CHAPTER 23

SCIENTIFIC REVOLUTION

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The scientific revolution marks one of the decisive breaks between the Middle Ages and the modern world. For all its novelty, however, it was rooted in earlier developments. Medieval artists and intellectuals had been observing and illustrating the natural world with great precision since at least the twelfth century. Medieval sculptors carved plants and vines with extraordinary accuracy, and fifteenth-century painters and sculptors devoted the same careful attention to the human face and form. Nor was the link between observation, experiment, and invention new to the sixteenth century. The magnetic compass had been known in Europe since the thirteenth century; gunpowder since the early fourteenth; printing, which permeated and invigorated the intellectual life of the period, since the middle of the fifteenth. A fascination with light, which was a powerful symbol of divine illumination for medieval thinkers, encouraged the study of optics and, in turn, new techniques for grinding lenses. Lens grinders laid the groundwork for the seventeenth-century inventions of the telescope and microscope, creating reading glasses along the way. Astrologers were also active in the later Middle Ages, charting the heavens in the firm belief that the position of the stars influenced the lives of humans below.

Behind these efforts to understand the natural world lay a universal conviction that all of this world had been created by God. Religious belief thus spurred scientific study. One school of thinkers (the Neoplatonists) argued that nature was a book written by its Creator to reveal the ways of God to humanity. Convinced that God's perfection must be reflected in nature, Neoplatonists searched for the ideal and perfect structures they believed must lie behind the "shadows" of the everyday world. Mathematics, particularly geometry, was an important tool in this quest. The mathematician and astronomer Johannes Kepler, for example, was deeply influenced by Neoplatonism.

Renaissance humanism also helped prepare the grounds for the scientific revolution. The humanists' educational program placed a relatively low value on natural philosophy, directing attention instead toward the recovery and study of classical antiquity. Humanists revered the authority of the ancients. Yet the energies the humanists poured into recovering, translating, and understanding classical texts (which themselves discussed the natural world) made many of those important works available for the first time, and to a wider audience. Previously, Arabic sources had provided Europeans with the main route to ancient Greek learning; Greek classics were translated into Arabic and then picked up by twelfth-century medieval scholars in Spain and Sicily. The humanists' return to the texts themselves – and the fact that the new texts could be more easily printed and circulated – encouraged new study and debate. For example, Islamic scholars knew Ptolemy better than did Europeans until the humanist scholar and printer Ahannes Regiomontanus recovered and prepared a new summary of Ptolemy's work. The humanist rediscovery of works by Archimedes – the great Greek mathematician who had proposed that the natural world operated on the basis of mechanical forces, like a great machine, and that these forces could be described mathematically – profoundly impressed important late-sixteenth- and seventeenth-century thinkers, including the Italian scientist Galileo who in turn inspired Newton.

What of the voyages of European explorers to the New World? Their discoveries made the most immediate impact in the field of natural history, which was vastly enriched by travelers' detailed accounts of the flora and fauna of the Americas. Additionally, finding new lands and cultures in Africa and Asia and the revelation of the Americas, a world unknown to the ancients and unmentioned in the Bible, also laid bare gaps in Europeans' inherited body of knowledge. In this sense, the exploration of the New World called into question the authority of the ancients, an authority which was clearly ignorant of some important truths. In sum, the late medieval recovery of ancient texts long thought to have been lost, the expansion of print culture and reading, the turmoil in the Church, the fierce wars and political maneuvering that followed the Protestant revolt, and the discovery of a new world across the oceans inspired many Europeans to reassess older ways of thinking.

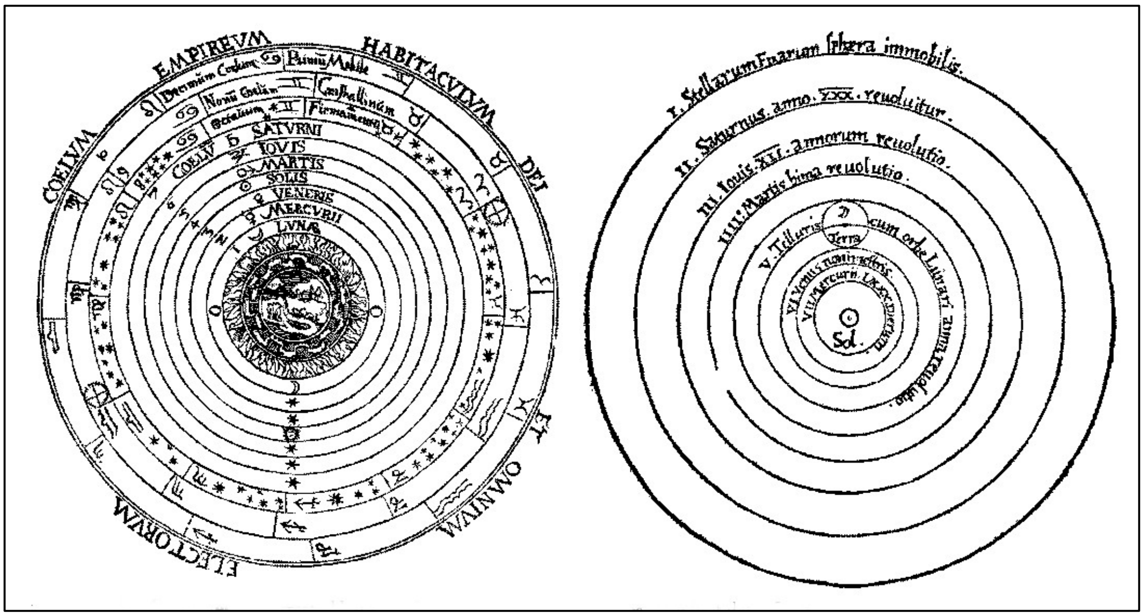
Medieval cosmologists, like their successors during the scientific revolution, wrestled with the contradictions between ancient texts and the evidence of their own observations. Their view of an earth-centered universe was particularly influenced by the teachings of Aristotle (d. 322 B.C.), especially as they were systematized by Ptolemy of Alexandria (d. 178 A.D.) over four hundred years later. In fact, Ptolemy's vision of an earth-centered universe contradicted an earlier proposal by Aristarchus of Samos (d. 230 B.C.), who had deduced that the earth and other planets revolve around the sun. Like the ancient Greeks, Ptolemy's medieval followers used astronomical observations to support their theory, but the persuasiveness of the model for medieval scholars also derived from the ways that it fit with their Christian beliefs. According to Ptolemy, the heavens orbited the earth in a carefully organized hierarchy of spheres. Earth and the heavens were fundamentally different, made of different matter and subject to different laws of motion. The sun, moon, stars, and planets were formed of an unchanging and incorruptible quintessence or ether. The earth, by contrast, was composed of four elements (earth, water, fire, and air), and each of these elements had its natural place : the heavy elements (earth and water) towards the center and the lighter ones (air and fire) further out. The heavens – first the planets, then the stars – traced perfect circular paths around the stationary earth. The motion of these celestial bodies was produced by a prime mover, whom Christians identified as God. The view fit Aristotelian physics, according to which objects could move only if acted on by an external force, and it fit with a belief that each fundamental element of the universe had a natural place.

By the late Middle Ages astronomers knew that this cosmology, called the "Ptolemaic system," did not correspond exactly to what many had observed. Orbits did not conform to the Aristotelian ideal of perfect circles. Planets, Mars in particular, sometimes appeared to loop backward before continuing on their paths. Ptolemy had managed to account for these orbital irregularities, but with complicated mathematics. By the early fifteenth century, the efforts to make the observed motions of the planets fit into the model of perfect circles in a geocentric (earth-centered) cosmos had produced astronomical charts that were mazes of complexity. Finally, the Ptolemaic system proved unable to solve serious difficulties with the calendar. That practical crisis precipitated Nicolaus Copernicus's intellectual leap forward.

By the early sixteenth century the old Roman calendar was significantly out of alignment with the movement of the heavenly bodies. The major saints' days, Easter, and the other holy days were sometimes weeks off where they should have been according to the stars. Catholic authorities tried to correct this problem, consulting mathematicians and astronomers all over Europe. One of these was a Polish church official and astronomer, Nicolaus Copernicus (1473-1543). Educated in Poland and northern Italy, he was a man of diverse talents. He was trained in astronomy, canon law, and medicine. He read Greek. He was well versed in ancient philosophy. He was also a careful mathematician and a devout Catholic, who did not believe that God's perfectly ordered universe could be as messy as the one in Ptolemy's model. His proposed solution, based on mathematical calculations, was simple and radical: Ptolemy was mistaken; the earth was neither stationary nor at the center of the planetary system; the earth rotated on its axis and orbited with the other planets around the sun. Reordering the Ptolemaic system simplified the geometry of astronomy and made the orbits of the planets comprehensible.

Copernicus was in many ways a conservative thinker. He did not consider his work to be a break with either Church teachings or with the authority of ancient texts. He believed, rather, that he had restored a pure understanding of God's design, one that had been lost over the centuries. Still, the implications of his theory troubled him. His ideas contradicted centuries of astronomical thought, and they were hard to reconcile with the observed behavior of objects on earth. If the earth moved, why was that movement imperceptible? Copernicus calculated the distance from the earth to the sun to be at least six million miles. Even by Copernicus's very low estimate, the earth was hurtling around the sun at the dizzying rate of many thousands of miles an hour. How did people and objects remain standing? (The earth is actually about ninety-three million miles from the sun, moving through space at sixty-seven thousand miles an hour and spinning on its axis at a thousand miles an hour!)

Copernicus was not a physicist. He tried to refine, rather than overturn, traditional Aristotelian physics, but his effort to reconcile traditional physics with his new model of a sun-centered universe created new problems and inconsistencies that he could not resolve. These frustrations and complications dogged Copernicus's later years, and he hesitated to publish his findings. Just before his death, he consented to the release of his major treatise, *On the Revolutions of the Heavenly Spheres*, in 1543. For decades, Copernicus's ideas were taken simply as useful but not realistic mathematical hypotheses. In the long run, however, Copernicanism represented the first serious challenge to the long-accepted Ptolemaic conception of the universe.



Ptolemaic (geocentric) model Copernican (heliocentric) model

Within fifty years, Copernicus's cosmology was revived and modified by two astronomers also critical of the Ptolemaic model of the universe: Tycho Brahe (1546-1601) and Johannes Kepler (1571-1630). Each was considered the greatest astronomer of his day. Tycho was born into the Danish nobility but he abandoned his family's military and political legacy to pursue his passion for astronomy. He was hot-headed as well as talented; at twenty he lost part of his nose in a duel. Like Copernicus he sought to correct the contradictions in traditional astronomy. Unlike Copernicus, who was a theoretician, Tycho championed observation and believed careful study of the heavens would unlock the secrets of the universe. He first made a name for himself by observing a completely new star, a "nova," that flared into sight in 1572. The Danish king Friedrich II, impressed by Tycho's work, granted him the use of a small island where he built a castle specially designed to house an observatory. For over twenty years Tycho meticulously charted the movements of each significant object in the night sky, compiling the finest set of astronomical data in Europe.

Tycho was not a Copernican. He suggested that the planets orbited the sun and the whole system then orbited a stationary earth. This picture of the cosmic order, though clumsy, seemed to fit the observed evidence better than the Ptolemaic system while also preserving a geocentric universe. In the late 1590s, Tycho moved his work and his huge collection of data to Prague where he became the court astronomer to the Holy Roman emperor Rudolph II. In Prague he was assisted by a young mathematician named Johannes Kepler. After Tycho's death, Kepler inherited Tycho's position in Prague, as well as his trove of observations and calculations. That data demonstrated to Kepler that two of Copernicus's assumptions about planetary motion simply did not match observations. Copernicus, in keeping with Aristotelian notions of perfection, had believed that planetary orbits were circular. Kepler calculated that the planets traveled in elliptical orbits around the sun. Copernicus also held that planetary motion was uniform; Kepler discovered that the speed of the planets varied with their distance from the sun. Kepler also argued that magnetic forces between the sun and planets kept the planets in orbital motion, an insight that paved the way for Newton's formulation of the law of universal gravitation nearly eighty years later at the end of the seventeenth century.

Kepler had a friend deliver a copy of his works to the "mathematician named Galileus Galileus," then teaching mathematics and astronomy at Padua, near Venice. Galileo (1564-1642) thanked Kepler, but noted that, as a university professor, he was not free to openly embrace the Copernican model. Kepler replied, urging Galileo to "come forward!" Galileo did not answer.

At Padua, Galileo couldn't teach what he believed; Ptolemaic astronomy and Aristotelian cosmology were the established curriculum supported by all the local university professors and Church officials. By the end of his career, however, Galileo had amassed powerful evidence in support of the Copernican model and laid the foundation for a new physics. His discoveries made him the most famous scientific figure of his time, but his work put him on a collision course with Aristotelian philosophy and the authority of the Catholic Church.

Galileo first became famous by way of discoveries made with the aid of a telescope. In 1609 he heard reports from Holland of a lens grinder who had made a spyglass that could magnify very distant objects. Excited, Galileo quickly devised his own (better) telescope; trained it first on earthly objects to demonstrate that it worked; and then, momentously, pointed it at the night sky. Galileo studied the moon, finding on it mountains, plains, and other features of an earth-like landscape. His observations suggested that celestial bodies resembled the earth, a view at odds with the conception of the planets as incorruptible spheres of heavenly perfection, inherently different from the corruptible earth. He saw moons orbiting Jupiter, evidence that earth was not at the center of all orbits. He saw spots (or imperfections) even on the sun. Galileo published these results, and his fame grew.

A seventeenth-century scientist needed powerful and wealthy patrons. As a professor of mathematics, Galileo chafed at the power of university authorities who were firmly committed to Aristotelian traditions. Princely courts offered an inviting alternative. The Medici family of Florence, like others, burnished its reputation and bolstered its power by surrounding itself with intellectuals as well as artists. Persuaded he would be freer at a princely court than at the University of Padua, Galileo took a position as tutor to the Medicis. He honored his patrons by naming the newly discovered moons orbiting Jupiter "the Medicean stars." He was rewarded with the title of chief mathematician and philosopher to Cosimo de' Medici, the grand duke of Tuscany. Now well positioned in Italy's networks of power and patronage, Galileo attempted to demonstrate openly that Copernicus's heliocentric (sun-centered) model of the planetary system was unmistakably correct.

Galileo argued that one could be a sincere Copernican and a sincere Catholic. The Church, Galileo said, did the sacred work of teaching religious truths and saving souls. Accounting for the workings of the physical world was a task better left to natural philosophy, grounded in observation and mathematics. Galileo thus envisioned natural philosophers and theologians as partners in a search for truth, but with different spheres of expertise. In a brilliant rhetorical moment, he quoted Cardinal Baronius in support of his own argument: the purpose of the Bible was to "teach us how to go to heaven, not how heaven goes."

Nevertheless, in 1616, ecclesiastical authorities moved against Galileo. The Roman inquisitors ruled that Copernicanism was "foolish and absurd in philosophy and formally heretical." The Bible, they argued, clearly indicated that the earth stood still while the sun orbited it (although the scriptural proof-texts they cite are rather unconvincing on this point). Copernicus's writings were placed on the Index of Prohibited Books, and Galileo was warned not to teach Copernicanism. For a while, he did as he was asked. But when his Florentine friend and admirer Maffeo Barberini was elected pope as Urban VIII in 1623, Galileo believed that he would be granted more leeway. He drafted one of his most famous works, *A Dialogue Concerning the Two Chief World Systems*, published in 1632. The *Dialogue* was a hypothetical debate between supporters of the old Ptolemaic system, represented by a character he named Simplicio (simpleton) on the one hand and proponents of the new astronomy on the other. Throughout the work Galileo gave the best lines to the Copernicans. At the very end, however, to satisfy the letter of the Inquisition's decree, he had them capitulate to Simplicio.

The Roman Inquisition quickly banned the *Dialogue* and ordered Galileo to stand trial in 1633. Pope Urban, insulted by Galileo's scorn for the Inquisition's earlier warnings and troubled by Galileo's brash rejection of Ptolemaic cosmology (taught in all the universities throughout Italy), refused to protect his former friend. The Inquisition demanded that Galileo either repent of his Copernican teachings or be labeled an obstinate heretic. Galileo submitted and officially repented. He was then banned from discussing Copernican ideas and placed under house arrest for life. Galileo nevertheless continued his research in private, and friends smuggled manuscripts containing his latest theories out of Italy to be printed in Protestant Holland.

As interest in new scientific theories spread, new thinkers began to spell out standards of practice and evidence. Sir Francis Bacon and René Descartes loomed especially large in this development by setting out methods or rules that should govern modern science. Bacon (1561-1626), an Englishman, lived at roughly the same time as Kepler and Galileo; Descartes (1596-1650), a Frenchman, was slightly younger. Both came to believe that theirs was an age of profound change, open to the possibility of astonishing discovery. Both were persuaded that new research and new methodology could take science far beyond the limits of ancient authorities. Both, therefore, set out to formulate a philosophy that could encompass and guide the new learning of their age.

"Knowledge is power." The phrase is Bacon's and captures the changing perspective of the seventeenth century and its new confidence in the potential of human thinking. Bacon trained as a lawyer, served in Parliament and, briefly, as lord chancellor to James I of England. His abiding concern was with the assumptions, methods, and practices that he believed should guide natural philosophers and the progress of knowledge. The authority of the ancients, he insisted, should not constrain the ambition of modern thinkers; deferring to accepted doctrines could block innovation or obstruct understanding. "There is but one course left … to try the whole thing anew upon a better plan, and to commence a total reconstruction of sciences, arts, and all human knowledge, raised upon the proper foundations." To pursue knowledge did not mean to think abstractly and leap to conclusions; it meant observing, experimenting, confirming ideas, or demonstrating points. If thinkers will be "content to begin with doubts," Bacon wrote, "they shall end with certainties." Bacon thus sought to reassess the entire Western intellectual tradition.

Bacon advocated an inductive approach to knowledge: amassing evidence from specific observations from which to draw general conclusions. In Bacon's view, many philosophical errors arose from beginning with assumed first principles. The traditional view of the cosmos, for instance, rested on the principles of a prime mover and the perfections of circular motion and incorruptible substance. The inductive method required accumulating data (as Tycho had done, for example) and then, after careful review and experiment, drawing appropriate conclusions. Bacon argued that knowledge was best tested through the cooperative efforts of researchers performing experiments that could be repeated and verified.

René Descartes, one of Bacon's contemporaries, also insisted that the traditional intellectual assumptions of his day must be reassessed. Descartes was French, though he lived all over Europe. He was intellectually restless as well; he worked in geometry, cosmology, optics, and physiology – for a while dissecting cow carcasses daily. He was writing a (Copernican) book on physics when he heard of Galileo's condemnation in 1633, a judgement that impressed on him the dangers of "expressing judgements on this world." He fled from Catholic France to Protestant Holland in order to avoid censorship. While there, Descartes published *The Discourse on Method* (1637), his best known work. The *Discourse* began simply as a preface to three essays on optics, geometry, and meteorology. It is personal, recounting Descartes' dismay at the "strange and unbelievable" theories he encountered in his traditional education. His first response, as he described it, was to systematically doubt everything he had ever known or been taught. Better to clear the slate, he believed, than to build an edifice of knowledge on received assumptions. His first rule was "never to receive anything as a truth which [he] did not clearly know to be such." He took the subjective human ability to think as his point of departure, summed up in his famous and enigmatic, *Je pense, donc je suis*, later translated into Latin as *cogito ergo sum* and into English as "I think, therefore I am."

Descartes, like Bacon, sought a "fresh start for knowledge" by establishing rules for understanding the world as it was, free from prejudice and tradition. Unlike Bacon, however, Descartes emphasized deductive reasoning, proceeding logically from one certainty to another. "So long as we avoid accepting as true what is not so," he wrote in his *Discourse on Method*, "and always preserve the right order of deduction of one thing from another, there can be nothing too remote to be reached in the end, or too well hidden to be discovered." For Descartes, mathematical thought expressed the highest standards of reason, and his work contributed greatly to the authority of mathematics as a model for scientific reasoning.

Descartes made a particularly forceful statement for "mechanism," a view of the world shared by Bacon and Galileo and one that came to dominate seventeenth-century scientific thought. As the name suggests, mechanical philosophy proposed to consider nature as a machine. It rejected the traditional Aristotelian distinction between the works of humans and those of nature and the view that nature, as God's creation, necessarily belonged to a different – and higher – order. In the new mechanical picture of the universe, it seemed that all matter was composed of the same material and all motion obeyed the same laws, whether in the heavens or on earth. Descartes sought to explain everything, including the human body, mechanically. As he put it firmly, "There is no difference between the machines built by artisans and the diverse bodies that nature alone composes." Nature operated according to regular and predictable laws and was thus accessible to human reason. This belief guided, indeed inspired, much of the scientific experiment and argumentation of the seventeenth century.

Sir Isaac Newton's (1642-1727) work marks the culmination of the scientific revolution and the triumph of mechanical philosophy. Galileo, peering through his telescope in the early 1600s, had come to believe that the earth and the heavens were made of the same material. Galileo's experiments with pendulums aimed to discover the laws of motion, and he proposed theories of inertia. Yet it was Newton, an Englishman, who articulated those laws and presented a coherent, unified vision of how the universe worked. All bodies in the universe, Newton argued, whether on earth or in the heavens, obeyed the same basic laws. Thus one set of forces and one pattern, which could be expressed mathematically, explained why planets orbited in ellipses and why (and at what speed) apples fell from trees. Newton termed this attractive force between all objects "universal gravitation," or gravity for short.

Newton, after many years of study, expressed his mature ideas in the *Principia Mathematica* (1687). Its central proposition was that gravitation was a universal force and could be expressed mathematically. Newton built on Galileo's work on inertia, Kepler's findings concerning the elliptical orbits of planets, and Descartes' theories of mechanical philosophy. He once said – quoting a famous medieval saying – that "if I have seen further, it is by standing on the shoulders of giants." But Newton's universal theory of gravity, although it drew on work of others before him, formulated something entirely new. His synthesis offered a single, descriptive account of mass and motion; he posited in his *Mathematical Principles* that "all bodies whatsoever are endowed with a principle of mutual gravitation." The law of gravitation was then presented as a mathematical formula, one supported by observation and experience, and was literally universal.

Newton's work was widely read and highly respected. For example, John Locke read the *Principia* twice and summarized it in French for readers across the Channel. By 1713 pirated editions of the *Principia* were being published in Amsterdam for distribution throughout Europe. By the time Newton died in 1727 he had become an English national hero and was given a state funeral at Westminster Abbey. The poet Alexander Pope expressed the awe that Newton inspired in some of his contemporaries in a famous couplet:

> Nature and nature's law lay hid in night;
> God said, "Let Newton be!" and all was light.

Voltaire, the French champion of the Enlightenment (discussed in the next chapter), was largely responsible for Newton's reputation in France. For Voltaire and other Enlightenment thinkers, Newton represented a cultural transformation, a turning point in the history of knowledge, an awakening of human reason unshackled from the constraints of previous assumptions. Whereas Newton and the other intellectuals associated with the scientific revolution reassessed the workings of the physical world, Voltaire and other Enlightenment thinkers would reassess the very nature of human society – including education, politics, economics, and religion.

HOMEWORK QUESTIONS:

1.) How does inductive reasoning differ from deductive reasoning?

2.) Why did the Roman Inquisition eventually condemn the teachings of Copernicus and Galileo concerning heliocentrism?

** PRIMARY SOURCE **

Copernicus, *The Revolutions of the Heavenly Orbs*

Excerpted from Nicolaus Copernicus, *On the Revolutions of the Heavenly Spheres*, trans. C. Wallis (Amherst, 1996) pp. 4-7 and 15-19.

*** The Polish cleric and astronomer Nicolaus Copernicus (1473-1543) is generally credited as the author of the heliocentric theory of the solar system. He proposed and demonstrated mathematically how the observed motions of stars and planets might be reconciled by assuming that the Sun was a fixed point and that the Earth rotated around the Sun while revolving on its own axis. His interest in the heavens probably began during a period of study at the University of Bologna, where he came into contact with Domenic Maria de Novara, the university's leading astronomer. While his principal interests were scientific, his career remained ecclesiastical. He served as a church canon, involved in administrative matters, and pursued astronomy in his spare time. Troubled by the discrepancies between theoretical descriptions and direct observations of planetary motion, he eventually postulated that were the Sun assumed to be at rest and the Earth assumed to be in motion, the remaining planets would resolve themselves into an ordered progression according to their sidereal periods. While his findings solved the problem of ordering the planets, they created new ones by casting much of Aristotelian natural philosophy in doubt. Though he is thought to have developed his theory between 1508 and 1514, he did not publish his conclusions until the year of his death, 1543. Its full implications as a new theory concerning the fundamental structure of the universe would not be recognized until Kepler published his own theories a century later. ***

Preface and Dedication to Pope Paul III

I can reckon easily enough, Most Holy Father, that as soon as certain people learn that in these books of mine which I have written about the revolutions of the spheres of the world I attribute certain motions to the terrestrial globe, they will immediately shout to have me and my opinion hooted off the stage. For my own works do not please me so much that I do not weigh what judgments others will pronounce concerning them. And although I realize that the conceptions of a philosopher are placed beyond the judgment of the crowd, because it is his loving duty to seek the truth in all things insofar as God has granted that to human reason; nevertheless I think we should avoid opinions utterly foreign to rightness. And then I considered how absurd this "lecture" would be held by those who know that the opinion that the Earth rests immovable in the middle of the heavens as if their center had been confirmed by the judgments of many ages, if I were to assert to the contrary that the Earth moves. For a long time I was in great difficulty as to whether I should bring to light my commentaries written to demonstrate the Earth's movement, or whether it would not be better to follow the example of the Pythagoreans and certain others who used to hand down the mysteries of their philosophy not in writing but by word of mouth and only to their relatives and friends – witness the letter of Lysis to Hipparchus. They however seem to me to have done that not, as some judge, out of a jealous unwillingness to communicate their doctrines but in order that things of very great beauty which have been investigated by the loving care of great men should not be scorned by those who find it a bother to expend any great energy on letters (except on the money-making variety) or who are provoked by the exhortations and examples of others to the liberal study of philosophy, but on account of their natural stupidity hold the position among philosophers that drones hold among bees. Therefore, when I weighed these things in my mind, the scorn which I had to fear on account of the newness and absurdity of my opinion almost drove me to abandon a work already undertaken.

But though I long hesitated and even resisted, my friends drove me back to it, especially Nicolaus Schonberg, Cardinal of Capua, famous in every kind of learning, and next to him my very good friend Tiedemann Giese, Bishop of Kuhn, zealous student of sacred and of all good writings. For he has often urged me, and demanded of me, sometimes with reproaches as well, to issue this book and at last allow it to come into the light of day, after I have kept it suppressed and hidden not just for nearly nine years but for almost four times nine years already. The same thing has been pressed on me by not a few other most eminent and learned men, who urged me not to refuse any longer on account of this belief of mine to make my work available for the general use of students of mathematics; for they said that the more absurd this doctrine of mine about the motion of the

Earth now seemed to most people, the greater would be the admiration and gratitude which it would command when by the publication of my treatise they saw that the mist of absurdity had been lifted by the clearest demonstrations. Accordingly, I was eventually induced by their persuasion and this hope to allow my friends to publish this work, as they had long been asking me.

But perhaps Your Holiness will not be so much surprised at my giving the results of my nocturnal study to the light – after having taken such care in working them out that I did not hesitate to put in writing my conceptions as to the movement of the Earth – as you will be eager to hear from me what came into my mind that in opposition to the general opinion of mathematicians and almost in opposition to common sense I should dare to imagine some movement of the Earth. And so I am unwilling to hide from Your Holiness that nothing except my knowledge that mathematicians have not agreed with one another in their researches moved me to think out a different scheme of drawing up the movements of the spheres of the world. For in the first place mathematicians are so uncertain about the movements of the sun and moon that they can neither demonstrate nor observe the unchanging magnitude of the revolving year. Then in setting up the solar and lunar movements and those of the other five wandering stars, they do not employ the same principles, assumptions, or demonstrations for the revolutions and apparent movements. …

Moreover, they have not been able to discover or to infer the chief point of all, i.e. the form of the world and the certain commensurability of its parts. But they are in exactly the same fix as someone taking from different places hands, feet, head, and the other limbs – shaped very beautifully but not with reference to one body and without correspondence to one another – so that such parts made up a monster rather than a man. And so, in the process of demonstration which they call "method," they are found either to have omitted something necessary or to have admitted something foreign which by no means pertains to the matter; and they would by no means have been in this fix, if they had followed sure principles. For if the hypotheses they assumed were not false, everything which followed from the hypotheses would have been verified without fail; and though what I am saying may be obscure right now, nevertheless it will become clearer in the proper place.

Accordingly, when I had meditated upon this lack of certitude in the traditional mathematics concerning the composition of movements of the spheres of the world, I began to be annoyed that the philosophers, who in other respects had made a very careful scrutiny of the least details of the world, had discovered no sure scheme for the movements of the machinery of the world, which has been built for us by the Best and Most Orderly Workman of all. Wherefore, I took the trouble to reread all the books by philosophers which I could get hold of, to see if any of them even supposed that the movements of the spheres of the world were different from those laid down by those who taught mathematics in the schools. And as a matter of fact, I found first in Cicero that Nicetas thought that the Earth moved. And afterwards I found in Plutarch that there were some others of the same opinion – I shall copy out his words here, so that they may be known to all:

> Some think that the Earth is at rest; but Philolaus the Pythagorean says that it moves around the fire with an obliquely circular motion, like the sun and moon. Herakleides of Pontus and Ekphantus the Pythagorean do not give the Earth any movement of locomotion, but rather a limited movement of rising and setting around its center, like a wheel.

Therefore I also, having found occasion, began to meditate upon the mobility of the Earth. And although the opinion seemed absurd, nevertheless because I knew that others before me had been granted the liberty of constructing whatever circles they pleased in order to demonstrate astral phenomena, I thought that I too would be readily permitted to test whether or not, by the laying down that the Earth had some movement, demonstrations less shaky than those of my predecessors could be found for the revolutions of the celestial spheres.

And so, having laid down the movements which I attribute to the Earth farther on in the work, I finally discovered by the help of long and numerous observations that if the movements of the other wandering stars are correlated with the circular movement of the Earth, and if the movements are computed in accordance with the revolution of each planet, not only do all their phenomena follow from that but also this correlation binds together so closely the order and magnitudes of all the planets and of their spheres or orbital circles and the heavens themselves that nothing can be shifted around in any part of them without disrupting the remaining parts and the universe as a whole.

Accordingly, in composing my work I adopted the following order: in the first book I describe all the locations of the spheres or orbital circles together with the movements which I attribute to the earth, so that this book contains as it were the general set-up of the universe. But afterwards in the remaining books I correlate all the movements of the other planets and their spheres or orbital circles with the mobility of the Earth, so that it can be gathered from that how far the apparent movements of the remaining planets and their orbital circles can be saved by being correlated with the movements of the Earth. And I have no doubt that talented and learned mathematicians will agree with me, if – as philosophy demands in the first place – they are willing to give not superficial but profound thought and effort to what I bring forward in this work in demonstrating these things. And in order that the unlearned as well as the learned might see that I was not seeking to flee from the judgment of any man, I preferred to dedicate these results of my nocturnal study to Your Holiness rather than to anyone else; because, even in this remote corner of the earth where I live, you are held to be most eminent both in the dignity of your order and in your love of letters and even of mathematics; hence, by the authority of your judgment you can easily provide a guard against the bites of slanderers, despite the proverb that there is no medicine for the bite of a sycophant.

But if perchance there are certain "idle talkers" who take it upon themselves to pronounce judgment, although wholly ignorant of mathematics, and if by shamelessly distorting the sense of some passage in Holy Writ to suit their purpose, they dare to reprehend and to attack my work; they worry me so little that I shall even scorn their judgments as foolhardy. For it is not unknown that Lactantius, otherwise a distinguished writer but hardly a mathematician, speaks in an utterly childish fashion concerning the shape of the Earth, when he laughs at those who have affirmed that the Earth has the form of a globe. And so the studious need not be surprised if people like that laugh at us. Mathematics is written for mathematicians; and among them, if I am not mistaken, my labors will be seen to contribute something to the ecclesiastical commonwealth, the principate of which Your Holiness now holds. For not many years ago under Leo X when the Lateran Council was considering the question of reforming the Ecclesiastical Calendar, no decision was reached, for the sole reason that the magnitude of the year and the months and the movements of the sun and moon had not yet been measured with sufficient accuracy. From that time on I gave attention to making more exact observations of these things and was encouraged to do so by that most distinguished man, Paul, Bishop of Fossombrone, who had been present at those deliberations. But what I have accomplished in this matter I leave to the judgment of Your Holiness in particular and to that of all other learned mathematicians. And so as not to appear to Your Holiness to make more promises concerning the utility of this book than I can fulfill, I now pass on to the body of the work. …

HOMEWORK QUESTIONS:

1.) Why did Copernicus long delay the publication of his findings concerning the motion of the earth around the sun?

2.) What problems and questions does he claim to resolve in this work?