred to many ancient and medieval scholars, he never mentioned Euclid, Archimedes, or Vitruvius, who were well known in Europe in Gilbert's time. "The three omissions," Zilsel concludes, "show that Gilbert was not concerned with the mathematical literature of the period, [and] that he was not interested in mechanics." To this one can add that *On the Magnet* also fails to mention either Robert Recorde or John Dee, who widely known in England and are indispensable to any discussion of the new mathematical technology and science. Accordingly, the nature of Gilbert's experimental and observations were fundamentally different from those conducted in the seventeenth century by, say, Galileo on inclined planes, or Robert Boyle and Robert Hooke on atmospheric pressure. While praising *On the magnet* highly, Galileo also chided that "what I might have wished for in Gilbert would be a little more of the mathematician, and especially a through grounding in geometry" In that sense, Gilbert can be viewed, as Kay puts it "not as the anticipation of the seventeenth-century [sic] but as the culmination of the sixteenth" It is also worth mentioning in this connection that some have credited Edward Wright as the true author of the most mathematical and technical portion of *On the Magnet,* chapter 12 of book 4.

Nonetheless, it was under the tremendous influence of Gilbert's work that Kepler developed his new astronomy. Kepler's law of planetary motion represented the very first law of physics that were modern in the sense that they were expressed in terms of mathematically rigorous concepts and supported by quantitatively precise observations. Kepler announced the first and second laws in 1609, just nine years after the publication of On the Magnet, and the third law in 1609. From these laws on the one hand and Gilbert's magnetic philosophy on the other, Kepler derived the pivotal concept of gravity acting between astronomical bodies, and it was from this point that the modern view of the universe evolved. In other words, Gilbert's magnetic philosophy provided the foundation for the view of the Earth from which Kepler conceived his idea of gravity, as we will examine in the next chapter. Thus Gilbert's surmise that the Earth moved of its own accord because it was a magnet became an important inspiration for the dramatic advances in physics that followed in the seventeenth century.

●Chapter18—Johannes Kepler and the Magnetical Philosophy (599-653).

Contents

Brief Summary (650-653)

Although Kepler sowed the seeds of the concept of universal gravitation, the premises behind his thinking were not entirely modern. In book 4 of *Epitome of Copernican Astronomy* he offers the following account of the sun's role as a source of power:

> The function of the sun in the world seems to persuade us of nothing else except that just as it has to illuminate all things, so it is possessed of light in its body; and as it has to make all things warm, it is possessed of heat; as it has to make all things live, of a bodily life; and as it has to move all things, itself is the beginning of the movement; and so it has a soul in itself.(ECA,897)

It must be admitted that, even while on the one hand attaining a quite modern view of force and motion, on the other Kepler failed to make a complete break from the hylozoistic view of the sun and other celestial bodies.

It is also known that Kepler practiced astrology. This was at least partly to make a living, but it is still not clear what he really thought of the practice. While on the one had critical of the kind of irresponsible astrology that was popular around town, on the other he warned his fellow intellectuals that "while justly rejecting the stargazers' superstitions, they should not throw out the child the bathwater." Ultimately, it seems, he accepted some part of astrology, with certain reservations. In book4 of *The Harmony of the World* he rejects superstitious astrology as dubious but affirms what he regards as strology proven empirically. The latter kind refers to his "theory of aspects" an "aspect" being "an angle formed at the earth by the luminous rays of two planets which is effective in stimulating a sublunary being." At very least, Kepler allowed that the disposition of celestial bodies exerted some kind of influence on terrestrial bodies, and he maintained that stance throughout his entire life.

In *The Mathematical Praeface*, John Dee describes "Astronomie" as "an Arte Mathematical, which demonstrateth the distance, magnitudes, and all natural motions, apparences, and passions propre to the Planets and fixed Sterres: for any time past, present and to come; in other words, a merely descriptive science of the heavens that does not inquire into the physical causes of the motions of celestial bodies. He contrasts this with "Astrologie," which he describe as "an Arte Mathematical, which reasonable demonstrateth the operations and effects, of the natural beames, of light, and secrete influence: of the Sterres and Planets: in euery element and elementall body: at all times." Correlating this distinction to Kepler's distinction between astronomy prior to Copernicus and his own "celestial physics," we can see that his "celestial physics" was actually closer to Dee's idea of astrology, and that in that sense the astrological view of nature was one of the sources of the concept of gravitational force between astronomical bodies.

Among example of celestial influence, along with the moon's effect on sea and river tides Dee also cites "Force, as they see in a little peece of a *Magnes stone*: which, at great distance, shewth his operation." Here too, then, magnetism provides the model for action at a distance between celestial bodies. Moreover, if instead of "secrete influence" we call that action "gravity as action at a distance." We see how close Dee's "astrology" came to Newton's theory of tides. A further break with previous thought was the move to quantify gravity and comprehend it by mathematical concepts.

For Kepler, too, who was already under the influence of Gilbert's magnetic philosophy, magnetism was the model for force acting over distance between planets. Modern mechanics and modern astronomy began when Kepler conceived of the force exerted between celestial bodies (gravity) as something akin to magnetism. Unlike in previous astronomy, which had sought to determine the orbits and positions of the individual planets separately, his starting point was to regard the entire solar system not as a miscellany of planets but as a single, harmonious dynamical order and to elucidate the underpinnings of that order –In other words, to interpret in physical terms the mathematical, heliocentric solar system of Copernicus. He sustained that approach consistently from the platonic solids theory of his debut work, *The Secret of the Universe*, right up to the establishment of his third law of planetary motion in *The*

Harmony of the World, written toward the end of his life. The result was the idea of a force that acts between astronomical bodies and can be expressed as a single mathematical function. This was something that could not be found in the philosophies of either Aristotle or Plato. If one had to identify its precursors, they would be the "hidden powers" speculated upon in natural magic and astrology and epitomized by magnetism.

I have noted that by inquiring into the physical causes of the motions of heavenly bodies Kepler revolutionized astronomy, but that also implied a revolution in physics itself. When he remarks in his introduction to New Astronomy that "I have mingled celestial physics with astronomy in this work" (NA, Introduction,47), we can infer that until then physics(natural philosophy)and astronomy were regarded as separate. Previously, astronomy, though geometrical and quantitative, did not involve ontology and therefore did not inquire into causes; while natural philosophy, which did seek causal explanations, was nonetheless a qualitative discipline that eschewed quantitative understanding and mathematical representation. Kepler made it possible to combine astronomy and physics, on the one hand by infusing astronomy with an efficient cause (the concept of force) and causal understanding, and on the other by understanding gravity—something previously bundled together with "hidden powers"—as a mathematical function and thus preparing the ground for physics (natural philosophy), too, to become a quantitative discipline.

In terms of Dee's distinction, the essence of the pivotal shift Kepler made was his reinterpretation of "Astronomie" and "Astrologie" by incorporating both. If so, then rather than considering astronomy to be the child of astrology, it is perhaps more accurate to say that astrology's "secrete influences" and magic's "hidden powers" were reincarnated in the form of physical force represented as a mathematical function; and that what until then had been astronomy as geometry and astrology as s study of force (influence) were both integrated and sublated into a dynamical astronomy (celestial mechanics). This achievement then gave rise, via refinement in Newton's more correct law of motion, to modern physics. In that sense, it was the point where the history of the physics of magnetism and gravity finally began.

●Chapter19—Seventeenth-century Mechanism and Notions of force (654-693)

Contents

Brief Summary (691-693)

In its impatience to "explain" forces that Renaissance magical thinkers had previously discussed in such terms as "occult powers" and "sympathy and antipathy," early-seventeenth-century mechanism threw up one arbitrary model after another. But no matter how ingeniously one crafts a mechanical model of transmission of force using ideas about "minute matter" or "effluvia," until one can confirm the existence of the "grooved particles" or "magnetical atoms" or whatever one suppose, it is just speculation; it does not lead to the formulation of a new theory of physics. As the antithesis of magical thought, such naive mechanism tried to dismantle magic, to expose the hidden cogs and levers underlying seemingly magical phenomena; but insofar as it was preoccupied with that task it remained no more than magic inversed.

Nonetheless, to people fed up with previous notions—with "substantial form" and "sympathy and antipathy," with Scholasticism's fruitless inflation of terms, and with the vague, expedient explanations offered by magical thought – the simple, straightforward arguments of mechanism had the appeal of being fresh and clear-cut. Above all, mechanism was readily comprehensible to ordinary people. Indeed, Cartesian mechanism in not mathematical as even Descartes himself, the founder of analytic geometry, imagined. Whereas the painstaking geometrical and mathematical proof of Kepler's *New Astronomy* and Newton's *Mathematical Principles* were impenetrable to most people, Descartes' mechanism had many elements that appealed to the popular mind. Descartes' theory was even bandied about in salons, as depicted satirically in one Moliere comedy in which characters make such remarks as "I must prefer subtle matter," "I quite agree with Descartes about magnetism," and "I like his vortices." But the theory was specious and shallow nonetheless, and for all the attention it attracted its useful life turned out to be quite short.

Born roughly at the midpoint of the period between Descartes' birth and Fontenelle's, the Dutch scientist Christiaan Huygens(1629-1695) was , like many others, fervently

taken with Cartesianism as a young man. Near the end of his life, however, he reflected as follows on how his attitude changed:

> When I read the book of Principle [i.e., Descartes' *Principles*] the first time, it seemed to me that everything proceeded perfectly; and when I found some difficulty, I believed it was my fault in not fully understanding his thought, I was only fifteen or sixteen years old. But since then, having discovered in it from time to time things that are obviously false and others, that are very improbable, I have rid myself entirely of the prepossession I had conceived, and I now find almost nothing in all his physics that I can accepts as true, nor in his metaphysics and his meteorology.

Magnetism had been regarded since ancient times as a mysterious and sometimes as even a magical power. Then the idea of gravity acting between astronomical bodies as a force exerted at a distance emerged from geomagnetic theory. Galileo's mathematical phenomenalism, Descartes' mechanism, and Charleton's atomism all failed to recognize these notion's entitlement as worthy new scientific concepts, failed to determine the laws by which they operated, and failed to accord them their proper place in scientific theory. They neither paid attention to the laws that Kepler had arrived at nor nurtured the nascent concept of gravitational force that Kepler had conceived.

"The mechanical world view," observes one scholar, "rested on a single, fundamental assumption: *matter is passive*." As long as it retained that premise, naive mechanism was inherently incapable of dealing with such phenomena as magnetism and astronomical gravity—Phenomena, that is, of force exerted over distance by one body on another. Instead, ideas about magnetic force and gravitational force were gradually being cultivated elsewhere, as part of a view of nature that mechanism specifically sought to repudiate.

●Chapter20—Robert Boyle and the Transformation of Mechanism in Britain (694-732)

Contents

Brief Summary (731-733)

Thomas Browne, who embodies the intellectual transition that marked the early seventeenth century, accepted Cartesian natural philosophy yet sought to transplant it to the soil of Baconian. Hence, on the one hand he did not adopt Bacon’s stance of rejecting every hypothesis that was not supported by direct experiment, but on the other he considered what Descartes claimed to have “proved” by *a priori* deduction to be no more than working hypotheses the validity of which should be determined by experiment. This attitude toward Cartesianism was characteristic of British intellectuals in the seventeenth century. Under the influence of Bacon’s empiricism, along with dramatic improvements in experimental and observational instruments, more and more thinkers accepted the view that the premises of mechanism must be tested experimentally.

Henry power, one of the first in Britain to embrace mechanism, nonetheless broke with the Continental mechanist tradition by introducing the concept of “subtle spirits” as the basic substance underlying all motion in nature. This was the first step in the gradual transformation of mechanical philosophy.

Robert Boyle was also a mechanist who considered the world to be a vast automaton. At same time, however, his own experiments, showing that air sustained fire and living things, formed the basis of his conviction that there exists in air a fundamental substance with unique qualities indispensable to life and combustion. From there he conjectured that air also contained a variety of other “effluvia” each with its own kind of active quality. This idea represented a clear departure from the principle, central to mechanistic natural philosophy, that matter itself is devoid of qualities. As a result, discourse about magnetism, electricity, and other so-called occult qualities was steered in a new direction according to which all manner of hypothetical effluvia were conceived in order to “explain” such qualities.

Thus, through the debates presented and provoked by Power, Boyle, and others, a materialistic approach to natural philosophy gradually emerged from within mechanism. This helps to explain why Newton’s subsequent theory of universal gravitation, which was scored on the Continent, was accepted relatively easily in

Britain.

Boyle's law about the pressure of air was initially tied to the mechanistic interpretation that air exhibited elasticity because its corpuscle had spring-shaped appendages. Although, this interpretation was soon rejected, Boyle's law itself, which expresses a quantitative relation on the basis of precise measurement, survived independently of such models. In a similar way, for magnetic, electrostatic, gravitational, and other forces to become the proper subjects of physics as a modern, mathematical science, it was necessary not to concoct mechanism by which such forces were conveyed or conjecture about the qualities of special effluvia for each one but rather to accept, provisionally, that such forces were indeed cases of action at a distance and then accurately and quantitatively *measur*e the variations of their strength. Science had to wait until after Boyle for the dawn of this decisive new phase of its history.

In the will executed after his death in 1691, Boyle declares. "I give to Mr. Robert Hooke now Professor of Mathematicks in Gresham Colledge my best Microscope and my best Load-stone wch I shall have att the time of my death. It was Hooke who, under the influence of both the mechanism Descartes and Boyle and the "magnetic philosophy" of Gilbert and Kepler, first attempted to quantitatively, measure magnetic force and gravity, though he failed to discover their underlying principles. Then, out of the same milieu, came Isaac Newton, who proposed a pivotal new theoretical approach to the problem of gravity.

●chapter21— Magnetism and Gravity: Hooke and Newton (.734-793)

contents

Brief Summary (790-793)

In the seventeenth century, the emergent philosophy of mechanism and the revived philosophy of atomism were extolled in Continental Europe as the cornerstones of the new science. According to that science, material bodies were essentially inert and force could be propagated only by direct contact. This thinking came to exert considerable influence in Britain as well.

At the same time, however British thinkers, particularly the group that formed around Wilkins and eventually evolved into the Royal Society, carried on, along with Bacon's "experimental philosophy," the "magnetical philosophy" of Gilbert and Kepler, which held that astronomical bodies exerted a seemingly magnetic influence upon one another. Britain therefore enjoyed a culture climate more receptive to the idea that the force acting between astronomical bodies was a kind of a action at a distance similar to magnetic force.

Hence, even the mechanist Hooke explored two different positions concerning the force acting on planets and making them orbit the sun: a Cartesian view that attributed the force to the varying density of the fluid medium filling the intervening space; and the supposition that the sun pulled the planets toward it by some form of action at a distance.

Then, regarding actual planetary motion, Hooke put forward the view that what scientists should investigate was not how a force diverting planets toward a central body could possibly arise or be transmitted, but simply how the strength of that force changed (decreased) with increasing distance from the central body. This marked a watershed in mechanistic thinking –as is illustrated in simplified form in Hooke's fundamental opinion that whether or not magnetic force and gravitational force are the same depends on whether or not they can be represented by the same form of mathematical function.

Hooke further proposed a method of analysis by which, taking planetary motion to be a superposition of rectilinear inertial motion tangential to the orbit and deflected motion toward the center due to an external force, one could then derive the attractive force from the sun. This analysis was then realized mathematically in Newton's *Mathematical Principle*.

In this connection it is worth noting Newton's candid statement of his basic perspective on natural philosophy (physics) in query 31 of his *Opticks*. First he asserts that

The *Aristotelians* gave the Name of occult Qualities…..to such Qualities only as they supposed to lie hid in Bodies, and to be the unknown Causes of manifest Effects: Such as would be the Causes of Gravity. And of magnetick and electrick Attractions, and of Fermentations, if we should suppose that these Force or Action arose from Qualities unknown to us, and uncapable of being discovered and made manifest. Such occult Qualities put a stop to the Improvement of natural Philosophy, and therefore of late Years have been rejected. To tell us that every Species of Things is endow'd with an occult specifick Quality by which it acts and produces manifest Effects, is to tell us nothing.

Up to this point, Newton's view is identical to that of mechanist thinkers from Galileo and Descartes to Power. But in the words that immediately follow the above we find the originality and novelty than set Newton apart:

But to derive two or three general Principles of Motion from Phaenomena, and afterwards to tell us how the Properties and Actions of all corporeal Thing follow from those manifest Principles. Would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd.

Newton's position on the question of force was that it was enough to derive a mathematical law from phenomena and then apply that law to explain various other phenomena.

In this manner, Newton advocated a philosophy whereby, once one derives from Kepler's law the fact that an attractive force (universal gravitation) acts between astronomical bodies in inverse proportion to the square of their distance from each other and in direct proportion to their mass, and furthermore thereby fully and quantitatively explains the motions of planets, comets, moons, and so on, then there is little point probing further into the nature of that force or its mechanism of transmission. And indeed, the success of mechanics rested on the fact that the law of universal gravitation that Newton thus derived did in fact explain the ebb and flow of tides, account for the shape of the Earth, and enable accurate prediction of the return of Halley's comet. Whereas mechanism had sought to explode magic by revealing the apparatus by which force was transmitted, Newton, by elucidating a law of force, rationalized magic and incorporated it into the mathematical science of physics. But Newton did more than rationalize a seemingly magical force; he also had to sanctify it by identifying its ultimate source as the omnipresent God of Christianity. Such were the constraints of his age.

Regarding the relationship between gravitational force and magnetic force, however, Newton, having avoided the influence of magnetical philosophy, had always distanced himself from the magnetic-gravity theories advanced by thinkers in the lineage from Kepler to Hooke. Moreover, Newton, like Hooke, considered the gravity-magnetism relationship in terms of whether or not the relevant mathematical functions matched one another. Since the inverse-square law could not be shown to apply in the case of magnetic force, he reasoned that it must be fundamentally different from the force of gravitation, and conceived of former in mechanistic and materialistic terms as a type of mediated action involving "magnetic effluvia," "magnetical rays", or "magnetic matter." This was the state of thought about gravitational and magnetic force at the end of the first third of the eighteenth century, when Newton died.

It was not until after his death that the laws of magnetic force were likewise mathematically ascertained, the constraints of seventeenth century naive mechanism thereby finally thrown off, and the study of magnetism properly incorporated into the mathematical sciences. Those developments were also a process of purging from the concept of force the metaphysical and theological impurities that Newton had attached to it.

●chapter22— (Epilogue) Ascertaining the Law of Magnetic Force (794-843)

Contents

Brief Summary (840-843)
From the late medieval period to dawn of the modern era, magic, alchemy, and astrology were the intellectual traditions that seriously addressed questions of force and natural action, particularly action at a distance –which scholastic philosophy could not explain rationally. Magic, especially the natural magic of the late Renaissance, described electric force (the amber effect), magnetic force, and other actions of the natural world in terms of "sympathy and antipathy" and "occult power." Moreover, rather than probing the essential nature of such forces, magic took the approach of investigating, through experiment and observation, how such forces behaved so as make use of them. Alchemy was likewise intellectually progressive in its similar emphasis on experiment and observation. This approach ran directly counter to the Scholastic method of logical deduction from the "true natures" of things—which implied that nothing could be understood without first knowing its ontological essence.

Meanwhile, mechanism, such as was advocated by Descartes, Gassendi, and others, which emerged in the early modern period as a philosophy to supersede Scholasticism, attempted to dismantle magic by providing mechanical explanations of forces, or rather of their causes and mechanism of propagation. However, mechanism failed to achieve that self-imposed goal.

Ultimately, what deepened our understanding of force and opened the way to new scientific advances was not the invention of models for the propagation of force, as mechanism had attempted, much less the purely rational deduction of the nature of force from supposedly absolute first principles. The breakthrough came, rather, from an approach that laid aside such questions of essence and cause in favor of ascertaining the mathematical law underlying force through experiment and observation and particularly through precise measurement. The final steps in that process—achieved by Hook concerning gravity and Mayer and Coulomb concerning magnetism –Marked the birth of the concept of force as it is understood in modern physics.

We thus observe that the progress of inquiry into magnetic force and force in general unfolded not along the path of reductionism charted by Plato, Epicurus, and Lucretius in antiquity and by Descartes and Gassendi in the modern era but rather in the direction anticipated by such thinkers as the mystic Cusanus and the magician Della Porta. Thus the notion of action at a distance—having orinated in a hylozoistic and magical world view, having persisted even in the ideas of Gilbert and Kepler, and despite being rejected by mechanism precisely for those hylozoistic and magical aspects –was ultimately affirmed in the form of laws expressed as mathematical functions. With that step, action at a distance secured its place in natural science, the Copernican system was given s truly dynamical foundation, and thus modern physics was born.

Accordingly, any simplistic schema suggesting that modern mechanism supplanted medieval Scholasticism and thus brought about a scientific revolution is inaccurate, at least with respect to the question of force, the core issue of modern physics. The mechanist Galileo, for example, considered the problem of the solar system to be a matter beyond the province of physical science; Cartestian mechanism was mere fancy with no connection to Tycho Brahe's observations or Kepler's theories; and neither Galileo nor Descartes was able to understand gravity, especially gravitational force between celestial bodies. By contrast, it was figures whose ideas retained the influence of hylozoism—Gilbert, Kepler, and so on—That incorporated the concept of force into the very heart of natural science in the early years of the modern age; and it was their ideas that continued to have a major impact in the seventeenth century, particularly in England, in the form of "magnetic philosophy." Under that influence, thinkers such as Hook—a mechanist who was nonetheless heavily influenced by magnetic philosophy—and Newton –who devoted himself to alchemy and was influenced by the Cambridge Platonists—built up the theory of gravitational force. And among the core ideas that have in fact survived far beyond those early stages of the modern era we find Kepler's law of planetary motion, Boyles law of air pressure, Newton's law of gravitation, and Coulomb's law of electromagnetic force.

We see, then, that there was no tearing down of magic in the way mechanism had intended. Once the magical concept of action at a distance had been grasped and rationalized in terms of mathematical laws, the general principle was established that natural philosophy (physics) was a science dealing with verifiable laws that could also be expressed with mathematical rigor. As a result, natural philosophers simply lost interest in the problems peculiar to magic.

To be sure, in the formative process that gave rise to modern science, science was inspired by natural magic; particularly in the formulation of the concept of force, science inherited from magic and astrology the notion of action at a distance and from alchemy the notion of active principle. But once natural philosophy had established its own method, magic was no longer a subject of discourse among the natural philosophers and no longer had any significant impact on people's view of the natural world. It would be wrong to underestimate in hindsight the contribution that magic made at the infancy of modern science; but, of course, it would be an even greater error to suggest that magic has retained some kind of persisting significance simply because it played that role at one stage in the evolution of modern science.

And with that, our long story of the protoscience of magnetism and gravity comes to an end. Before long, the Newtonian and Coulombian concept of action at a distance was revised in a process leading from Faraday to Einstein.　But that is a later story.

Note (845—891)
Bibliography (893-944)