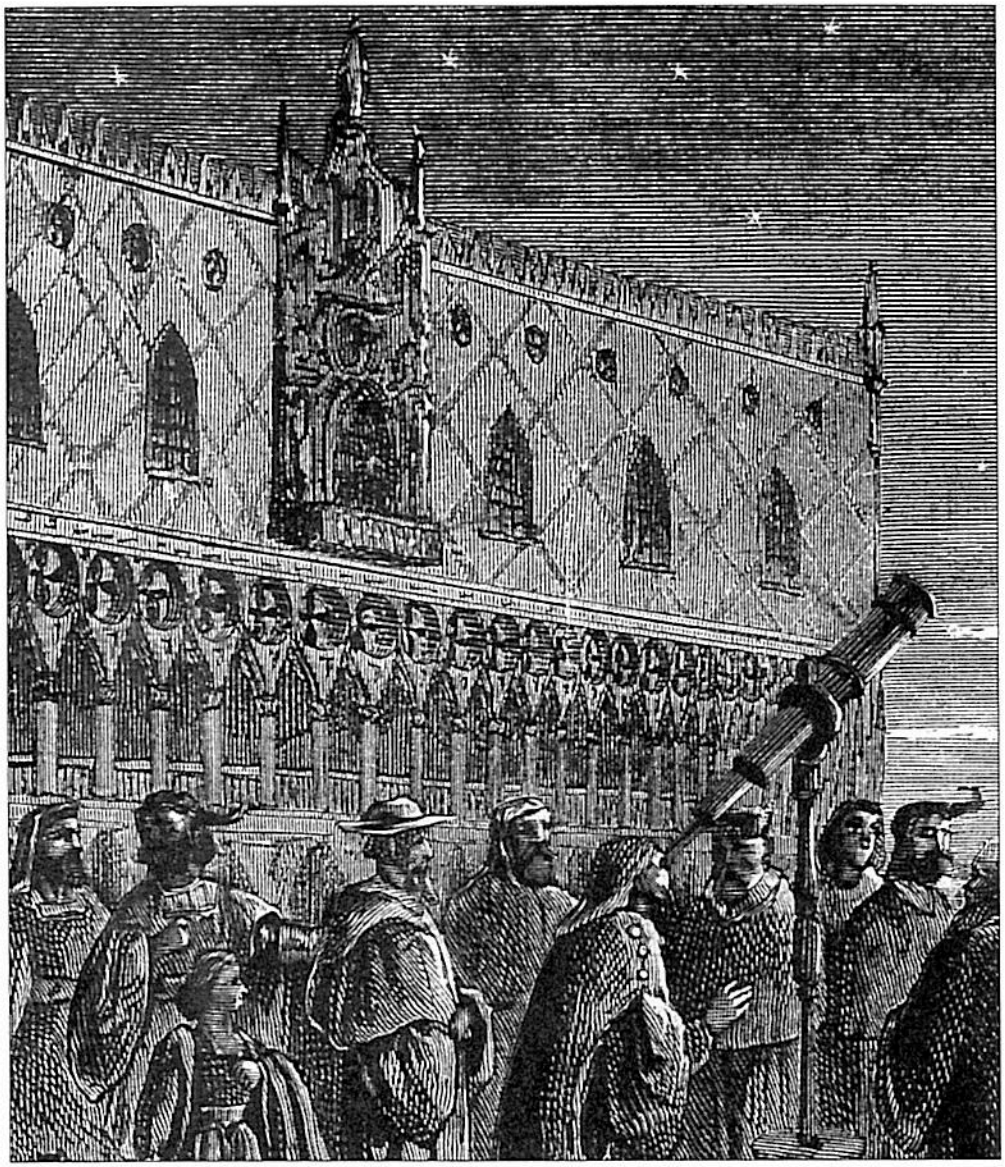
CHAPTER 2

# *The Scientific Revolution*



GALILEO IN VENICE demonstrating the satellites of Jupiter through his telescope. *(Stock Montage)*

The Scientific Revolution of the sixteenth and seventeenth centuries replaced the medieval view of the universe with a new cosmology and produced a new way of investigating nature. It overthrew the medieval conception of nature as a hierarchical order ascending toward a realm of perfection. Rejecting reliance on authority, the thinkers of the Scientific Revolution affirmed the individual's ability to know the natural world through the method of mathematical reasoning, the direct observation of nature, and carefully controlled experiments.

The medieval view of the universe had blended the theories of Aristotle and Ptolemy, two ancient Greek thinkers, with Christian teachings. In that view, a stationary earth stood in the center of the universe just above hell. Revolving around the earth were seven planets: the moon, Mercury, Venus, the sun, Mars, Jupiter, and Saturn. Because people believed that earth did not move, it was not considered a planet. Each planet was attached to a transparent sphere that turned around the earth. Encompassing the universe was a sphere of fixed stars; beyond the stars lay three heavenly spheres, the outermost of which was the abode of God. An earth-centered universe accorded with the Christian idea that God had created the universe for men and women and that salvation was the aim of life.

Also agreeable to the medieval Christian view was Aristotle's division of the universe into a lower, earthly realm and a higher realm beyond the moon. Two sets of laws operated in the universe, one on earth and the other in the celestial realm. Earthly objects were composed of four elements: earth, water, fire, and air; celestial objects were composed of the divine ether—a substance too pure, too clear, too fine, too spiritual to be found on earth. Celestial objects naturally moved in perfectly circular orbits around the earth; earthly objects, composed mainly of the heavy elements of earth and water, naturally fell downward, whereas objects made of the lighter elements of air and fire naturally flew upward toward the sky.

The destruction of the medieval world picture began with the publication in 1543 of *On the Revolutions of the Heavenly Spheres,* by Nicolaus Copernicus, a Polish mathematician, astronomer, and clergyman. In Copernicus's system, the sun was in the center of the universe, and the earth was another planet that moved around the sun. Most thinkers of the time, committed to the Aristotelian-Ptolemaic system and to the biblical statements that seemed to support it, rejected Copernicus's conclusions.

The work of Galileo Galilei, an Italian mathematician, astronomer, and physicist, was decisive in the shattering of the medieval cosmos and the shaping of the modern scientific outlook. Galileo advanced the modern view that knowledge of nature derives from direct observation and from mathematics. For Galileo, the universe was a "grand book which . . . is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without

which it is humanly impossible to understand a single word of it." Galileo also pioneered experimental physics, advanced the modern idea that nature is uniform throughout the universe, and attacked reliance on scholastic authority rather than on experimentation in resolving scientific controversies.

Johannes Kepler (1571–1630), a contemporary of Galileo, discovered three laws of planetary motion that greatly advanced astronomical knowledge. Kepler showed that the path of a planet was an ellipse, not a circle as Ptolemy (and Copernicus) had believed, and that planets do not move at uniform speed but accelerate as they near the sun. He devised formulas to calculate accurately both a planet's speed at each point in its orbit around the sun and a planet's location at a particular time. Kepler's laws provided further evidence that Copernicus had been right, for they made sense only in a sun-centered universe, but Kepler could not explain why planets stayed in their orbits rather than flying off into space or crashing into the sun. The resolution of that question was left to Sir Isaac Newton.

Newton's great achievement was integrating the findings of Copernicus, Galileo, and Kepler into a single theoretical system. In *Principia Mathematica* (1687), he formulated the mechanical laws of motion and attraction that govern celestial and terrestrial objects.

The creation of a new model of the universe was one great achievement of the Scientific Revolution; another accomplishment was the formulation of the scientific method. The scientific method encompasses two approaches to knowledge, which usually complement each other: the empirical (inductive) and the rational (deductive). Although all sciences use both approaches, the inductive method is generally more applicable in such descriptive sciences as biology, anatomy, and geology, which rely on the accumulation of data. In the inductive approach, general principles are derived from analyzing external experiences—observations and the results of experiments. In the deductive approach, used in mathematics and theoretical physics, truths are derived in successive steps from indubitable axioms. Whereas the inductive method builds its concepts from an analysis of sense experience, the deductive approach constructs its ideas from self-evident principles that are conceived by the mind itself without external experience. The deductive and inductive approaches to knowledge, and their interplay, have been a constantly recurring feature in Western intellectual history since the rationalism of Plato and the empiricism of Aristotle. The success of the scientific method in modern times arose from the skillful synchronization of induction and deduction by such giants as Leonardo, Copernicus, Kepler, Galileo, and Newton.

The Scientific Revolution was instrumental in shaping the modern outlook. It destroyed the medieval conception of the universe and established the scientific method as the means for investigating nature and acquiring knowledge, even in areas having little to do with the

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study of the physical world. By demonstrating the powers of the human mind, the Scientific Revolution gave thinkers great confidence in reason and led eventually to a rejection of traditional beliefs in magic, astrology, and witches. In the eighteenth century, this growing skepticism led thinkers to question miracles and other Christian beliefs that seemed contrary to reason.

## 1 The Copernican Revolution

In proclaiming that the earth was not stationary but revolved around the sun, Nicolaus Copernicus (1473–1543) revolutionized the science of astronomy. Fearing controversy and scorn, Copernicus long refused to publish his great work, *On the Revolutions of the Heavenly Spheres.* However, persuaded by friends, he finally relented and permitted publication; a copy of his book reached him on his deathbed. As Copernicus anticipated, his ideas aroused the ire of many thinkers.

Both Catholic and Protestant philosophers and theologians, including Martin Luther, attacked Copernicus for contradicting the Bible and Aristotle and Ptolemy, and they raised several specific objections. First, certain passages in the Bible imply a stationary earth and a sun that moves (for example, Psalm 93 says, "Yea, the world is established; it shall never be moved"; and in attacking Copernicus, Luther pointed out that "sacred Scripture tells us that Joshua commanded the sun to stand still, and not the earth"). Second, a body as heavy as the earth cannot move through space at such speed as Copernicus suggested. Third, if the earth spins on its axis, why does a stone dropped from a height land directly below instead of at a point behind where it was dropped? Fourth, if the earth moved, objects would fly off it. And finally, the moon cannot orbit both the earth and the sun at the same time.

### Nicolaus Copernicus
### *ON THE REVOLUTIONS OF THE HEAVENLY SPHERES*

*On the Revolutions of the Heavenly Spheres* was dedicated to Pope Paul III, whom Copernicus asked to protect him from vilification. In the dedication, Copernicus explains his reason for delaying publication of *Revolutions.*

spheres of the universe, I ascribe certain motions to the terrestrial globe, they will shout that I must be immediately repudiated together with this belief. For I am not so enamored of my own opinions that I disregard what others may think of them. I am aware that a philosopher's ideas are not subject to the judgement of ordinary persons, because it is his endeavor to seek the truth in all things, to the extent permitted to human reason by God. Yet I hold that completely erroneous views should be shunned. Those who know that the consensus of many centuries has sanctioned the conception that the earth remains at rest in the middle of the heaven as its center would, I reflected, regard it as an insane pronouncement if I made the opposite assertion that the earth moves. Therefore I debated with myself for a long time whether to publish the volume which I wrote to prove the earth's motion or rather to follow the example of the Pythagoreans[1] and certain others, who used to transmit philosophy's secrets only to kinsmen and friends, not in writing but by word of mouth. . . . And they did so, it seems to me, not, as some suppose, because they were in some way jealous about their teachings, which would be spread around; on the contrary, they wanted the very beautiful thoughts attained by great men of deep devotion not to be ridiculed by those who are reluctant to exert themselves vigorously in any literary pursuit unless it is lucrative; or if they are stimulated to the nonacquisitive study of philosophy by the exhortation and example of others, yet because of their dullness of mind they play the same part among philosophers as drones among bees. When I weighed these considerations, the scorn which I had reason to fear on account of the novelty and unconventionality of my opinion almost induced me to abandon completely the work which I had undertaken.

But while I hesitated for a long time and even resisted, my friends [encouraged me]. . . . Foremost among them was the cardinal of Capua [a city in southern Italy], Nicholas Schönberg, renowned in every field of learning. Next to him was a man who loves me dearly, Tiedemann Giese, bishop of Chelmno [a city in northern Poland], a close student of sacred letters as well as of all good literature. For he repeatedly encouraged me and, sometimes adding reproaches, urgently requested me to publish this volume and finally permit it to appear after being buried among my papers and lying concealed not merely until the ninth year[2] but by now the fourth period of nine years. The same conduct was recommended to me by not a few other very eminent scholars. They exhorted me no longer to refuse, on account of the fear which I felt, to make my work available for the general use of students of astronomy. The crazier my doctrine of the earth's motion now appeared to most people, the argument ran, so much the more admiration and thanks would it gain after they saw the publication of my writings dispel the fog of absurdity by most luminous proofs. Influenced therefore by these persuasive men and by this hope, in the end I allowed my friends to bring out an edition of the volume, as they had long besought me to do. . . .

But you [your Holiness] are rather waiting to hear from me how it occurred to me to venture to conceive any motion of the earth, against the traditional opinion of astronomers and almost against common sense. . . . [Copernicus then describes some of the problems connected with the Ptolemaic system.]

For a long time, then, I reflected on this confusion in the astronomical traditions concerning the derivation of the motions of the universe's spheres. I began to be annoyed that the movements of the world machine, created for our sake by the best and most systematic

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[1]Pythagoreans were followers of Pythagoras, a Greek mathematician and philosopher of the sixth century B.C.; they were particularly interested in cosmology.

[2]The Roman poet Horace, who lived in the first century B.C., suggested in *Ars Poetica* that writers should keep a new manuscript in a cupboard "until the ninth year" before publishing it. Only then, he argued, would they have enough objectivity to judge its value. Copernicus is referring to this famous piece of advice.

Artisan of all [God], were not understood with greater certainty by the philosophers, who otherwise examined so precisely the most insignificant trifles of this world. For this reason I undertook the task of rereading the works of all the philosophers which I could obtain to learn whether anyone had ever proposed other motions of the universe's spheres than those expounded by the teachers of astronomy in the schools. And in fact first I found in Cicero that Hicetas supposed the earth to move. Later I also discovered in Plutarch[3] that certain others were of this opinion. . . .

Therefore, having obtained the opportunity from these sources, I too began to consider the mobility of the earth. . . . I thought that I too would be readily permitted to ascertain whether explanations sounder than those of my predecessors could be found for the revolution of the celestial spheres on the assumption of some motion of the earth.

Having thus assumed the motions which I ascribe to the earth later on in the volume, by long and intense study I finally found that if the motions of the other planets are correlated with the orbiting of the earth, and are computed for the revolution of each planet, not only do their phenomena follow therefrom but also the order and size of all the planets and spheres, and heaven itself is so linked together that in no portion of it can anything be shifted without disrupting the remaining parts and the universe as a whole. Accordingly in the arrangement of the volume too I have adopted the following order. In the first book I set forth the entire distribution of the spheres together with the motions which I attribute to the earth, so that this book contains, as it were, the general structure of the universe. Then in the remaining books I correlate the motions of the other planets and of all the spheres with the movement of the earth so that I may thereby determine to what extent the motions and appearances of the other planets and spheres can be saved if they are correlated with the earth's motions. I have no doubt that acute and learned astronomers will agree with me if, as this discipline especially requires, they are willing to examine and consider, not superficially but thoroughly, what I adduce in this volume in proof of these matters. However, in order that the educated and uneducated alike may see that I do not run away from the judgement of anybody at all, I have preferred dedicating my studies to Your Holiness rather than to anyone else. For even in this very remote corner of the earth where I live you are considered the highest authority by virtue of the loftiness of your office and your love for all literature and astronomy too. Hence by your prestige and judgement you can easily suppress calumnious attacks although, as the proverb has it, there is no remedy for a backbite.

Perhaps there will be babblers who claim to be judges of astronomy although completely ignorant of the subject and, badly distorting some passage of Scripture to their purpose, will dare to find fault with my undertaking and censure it. I disregard them even to the extent of despising their criticism as unfounded. For it is not unknown that Lactantius,[4] otherwise an illustrious writer but hardly an astronomer, speaks quite childishly about the earth's shape, when he mocks those who declared that the earth has the form of a globe. Hence scholars need not be surprised if any such persons will likewise ridicule me. Astronomy is written for astronomers. To them my work too will seem, unless I am mistaken, to make some contribution.

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[3]Hicetas, a Pythagorean philosopher of the fourth century B.C., taught that the earth rotated on its axis while the other heavenly bodies were at rest. Cicero was a Roman statesman of the first century B.C. Plutarch (A.D. c. 50–

[4]Renaissance humanists admired Lactantius (c. 240–c. 320), a Latin rhetorician and Christian apologist, for his classical, Ciceronian literary style.

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# Cardinal Bellarmine
# ATTACK ON THE COPERNICAN THEORY

**In 1615, Cardinal Bellarmine, who in the name of the Inquisition warned Galileo (see Sections 2 and 3) not to defend the Copernican theory, expressed his displeasure with heliocentrism in a letter to Paolo Antonio Foscarini. Foscarini, head of the Carmelites, an order of mendicant friars, in Calabria and professor of theology, had tried to show that the earth's motion was not incompatible with biblical statements.**

*Cardinal Bellarmine to Foscarini (12 April 1615)*

My Very Reverend Father,

I have read with interest the letter in Italian and the essay in Latin which Your [Reverence] sent me; I thank you for the one and for the other and confess that they are full of intelligence and erudition. You ask for my opinion, and so I shall give it to you, but very briefly, since now you have little time for reading and I for writing.

First, . . . to want to affirm that in reality the sun is at the center of the world and only turns on itself without moving from east to west, and the earth . . . revolves with great speed around the sun . . . is a very dangerous thing, likely not only to irritate all scholastic philosophers and theologians, but also to harm the Holy Faith by rendering Holy Scripture false. For your [Reverence] has well shown many ways of interpreting Holy Scripture, but has not applied them to particular cases; without a doubt you would have encountered very great difficulties if you had wanted to interpret all those passages you yourself cited.

Second, I say that, as you know, the Council [of Trent] prohibits interpreting Scripture against the common consensus of the Holy Fathers; and if Your [Reverence] wants to read not only the Holy Fathers, but also the modern commentaries on Genesis, the Psalms, Ecclesiastes, and Joshua, you will find all agreeing in the literal interpretation that the sun is in heaven and turns around the earth with great speed, and that the earth is very far from heaven and sits motionless at the center of the world. Consider now, with your sense of prudence, whether the Church can tolerate giving Scripture a meaning contrary to the Holy Fathers and to all the Greek and Latin commentators. Nor can one answer that this is not a matter of faith, since if it is not a matter of faith "as regards the topic," it is a matter of faith "as regards the speaker"; and so it would be heretical to say that Abraham did not have two children and Jacob twelve, as well as to say that Christ was not born of a virgin, because both are said by the Holy Spirit through the mouth of the prophets and the apostles.

Third, I say that if there were a true demonstration that the sun is at the center of the world and the earth in the third heaven, and that the sun does not circle the earth but the earth circles the sun, then one would have to proceed with great care in explaining the Scriptures that appear contrary, and say rather that we do not understand them than that what is demonstrated is false. But I will not believe that there is such a demonstration, until it is shown to me. . . . and in case of doubt one must not abandon the Holy Scripture as interpreted by the Holy Fathers. I add that the one who wrote, "The sun also ariseth, and the sun goeth down, and hasteth to his place where he arose," was Solomon [King of ancient Israel], who not only spoke inspired by God, but was a man above all others wise and learned in the human sciences and in the knowledge of created things; he received all this wisdom from God; therefore it is not likely that he was affirming something that was contrary to truth already demonstrated or capable of being demonstrated.

*REVIEW QUESTIONS*

1. What led Nicolaus Copernicus to investigate the motions of the universe's spheres?
2. Why did he fear to publish his theory about the earth's motion?
3. On what grounds did Cardinal Bellarmine reject the Copernican theory?

## 2 Expanding the New Astronomy

**The brilliant Italian scientist Galileo Galilei (1564–1642) rejected the medieval division of the universe into higher and lower realms and proclaimed the modern idea of nature's uniformity. Learning that a telescope had been invented in Holland, Galileo built one for himself and used it to investigate the heavens. Through his telescope, Galileo saw craters and mountains on the moon; he concluded that celestial bodies were not pure, perfect, and immutable, as had been believed. There was no difference in quality between heavenly and earthly bodies; nature was the same throughout.**

### Galileo Galilei
### *THE STARRY MESSENGER*

**In the following reading from *The Starry Messenger* (1610), Galileo reported the findings observed through his telescope, which led him to proclaim the uniformity of nature, a key principle of modern science.**

About ten months ago a report reached my ears that a certain Fleming [a native of Flanders]* had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. Of this truly remarkable effect several experiences were related, to which some persons gave credence while others denied them. A few days later the report was confirmed to me in a letter from a noble Frenchman at Paris, Jacques Badovere,† which caused me to apply myself wholeheartedly to inquire into the means by which I might arrive at the invention of a similar instrument. This I did shortly afterwards, my basis being the theory of refraction. First I prepared a tube of lead, at the ends of which I fitted two glass lenses, both plane on one side while on the other side one was spherically convex and the other concave. Then placing my eye near the concave lens I perceived objects satisfactorily large and near, for they appeared three times closer and nine times larger than when seen with the naked eye alone. Next I constructed another one, more accurate, which represented objects as enlarged more than sixty times. Finally, sparing neither labor nor expense, I succeeded in constructing for myself so excellent an instrument that objects

*Credit for the original invention is generally assigned to Hans Lipperhey, a lens grinder in Holland who chanced upon this property of combined lenses and applied for a patent on it in 1608.

†Badovere studied in Italy toward the close of the six-

It would be superfluous to enumerate the number and importance of the advantages of such an instrument at sea as well as on land. But forsaking terrestrial observations, I turned to celestial ones, and first I saw the moon from as near at hand as if it were scarcely two terrestrial radii [a measure of distance, obscure today] away. After that I observed often with wondering delight both the planets and the fixed stars, and since I saw these latter to be very crowded, I began to seek (and eventually found) a method by which I might measure their distances apart. . . .

Now let us review the observations made during the past two months, once more inviting the attention of all who are eager for true philosophy to the first steps of such important contemplations. Let us speak first of that surface of the moon which faces us. For greater clarity I distinguish two parts of this surface, a lighter and a darker; the lighter part seems to surround and to pervade the whole hemisphere, while the darker part discolors the moon's surface like a kind of cloud, and makes it appear covered with spots. Now those spots which are fairly dark and rather large are plain to everyone and have been seen throughout the ages; these I shall call the "large" or "ancient" spots, distinguishing them from others that are smaller in size but so numerous as to occur all over the lunar surface, and especially the lighter part. The latter spots had never been seen by anyone before me. From observations of these spots repeated many times I have been led to the opinion and conviction that the surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and the other heavenly bodies) to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the earth, relieved by chains of mountains and deep valleys. . . .

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With his telescope, Galileo discovered four moons orbiting Jupiter, an observation that overcame a principal objection to the Copernican system. Galileo showed that a celestial body could indeed move around a center other than the earth; that earth was not the common center for all celestial bodies; that a celestial body (earth's moon or Jupiter's moons) could orbit a planet at the same time that the planet revolved around another body (namely, the sun).

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On the seventh day of January in this present year 1610, at the first hour of night, when I was viewing the heavenly bodies with a telescope, Jupiter presented itself to me; and because I had prepared a very excellent instrument for myself, I perceived (as I had not before, on account of the weakness of my previous instrument) that beside the planet there were three starlets, small indeed, but very bright. Though I believed them to be among the host of fixed stars, they aroused my curiosity somewhat by appearing to lie in an exact straight line parallel to the ecliptic, and by their being more splendid than others of their size. Their arrangement with respect to Jupiter and each other was the following:

*East* * * O * *West*

that is, there were two stars on the eastern side and one to the west. The most easterly star and the western one appeared larger than the other. I paid no attention to the distances between them and Jupiter, for at the outset I thought them to be fixed stars, as I have said.‡ But returning to the same investigation on January eighth—led by what, I do not know—I found a very different arrangement. The three starlets

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‡The reader should remember that the telescope was nightly revealing to Galileo hundreds of fixed stars never previously observed. His unusual gifts for astronomical observation are illustrated by his having noticed and remembered these three merely by reason of their alignment, and recalling them so well that when by chance he happened to see them the following night he was certain that they had changed their positions.

were now all to the west of Jupiter, closer together, and at equal intervals from one another as shown in the following sketch:

*East* O * * * *West*

On the tenth of January, however, the stars appeared in this position with respect to Jupiter:

*East* * * O *West*

that is, there were but two of them, both easterly, the third (as I supposed) being hidden behind Jupiter. . . . There was no way in which such alterations could be attributed to Jupiter's motion, yet being certain that these were still the same stars I had observed . . . my perplexity was now transformed into amazement. I was sure that the apparent changes belonged not to Jupiter but to the observed stars, and I resolved to pursue this investigation with greater care and attention. . . .

I had now decided beyond all question that there existed in the heavens three stars wandering about Jupiter as do Venus and Mercury about the sun, and this became plainer than daylight from observations on similar occasions which followed. Nor were there just three such stars; four wanderers complete their revolutions about Jupiter. . . .

Here we have a fine and elegant argument for quieting the doubts of those who, while accepting with tranquil mind the revolutions of the planets about the sun in the Copernican system, are mightily disturbed to have the moon alone revolve about the earth and accompany it in an annual rotation about the sun. Some have believed that this structure of the universe should be rejected as impossible. But now we have not just one planet rotating about another while both run through a great orbit around the sun; our own eyes show us four stars which wander around Jupiter as does the moon around the earth, while all together trace out a grand revolution about the sun in the space of twelve years.

### *REVIEW QUESTIONS*

1. What methods did Galileo Galilei use in his scientific investigations?
2. What was the implication for modern astronomy of Galileo's observation of the surface of the moon? Of the moons of Jupiter?

## 3 Critique of Authority

Galileo appealed to the Roman Catholic authorities asking them to halt their actions against the theories of Copernicus, but was unsuccessful. His support of Copernicus aroused the ire of both clergy and scholastic philosophers. In 1616, the church placed Copernicus's book on the index of forbidden books, and Galileo was ordered to cease his defense of the Copernican theory. In 1632, Galileo published *Dialogue Concerning the Two Chief World Systems* in which he upheld the Copernican view. Widely distributed and acclaimed, the book antagonized Galileo's enemies, who succeeded in halting further printing. Summoned to Rome, the aging and infirm scientist was put on trial by the Inquisition and ordered to renounce the Copernican theory. Galileo bowed to the Inquisition, which condemned the *Dialogue* and sentenced him to life impris-

# Galileo Galilei
# LETTER TO THE GR
# CHRISTINA AND *DI*
# *CONCERNING THE*
# *TWO CHIEF WORLD*
# *PTOLEMAIC AND CO*

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**The second reading (from the *Dialo* Medieval scholastics regarded Aristotl concerning nature, an attitude that w tics. Galileo insisted that such relianc tific investigation, that it is through o one arrives at physical truth.**

## BIBLICAL AUTHORITY

Some years ago, as Your Serene Highness well knows, I discovered in the heavens many things that had not been seen before our own age. The novelty of these things, as well as some consequences which followed from them in contradiction to the physical notions commonly held among academic philosophers, stirred up against me no small number of professors—as if I had placed these things in the sky with my own hands in order to upset nature and overturn the sciences. They seemed to forget that the increase of known truths stimulates the investigation, establishment, and growth of the arts; not their diminution or destruction.

Showing a greater fondness for their own opinions than for truth, they sought to deny and disprove the new things which, if they had cared to look for themselves, their own senses would have demonstrated to them. To this end they hurled various charges and published nu-

I had now decided beyond all question that there existed in the heavens three stars wandering about Jupiter as do Venus and Mercury about the sun, and this became plainer than daylight from observations on similar occasions which followed. Nor were there just three such stars; four wanderers complete their revolutions about Jupiter. . . .

Here we have a fine and elegant argument for quieting the doubts of those who, while accepting with tranquil mind the revolutions of the planets about the sun in the Copernican system, are mightily disturbed to have the moon alone revolve about the earth and accompany it in an annual rotation about the sun. Some have believed that this structure of the universe should be rejected as impossible. But now we have not just one planet rotating about another while both run through a great orbit around the sun; our own eyes show us four stars which wander around Jupiter as does the moon around the earth, while all together trace out a grand revolution about the sun in the space of twelve years.

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# Galileo Galilei
# LETTER TO THE GRAND DUCHESS CHRISTINA AND *DIALOGUE CONCERNING THE TWO CHIEF WORLD SYSTEMS—PTOLEMAIC AND COPERNICAN*

**The first reading illustrates Galileo's active involvement in a struggle for freedom of inquiry many years before the *Dialogue* was published. In 1615, in a letter addressed to Grand Duchess Christina of Tuscany, Galileo argued that passages from the Bible had no authority in scientific disputes.**

**The second reading (from the *Dialogue*) reveals Galileo's views on Aristotle. Medieval scholastics regarded Aristotle as the supreme authority on questions concerning nature, an attitude that was perpetuated by early modern scholastics. Galileo insisted that such reliance on authority was a hindrance to scientific investigation, that it is through observation, experiment, and reason that one arrives at physical truth.**

## BIBLICAL AUTHORITY

Some years ago, as Your Serene Highness well knows, I discovered in the heavens many things that had not been seen before our own age. The novelty of these things, as well as some consequences which followed from them in contradiction to the physical notions commonly held among academic philosophers, stirred up against me no small number of professors—as if I had placed these things in the sky with my own hands in order to upset nature and overturn the sciences. They seemed to forget that the increase of known truths stimulates the investigation, establishment, and growth of the arts; not their diminution or destruction.

Showing a greater fondness for their own opinions than for truth, they sought to deny and disprove the new things which, if they had cared to look for themselves, their own senses would have demonstrated to them. To this end they hurled various charges and published numerous writings filled with vain arguments, and they made the grave mistake of sprinkling these with passages taken from places in the Bible which they had failed to understand properly, and which were ill suited to their purposes. . . .

. . . Men who were well grounded in astronomical and physical science were persuaded as soon as they received my first message. There were others who denied them or remained in doubt only because of their novel and unexpected character, and because they had not yet had the opportunity to see for themselves. These men have by degrees come to be satisfied. But some, besides allegiance to their original error, possess I know not what fanciful interest in remaining hostile not so much toward the things in question as toward their discoverer. No longer being able to deny them, these men now take refuge in obstinate silence, but being more than ever exasperated by that which has pacified and quieted other men, they divert their thoughts to other fancies and seek new ways to damage me. . . .

. . . Possibly because they are disturbed by the known truth of other propositions of mine which differ from those commonly held, and

therefore mistrusting their defense so long as they confine themselves to the field of philosophy, these men have resolved to fabricate a shield for their fallacies out of the mantle of pretended religion and the authority of the Bible. These they apply, with little judgment, to the refutation of arguments that they do not understand and have not even listened to.

First they have endeavored to spread the opinion that such propositions in general are contrary to the Bible and are consequently damnable and heretical. . . . Hence they have had no trouble in finding men who would preach the damnability and heresy of the new doctrine from their very pulpits with unwonted confidence, thus doing impious and inconsiderate injury not only to that doctrine and its followers but to all mathematics and mathematicians in general. . . .

. . . They go about invoking the Bible, which they would have minister to their deceitful purposes. Contrary to the sense of the Bible and the intention of the holy [Church] Fathers, if I am not mistaken, they would extend such authorities until even in purely physical matters—where faith is not involved—they would have us altogether abandon reason and the evidence of our senses in favor of some biblical passage, though under the surface meaning of its words this passage may contain a different sense.

I hope to show that I proceed with much greater piety than they do, when I argue not against condemning [Copernicus'] book, but against condemning it in the way they suggest—that is, without understanding it, weighing it, or so much as reading it. For Copernicus never discusses matters of religion or faith, nor does he use arguments that depend in any way upon the authority of sacred writings which he might have interpreted erroneously. He stands always upon physical conclusions pertaining to the celestial motions, and deals with them by astronomical and geometrical demonstrations, founded

trine were proved, then it could not contradict the Scriptures when they were rightly understood. . . .

The reason produced for condemning the opinion that the earth moves and the sun stands still is that in many places in the Bible one may read that the sun moves and the earth stands still. Since the Bible cannot err, it follows as a necessary consequence that anyone takes an erroneous and heretical position who maintains that the sun is inherently motionless and the earth movable.

With regard to this argument, I think in the first place that it is very pious to say and prudent to affirm that the holy Bible can never speak untruth—whenever its true meaning is understood. But I believe nobody will deny that it is often very abstruse, and may say things which are quite different from what its bare words signify. Hence in expounding the Bible if one were always to confine oneself to the unadorned grammatical meaning, one might fall into error. . . .

. . . Now the Bible, merely to condescend to popular capacity, has not hesitated to obscure some very important pronouncements, attributing to God himself some qualities extremely remote from (and even contrary to) His essence. Who, then, would positively declare that this principle has been set aside, and the Bible has confined itself rigorously to the bare and restricted sense of its words, when speaking but casually of the earth, of water, of the sun, or of any other created thing? Especially in view of the fact that these things in no way concern the primary purpose of the sacred writings, which is the service of God and the salvation of souls—matters infinitely beyond the comprehension of the common people.

This being granted, I think that in discussions of physical problems we ought to begin not from the authority of scriptural passages, but from sense-experiences and necessary demonstrations. . . . Nothing physical which sense-experience sets before our eyes, or which

may have some different meaning beneath their words. . . .

. . . I do not feel obliged to believe that that same God who has endowed us with senses reason, and intellect has intended to forgo their use and by some other means to give us knowledge which we can attain by them. He would not require us to deny sense and reason in physical matters which are set before our eyes and minds by direct experience or necessary demonstrations. . . .

It is obvious that such [anti-Copernican] authors, not having penetrated the true sense of Scripture, would impose upon others an obligation to subscribe to conclusions that are repugnant to manifest reason and sense, if they had any authority to do so. God forbid that this sort of abuse should gain countenance and authority, for then in a short time it would be necessary to proscribe all the contemplative sciences. People who are unable to understand perfectly both the Bible and the sciences far outnumber those who do understand. The former, glancing superficially through the Bible, would arrogate to themselves the authority to decree upon every question of physics on the strength of some words which they have misunderstood, and which was employed by the sacred authors for some different purpose. And the smaller number of understanding men could not dam up the furious torrent of such people, who would gain the majority of followers simply because it is much more pleasant to gain a reputation for wisdom without effort or study than to consume oneself tirelessly in the most laborious disciplines.

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Galileo attacked the unquestioning acceptance of Aristotle's teachings in his Dialogue Concerning the Two Chief World Systems—Ptolemaic and Copernican. In the Dialogue, Simplicio is an Aristotelian and Salviati is a spokesman for Galileo; Sagredo, a third participant, introduces the

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## ARISTOTELIAN AUTHORITY

SAGREDO One day I was at the home of a very famous doctor in Venice, where many persons came on account of their studies, and others occasionally came out of curiosity to see some anatomical dissection performed by a man who was truly no less learned than he was a careful and expert anatomist. It happened on this day that he was investigating the source and origin of the nerves, about which there exists a notorious controversy between the Galenist and Peripatetic doctors.[1] The anatomist showed that the great trunk of nerves, leaving the brain and passing through the nape, extended on down the spine and then branched out through the whole body, and that only a single strand as fine as a thread arrived at the heart. Turning to a gentleman whom we knew to be a Peripatetic philosopher, and on whose account he had been exhibiting and demonstrating everything with unusual care, he asked this man whether he was at last satisfied and convinced that the nerves originated in the brain and not in the heart. The philosopher, after considering for awhile, answered: "You have made me see this matter so plainly and palpably that if Aristotle's text were not contrary to it, stating clearly that the nerves originate in the heart, I should be forced to admit it to be true." . . .

SIMPLICIO But if Aristotle is to be abandoned, whom shall we have for a guide in philosophy? Suppose you name some author.

SALVIATI We need guides in forests and in unknown lands, but on plains and in open places only the blind need guides. It is better for such people to stay at home, but anyone with eyes in his head and his wits about him could serve as a guide for them. In saying this, I do not mean that a person should not listen to Aristotle; indeed, I applaud the reading

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[1]Galenist doctors followed the medical theories of Galen (A.D. 129–c. 199), a Greek anatomist and physician whose writings had great authority among medieval and early modern physicians. Peripatetic doctors followed Aristotle's teachings.

and careful study of his works, and I reproach only those who give themselves up as slaves to him in such a way as to subscribe blindly to everything he says and take it as an inviolable decree without looking for any other reasons. This abuse carries with it another profound disorder, that other people do not try harder to comprehend the strength of his demonstrations. And what is more revolting in a public dispute, when someone is dealing with demonstrable conclusions, than to hear him interrupted by a text (often written to some quite different purpose) thrown into his teeth by an opponent? If, indeed, you wish to continue in this method of studying, then put aside the name of philosophers and call yourselves historians, or memory experts; for it is not proper that those who never philosophize should usurp the honorable title of philosopher.

### *REVIEW QUESTIONS*

1. What was Galileo Galilei's objection to using the Bible as a source of knowledge of physical things? According to him, how did one acquire knowledge of nature?
2. What point was Galileo making in telling the story of the anatomical dissection?
3. What was Galileo's view on the use of Aristotle's works as a basis for scientific endeavors?

## 4 Prophet of Modern Science

Sir Francis Bacon (1561–1626), an English statesman and philosopher, vigorously supported the advancement of science and the scientific method. He believed that increased comprehension and mastery of nature would improve living conditions for people and therefore wanted science to encompass systematic research; he urged the state to fund scientific institutions. Bacon denounced universities for merely repeating Aristotelian concepts and discussing problems—Is matter formless? Are all natural substances composed of matter?—that did not increase understanding of nature or contribute to human betterment. The webs spun by these scholastics, he said, were ingenious but valueless. Bacon wanted an educational program that stressed direct contact with nature and fostered new discoveries.

Bacon was among the first to appreciate the new science's value and to explain its method clearly. Like Leonardo da Vinci, Bacon gave supreme value to the direct observation of nature; for this reason he is one of the founders of the empirical tradition in modern philosophy. Bacon upheld the inductive approach—careful investigation of nature, accumulation of data, and experimen-

## Francis Bacon
## ATTACK ON AUTHO AND ADVOCACY OF EXPERIMENTAL SCI

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But even though Aristotle were the man he is thought to be I should still warn you against receiving as oracles the thoughts and opinions of one man. What justification can there be for this self-imposed servitude [that] . . . you are content to repeat Aristotle after two thousand [years]? . . . But if you will be guided by me you will deny, not only to this man but to any mortal now living or who shall live hereafter, the right to dictate your opinions. . . . You will never be sorry for trusting your own strength, if you but once make trial of it. You may be inferior to Aristotle on the whole, but not in everything. Finally, and this is the head and front of the whole matter, there is at least one thing in which you are far ahead of him—in precedents, in experience, in the lessons of time. Aristotle, it is said, wrote a book in which he gathered together the laws and institutions of two hundred and fifty-five cities; yet I have no doubt that the customs of Rome are worth more than all of them combined so far as military and political science are concerned. The position is the same in natural philosophy. Are you of a mind to cast aside not only your own endowments but the gifts of time? Assert yourselves before it is too late. Apply yourselves to the study of things themselves. Be not for ever the property of one man.

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# Francis Bacon
# ATTACK ON AUTHORITY AND ADVOCACY OF EXPERIMENTAL SCIENCE

**Bacon was not himself a scientist; he made no discoveries and had no laboratory. Nevertheless, for his advocacy of the scientific method, Bacon is deservedly regarded as a prophet of modern science. In the first passage from *Redargutio Philosophiarum* (The Refutation of Philosophies), a treatise on the "idols of the theater"—fallacious ways of thinking based on given systems of philosophy—Bacon attacks the slavish reliance on Aristotle.**

But even though Aristotle were the man he is thought to be I should still warn you against receiving as oracles the thoughts and opinions of one man. What justification can there be for this self-imposed servitude [that] . . . you are content to repeat Aristotle after two thousand [years]? . . . But if you will be guided by me you will deny, not only to this man but to any mortal now living or who shall live hereafter, the right to dictate your opinions. . . . You will never be sorry for trusting your own strength, if you but once make trial of it. You may be inferior to Aristotle on the whole, but not in everything. Finally, and this is the head and front of the whole matter, there is at least one thing in which you are far ahead of him—in precedents, in experience, in the lessons of time. Aristotle, it is said, wrote a book in which he gathered together the laws and institutions of two hundred and fifty-five cities; yet I have no doubt that the customs of Rome are worth more than all of them combined so far as military and political science are concerned. The position is the same in natural philosophy. Are you of a mind to cast aside not only your own endowments but the gifts of time? Assert yourselves before it is too late. Apply yourselves to the study of things themselves. Be not for ever the property of one man.

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With these scattered excerpts from *The New Organon* (New System of Logic), in 1620 Bacon criticized contemporary methods used to inquire into nature. He expressed his ideas in the form of aphorisms—concise statements of principles or general truths.

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I. Man, being the servant and interpreter of Nature, can do and understand so much and so much only as he has observed in fact or in thought of the course of nature: beyond this he neither knows anything nor can do anything.

VIII. . . . The sciences we now possess are merely systems for the nice ordering and setting forth of things already invented; not methods of invention or directions for new works.

XII. The logic now in use serves rather to fix and give stability to the errors which have their foundation in commonly received notions than to help the search after truth. So it does more harm than good.

XIX. There are and can be only two ways of searching into and discovering truth. The one flies from the senses and particulars to the most general axioms, and from these principles, the truth of which it takes for settled and immoveable, proceeds to judgment and to the discovery of middle axioms. And this way is now in fashion. The other derives axioms from the senses and particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all. This is the true way, but as yet untried.

XXIII. There is a great difference between . . . certain empty dogmas, and the true signatures and marks set upon the works of creation as they are found in nature.

XXIV. It cannot be that axioms established by argumentation should avail for the discovery of new works; since the subtlety of nature is greater many times over than the subtlety of argument. But axioms duly and orderly formed from particulars easily discover the way to new particulars, and thus render sciences active.

XXXI. It is idle to expect any great advancement in science from the superinducing [adding] and engrafting of new things upon old. We must begin anew from the very foundations, unless we would revolve for ever in a circle with mean and contemptible progress.

CIX. There is therefore much ground for hoping that there are still laid up in the womb of nature many secrets of excellent use, having no affinity or parallelism with any thing that is now known, but lying entirely out of the beat of the imagination, which have not yet been found out. They too no doubt will some time or other, in the course and revolution of many ages, come to light of themselves, just as the others did; only by the method of which we are now treating they can be speedily and suddenly and simultaneously presented and anticipated.

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Bacon describes those "idols" or false notions that hamper human understanding.

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XXXVIII. The idols and false notions which are now in possession of the human understanding, and have taken deep root therein, not only so beset men's minds that truth can hardly find entrance, but even after entrance is obtained, they will again in the very instauration [renewal] of the sciences meet and trouble us, unless men being forewarned of the danger fortify themselves as far as may be against their tion's sake I have assigned names,—calling the first class *Idols of the Tribe*; the second, *Idols of the Cave*; the third, *Idols of the Market-place*; the fourth, *Idols of the Theatre.*

XLI. The Idols of the Tribe have their foundation in human nature itself, and in the tribe or race of men. For it is a false assertion that the sense of man is the measure of things. On the contrary, all perceptions as well of the sense as of the mind are according to the measure of the universe. And the human understanding is like a false mirror, which, receiving rays irregularly, distorts and discolours the nature of things by mingling its own nature with it.

XLII. The Idols of the Cave are the idols of the individual man. For every one (besides the errors common to human nature in general) has a cave or den of his own, which refracts and discolours the light of nature; owing either to his own proper and peculiar nature; or to his education and conversation with others; or to the reading of books, and the authority of those whom he esteems and admires; or to the differences of impressions, accordingly as they take place in a mind preoccupied and predisposed or in a mind indifferent and settled; or the like. . . .

XLIII. There are also Idols formed by the intercourse and association of men with each other, which I call Idols of the Market-place, on account of the commerce and consort of men there. For it is by discourse that men associate; and words are imposed according to the apprehension of the vulgar. And therefore the ill and unfit choice of words wonderfully obstructs the understanding. Nor do the definitions or explanations wherewith in some things learned men are wont to guard and defend themselves, by any means set the matter right. But words plainly force and overrule the understanding, and throw all into confusion, and lead men away into numberless empty controversies and idle fancies.

XLIV. Lastly, there are Idols which have immigrated into men's minds from the various

received systems are but so many stage-play representing worlds of their own creation aft an unreal and scenic fashion. Nor is it only the systems now in vogue, or only of the a cient sects and philosophies, that I speak; f many more plays of the same kind may yet composed and in like artificial manner s forth; seeing that errors the most widely diffe

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## 5 The Autonomy of the M

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XLIV. Lastly, there are Idols which have immigrated into men's minds from the various dogmas of philosophies, and also from wrong laws of demonstration. These I call Idols of the Theatre; because in my judgment all the received systems are but so many stage-plays, representing worlds of their own creation after an unreal and scenic fashion. Nor is it only of the systems now in vogue, or only of the ancient sects and philosophies, that I speak; for many more plays of the same kind may yet be composed and in like artificial manner set forth; seeing that errors the most widely different have nevertheless causes for the most part alike. Neither again do I mean this only of entire systems, but also of many principles and axioms in science, which by tradition, credulity, and negligence have come to be received.

But of these several kinds of Idols I must speak more largely and exactly, that the understanding may be duly cautioned.

### *REVIEW QUESTIONS*

1. What intellectual attitude did Francis Bacon believe obstructed new scientific discoveries in his time?
2. What method of scientific inquiry did Bacon advocate?
3. Explain how each one of Bacon's idols hampers human understanding.

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## 5 The Autonomy of the Mind

René Descartes (1596–1650), a French mathematician and philosopher, united the new currents of thought initiated during the Renaissance and the Scientific Revolution. Descartes said that the universe was a mechanical system whose inner laws could be discovered through mathematical thinking and formulated in mathematical terms. With Descartes' assertions on the power of thought, human beings became fully aware of their capacity to comprehend the world through their mental powers. For this reason he is regarded as the founder of modern philosophy.

The deductive approach stressed by Descartes presumes that inherent in the mind are mathematical principles, logical relationships, the principle of cause and effect, concepts of size and motion, and so on—ideas that exist independently of human experience with the external world. Descartes, for example, would say that the properties of a right-angle triangle ($a^2 + b^2 = c^2$) are implicit in human consciousness prior to any experience one might have with a triangle. These innate ideas, said Descartes, permit the mind to give order and coherence to the physical world. Descartes held that the mind arrives at truth when it "intuits" or comprehends the logical necessity of its own ideas and expresses these ideas with clarity, certainty, and precision.

## René Descartes
## *DISCOURSE ON METHOD*

In the *Discourse on Method* (1637), Descartes proclaimed the mind's autonomy and importance, and its ability and right to comprehend truth. In this work he offered a method whereby one could achieve certainty and thereby produce a comprehensive understanding of nature and human culture. In the following

passage from the *Discourse on Method,* he explained the purpose of his inquiry. How he did so is almost as revolutionary as the ideas he wished to express. He spoke in the first person, autobiographically, as an individual employing his own reason, and he addressed himself to other individuals, inviting them to use their reason. He brought to his narrative an unprecedented confidence in the power of his own judgment and a deep disenchantment with the learning of his times.

## PART ONE

From my childhood I lived in a world of books, and since I was taught that by their help I could gain a clear and assured knowledge of everything useful in life, I was eager to learn from them. But as soon as I had finished the course of studies which usually admits one to the ranks of the learned, I changed my opinion completely. For I found myself saddled with so many doubts and errors that I seemed to have gained nothing in trying to educate myself unless it was to discover more and more fully how ignorant I was.

Nevertheless I had been in one of the most celebrated schools in Europe, where I thought there should be wise men if wise men existed anywhere on earth. I had learned there everything that others learned, and, not satisfied with merely the knowledge that was taught, I had perused as many books as I could find which contained more unusual and recondite knowledge. . . . And finally, it did not seem to me that our times were less flourishing and fertile than were any of the earlier periods. All this led me to conclude that I could judge others by myself, and to decide that there was no such wisdom in the world as I had previously hoped to find. . . .

I revered our theology, and hoped as much as anyone else to get to heaven, but having learned on great authority that the road was just as open to the most ignorant as to the most learned, and that the truths of revelation which lead thereto are beyond our understanding, I would not have dared to submit them to the weakness of my reasonings. I thought that to succeed in their exam-

I will say nothing of philosophy except that it has been studied for many centuries by the most outstanding minds without having produced anything which is not in dispute and consequently doubtful. I did not have enough presumption to hope to succeed better than the others; and when I noticed how many different opinions learned men may hold on the same subject, despite the fact that no more than one of them can ever be right, I resolved to consider almost as false any opinion which was merely plausible. . . .

This is why I gave up my studies entirely as soon as I reached the age when I was no longer under the control of my teachers. I resolved to seek no other knowledge than that which I might find within myself, or perhaps in the great book of nature. I spent a few years of my adolescence traveling, seeing courts and armies, living with people of diverse types and stations of life, acquiring varied experience, testing myself in the episodes which fortune sent me, and, above all, thinking about the things around me so that I could derive some profit from them. For it seemed to me that I might find much more of the truth in the cogitations [reflections] which each man made on things which were important to him, and where he would be the loser if he judged badly, than in the cogitations of a man of letters in his study, concerned with speculations which produce no effect, and which have no consequences to him. . . .

. . . After spending several years in thus studying the book of nature and acquiring experience, I eventually reached the decision to

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## PART TWO

. . . As far as the opinions which I had been re ceiving since my birth were concerned, I coul not do better than to reject them completel for once in my lifetime, and to resume them af terwards, or perhaps accept better ones in thei place, when I had determined how they fitte into a rational scheme. And I firmly believe that by this means I would succeed in conduct ing my life much better than if I built onl upon the old foundations and gave credence t the principles which I had acquired in m childhood without ever having examined them to see whether they were true or not. . . .

. . . Never has my intention been more that to try to reform my own ideas, and rebuil them on foundations that would be wholl mine. . . . The decision to abandon all one' preconceived notions is not an example for al to follow. . . .

As for myself, I should no doubt have . . [never attempted it] if I had had but a singl teacher or if I had not known the differences which have always existed among the mos learned. I had discovered in college that on cannot imagine anything so strange and unbe lievable but that it has been upheld by som philosopher; and in my travels I had found tha those who held opinions contrary to ours were neither barbarians nor savages, but that many o them were at least as reasonable as ourselves. had considered how the same man, with th same capacity for reason, becomes different as result of being brought up among Frenchmen o Germans than he would be if he had bee brought up among Chinese or cannibals; an how, in our fashions, the thing which pleased u ten years ago and perhaps will please us again ten years in the future, now seems extravagant and ridiculous; and I felt that in all these ways we are much more greatly influenced by custom

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. . . After spending several years in thus studying the book of nature and acquiring experience, I eventually reached the decision to study my own self, and to employ all my abilities to try to choose the right path. This produced much better results in my case, I think, than would have been produced if I had never left my books and my country. . . .

## PART TWO

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. . . Never has my intention been more than to try to reform my own ideas, and rebuild them on foundations that would be wholly mine. . . . The decision to abandon all one's preconceived notions is not an example for all to follow. . . .

As for myself, I should no doubt have . . . [never attempted it] if I had had but a single teacher or if I had not known the differences which have always existed among the most learned. I had discovered in college that one cannot imagine anything so strange and unbelievable but that it has been upheld by some philosopher; and in my travels I had found that those who held opinions contrary to ours were neither barbarians nor savages, but that many of them were at least as reasonable as ourselves. I had considered how the same man, with the same capacity for reason, becomes different as a result of being brought up among Frenchmen or Germans than he would be if he had been brought up among Chinese or cannibals; and how, in our fashions, the thing which pleased us ten years ago and perhaps will please us again ten years in the future, now seems extravagant and ridiculous; and I felt that in all these ways we are much more greatly influenced by custom and example than by any certain knowledge. Faced with this divergence of opinion, I could not accept the testimony of the majority, for I thought it worthless as a proof of anything somewhat difficult to discover, since it is much more likely that a single man will have discovered it than a whole people. Nor, on the other hand, could I select anyone whose opinions seemed to me to be preferable to those of others, and I was thus constrained to embark on the investigation for myself.

Nevertheless, like a man who walks alone in the darkness, I resolved to go so slowly and circumspectly that if I did not get ahead very rapidly I was at least safe from falling. Also, I did not want to reject all the opinions which had slipped irrationally into my consciousness since birth, until I had first spent enough time planning how to accomplish the task which I was then undertaking, and seeking the true method of obtaining knowledge of everything which my mind was capable of understanding. . . .

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Descartes' method consists of four principles that place the capacity to arrive at truth entirely within the province of the human mind. First one finds a self-evident principle, such as a geometric axiom. From this general principle, other truths are deduced through logical reasoning. This is accomplished by breaking a problem down into its elementary components and then, step by step, moving toward more complex knowledge.

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. . . I thought that some other method [beside that of logic, algebra, and geometry] must be found to combine the advantages of these three and to escape their faults. Finally, just as the multitude of laws frequently furnishes an excuse for vice, and a state is much better governed with a few laws which are strictly adhered to, so I thought that instead of the great number of precepts of which logic is composed, I would have enough with the four following ones, provided that I made a firm and unalterable resolution not to violate them even in a single instance.

The first rule was never to accept anything as true unless I recognized it to be evidently such: that is, carefully to avoid precipitation

and prejudgment, and to include nothing in my conclusions unless it presented itself so clearly and distinctly to my mind that there was no occasion to doubt it.

The second was to divide each of the difficulties which I encountered into as many parts as possible, and as might be required for an easier solution.

The third was to think in an orderly fashion, beginning with the things which were simplest and easiest to understand, and gradually and by degrees reaching toward more complex knowledge, even treating as though ordered materials which were not necessarily so.

The last was always to make enumerations so complete, and reviews so general, that I would be certain that nothing was omitted. . . .

What pleased me most about this method was that it enabled me to reason in all things, if not perfectly, at least as well as was in my power. In addition, I felt that in practicing it my mind was gradually becoming accustomed to conceive its objects more clearly and distinctly. . . .

## PART FOUR

. . . As I desired to devote myself wholly to the search for truth, I thought that I should . . . reject as absolutely false anything of which I could have the least doubt, in order to see whether anything would be left after this procedure which could be called wholly certain. Thus, as our senses deceive us at times, I was ready to suppose that nothing was at all the way our senses represented them to be. As there are men who make mistakes in reasoning even on the simplest topics in geometry, I judged that I was as liable to error as any other, and rejected as false all the reasoning which I had previously accepted as valid demonstration. Finally, as the same precepts which we have when awake may come to us when asleep without their being true, I decided to suppose that nothing that had ever entered my mind was more real than the illusions of my dreams. But I soon noticed that while I thus wished to think everything false, it was necessarily true that I who thought so was something. Since this truth, *I think, therefore I am,* was so firm and assured that all the most extravagant suppositions of the sceptics[1] were unable to shake it, I judged that I could safely accept it as the first principle of the philosophy I was seeking.

Descartes was searching for an incontrovertible truth that could serve as the first principle of philosophy. His arrival at the famous dictum "I think, therefore I am" marks the beginning of modern philosophy.

[1]The skeptics belonged to the ancient Greek philosophic school that held true knowledge to be beyond human grasp and treated all knowledge as uncertain.

### *REVIEW QUESTIONS*

1. Why was René Descartes critical of the learning of his day?
2. What are the implications of Descartes' famous words: "I think, therefore I am"?
3. Compare Descartes' method with the approach advocated by Francis Bacon.

# 6 The Mechanical Universe

**By demonstrating that all bodies in the universe—earthly objects as well as moons, planets, and stars—obey the same laws of motion and gravitation, Sir**

**sharp division between a higher cele**
**the *Principia Mathematica* (1687), N**
**hold celestial bodies in their orbits**
**ground. For Newton, the universe v**
**obeyed strict mechanical principles a**
**To Newton's contemporaries, it seem**
**the universe.**

## Isaac Newton
## *PRINCIPIA MATHEA*

**In the first of the following passag**
**stated the principle of universal law**
**the means of acquiring knowledge.**

### RULES OF REASONING IN PHILOSOPHY

*Rule I.* We are to admit no more causes o natural things than such as are both true anc sufficient to explain their appearances.

To this purpose the philosophers say tha Nature does nothing in vain, and more is it vain when less will serve; for Nature is pleasec with simplicity, and affects not the pomp o superfluous causes.

*Rule II.* Therefore to the same natural effect we must, as far as possible, assign the sam causes.

As to respiration in a man and in a beast; th descent of stones [meteorites] in *Europe* and it *America*; the light of our culinary fire and o the sun; the reflection of light in the earth, anc in the planets.

*Rule III.* The qualities of bodies, which ad mit neither [intensification] nor remission o degrees, and which are found to belong to al bodies within the reach of our experiments, ar to be esteemed the universal qualities of al bodies whatsoever.

PART FOUR

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reign to medieval thinkers, who drew a

sharp division between a higher celestial world and a lower terrestrial one. In the *Principia Mathematica* (1687), Newton showed that the same forces that hold celestial bodies in their orbits around the sun make apples fall to the ground. For Newton, the universe was like a giant clock, all of whose parts obeyed strict mechanical principles and worked together in perfect precision. To Newton's contemporaries, it seemed as if mystery had been banished from the universe.

# Isaac Newton
# *PRINCIPIA MATHEMATICA*

In the first of the following passages from *Principia Mathematica,* Newton stated the principle of universal law and lauded the experimental method as the means of acquiring knowledge.

## RULES OF REASONING IN PHILOSOPHY

*Rule I.* We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp of superfluous causes.

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*Rule III.* The qualities of bodies, which admit neither [intensification] nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.

For since the qualities of bodies are only known to us by experiments, we are to hold for universal all such as universally agree with experiments; and such as are not liable to diminution can never be quite taken away. We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising; nor are we to recede from the analogy of Nature, which [is] . . . simple, and always consonant to itself. We no other way know the extension of bodies than by our senses, nor do these reach it in all bodies; but because we perceive extension in all that are sensible, therefore, we ascribe it universally to all others also. That abundance of bodies are hard, we learn by experience; and because the hardness of the whole arises from the hardness of the parts, we, therefore, justly infer the hardness of the undivided particles not only of the bodies we feel but of all others. That all bodies are impenetrable, we gather not from reason, but from sensation. The bodies which we handle we find impenetrable, and thence, conclude impenetrability to be an universal property of all bodies whatsoever. That all bodies are moveable, and endowed with certain powers (which we call . . . (*inertia*)) of persevering in their motion, or in their rest, we only infer from the like properties observed in the bodies which we have seen. The extension, hardness, impenetrability, mobility, . . . of the whole, result from the extension, hardness, impenetrability,

mobility, . . . of the parts; and thence we conclude the least particles of all bodies to be also all extended, and hard and impenetrable, and moveable, . . . And this is the foundation of all philosophy. . . .

Lastly, if it universally appears, by experiments and astronomical observations, that all bodies about the earth gravitate towards the earth, and that in proportion to the quantity of matter which they severally contain; that the moon likewise, according to the quantity of its matter, gravitates towards the earth; that, on the other hand, our sea gravitates towards the moon; and all the planets mutually one towards another; and the comets in like manner towards the sun; we must, in consequence of this rule, universally allow that all bodies whatsoever are endowed with a principle of mutual gravitation. . . .

*Rule IV.* In experimental philosophy we are to look upon propositions collected by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.

This rule we must follow, that the argument of induction may not be evaded by hypotheses.

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Newton describes further his concepts of gravity and scientific methodology.

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## GRAVITY

Hitherto, we have explained the phenomena of the heavens and of our sea by the power of gravity, but have not yet assigned the cause of this power. This is certain, that it must proceed from a cause that penetrates to the very centres of the sun and planets, without suffering the least diminution of its force; that operates not according to the quantity of the the quantity of the solid matter which they contain, and propagates its virtue on all sides to immense distances, decreasing always in the duplicate portion of the distances. . . .

Hitherto I have not been able to discover the cause of those properties of gravity from the phenomena, and I frame no hypothesis; for whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterward rendered general by induction. Thus it was the impenetrability, the mobility, and the impulsive forces of bodies, and the laws of motion and of gravitation were discovered. And to us it is enough that gravity does really exist, and acts according to the laws which we have explained, and abundantly serves to account for all the motions of the celestial bodies, and of our sea.

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A devoted Anglican, Newton believed that God had created this superbly organized universe. The following selection is also from the *Principia*.

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## GOD AND THE UNIVERSE

This most beautiful system of the sun, planets, and comets could only proceed from the counsel and dominion of an intelligent and powerful Being. And if the fixed stars are the centers of other like systems, these, being formed by the like wise counsel, must be all subject to the dominion of One, especially since the light of the fixed stars is of the same nature with the light of the sun and from every system light passes into all the other systems; and lest the systems of the fixed stars should, by their gravity, fall on each other mutually, he hath placed those systems at immense distances from one another.

This Being governs all things not as the soul of

God" . . . or "Universal Ruler." . . . It is the do minion of a spiritual being which constitutes God. . . . And from his true dominion it follow that the true God is a living, intelligent an powerful Being. . . . he governs all things, an knows all things that are or can be done. . . . H endures for ever, and is every where present; an by existing always and every where, he const tutes duration and space. . . . In him are a things contained and moved; yet neither affec the other: God suffers nothing from the motic of bodies; bodies find no resistance from the on nipresence of God. . . . As a blind man has r idea of colors so we have no idea of the mann by which the all-wise God preserves and unde stands all things. He is utterly void of all boc and bodily figure, and can therefore neither l seen, nor heard, nor touched; nor ought to l

## *REVIEW QUESTIONS*

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2. What method for investigating nature did N
3. Summarize Newton's arguments for God's e
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This Being governs all things not as the soul of the world, but as Lord over all; and on account of his dominion he is wont to be called "Lord God" . . . or "Universal Ruler." . . . It is the dominion of a spiritual being which constitutes a God. . . . And from his true dominion it follows that the true God is a living, intelligent and powerful Being. . . . he governs all things, and knows all things that are or can be done. . . . He endures for ever, and is every where present; and by existing always and every where, he constitutes duration and space. . . . In him are all things contained and moved; yet neither affects the other: God suffers nothing from the motion of bodies; bodies find no resistance from the omnipresence of God. . . . As a blind man has no idea of colors so we have no idea of the manner by which the all-wise God preserves and understands all things. He is utterly void of all body and bodily figure, and can therefore neither be seen, nor heard, nor touched; nor ought to be worshipped under the representation of any corporeal thing. We have ideas of his attributes, but what the real substance of any thing is we know not. . . . Much less, then, have we any idea of the substance of God. We know him only by his most wise and excellent contrivances of things. . . . [W]e reverence and adore him as his servants; and a god without dominion, providence, and final causes, is nothing else but Fate and Nature. Blind metaphysical necessity, which is certainly the same always and everywhere, could produce no variety of things. All that diversity of natural things which we find suited to different times and places could arise from nothing but the ideas and will of a Being necessarily existing. . . . And thus much concerning God; to discourse of whom from the appearances of things does certainly belong to Natural Philosophy.

### *REVIEW QUESTIONS*

1. What did Isaac Newton mean by universal law? What examples of universal law did he provide?
2. What method for investigating nature did Newton advocate?
3. Summarize Newton's arguments for God's existence.
4. For Newton, what is God's relationship to the universe?