

*Ptolemy's view of the sun, the planets, and the stars have long been discarded, but our perceptions are still Ptolemaic. We look to the east to see the sun rise (when in relation to Earth it is stationary); we still watch the heavens move over us and use the north, south, east, west directions, ignoring the fact that our Earth is a globe.*

## INTRODUCTION

"If I have seen farther, it is by standing on the shoulders of giants," wrote Isaac Newton in a letter to Robert Hooke in 1676. Although Newton was referring to his discoveries in optics rather than his more important work on gravity and the laws of motion, it is an apt comment on how science, and indeed the whole of civilization, is a series of incremental advances, each building on what went before. This is the theme of this fascinating volume, which uses the original texts to trace the evolution of our picture of the heavens from the revolutionary claim of Nicolaus Copernicus that the Earth orbits the sun to the equally revolutionary proposal of Albert Einstein that space and time are curved and warped by mass and energy. It is a compelling story because both Copernicus and Einstein have brought about profound changes in what we see as our position in the order of things. Gone is our privileged place at the center of the universe, gone are eternity and certainty, and gone are Absolute Space and Time to be replaced by rubber sheets.

It is no wonder both theories encountered violent opposition: the inquisition in the case of the Copernican theory and the Nazis in the case of relativity. We now have a tendency to dismiss as primitive the earlier world picture of Aristotle and Ptolemy in which the Earth was at the center and the Sun went round it. However we should not be too scornful of their model, which was anything but simpleminded. It incorporated Aristotle's deduction that the earth is a round ball rather than a flat plate, and it was reasonably accurate in its main function, that of predicting the apparent positions of the heavenly bodies in the sky for astrological purposes. In fact, it was about as accurate as the heretical suggestion put forward in 1543 by Copernicus that the Earth and the planets moved in circular orbits around the Sun.

Galileo found Copernicus' proposal convincing not because it better fit the observations of planetary positions but because of its simplicity and elegance, in contrast to the complicated epicycles of the Ptolemaic model. In *Dialogues Concerning Two New Sciences*, Galileo's characters, Salviati and Sagredo, put forward persuasive arguments in support of



## *Galileo Galilei (1564-1642)*

### **HIS LIFE AND WORK**

In 1633, ninety years after the death of Copernicus, the Italian astronomer and mathematician Galileo Galilei was taken to Rome to stand trial before the Inquisition for heresy. The charge stemmed from the publication of Galileo's *Dialogue Concerning the Two Chief World Systems: Ptolemaic and Copernican* (*Dialogo sopra li due massimi sistemi del mondo: Tolemaico, e Copernicano*). In this book, Galileo forcefully asserted, in defiance of a 1616 edict against the propagation of Copernican doctrine, that the heliocentric system was not just a hypothesis but was the truth. The outcome of the trial was never in doubt. Galileo admitted that he might have gone too far in his arguments for the Copernican system, despite previous warnings by the Roman Catholic Church. A majority of the cardinals in the tribunal found him "vehemently suspected of heresy" for supporting and teaching the idea that the Earth moves and is not the center of the universe, and they sentenced him to life imprisonment.

Galileo was also forced to sign a handwritten confession and to renounce his beliefs publicly. On his knees, and with his hands on the Bible, he pronounced this abjuration in Latin:

*I, Galileo Galilei, son of the late Vincenzio Galilei of Florence, aged 70 years, tried personally by this court, and kneeling before You, the most Eminent and Reverend Lord Cardinals, Inquisitors-General throughout the Christian Republic against heretical depravity, having before my eyes the Most Holy Gospels, and laying on them my own hands; I swear that I have always believed, I believe now,*



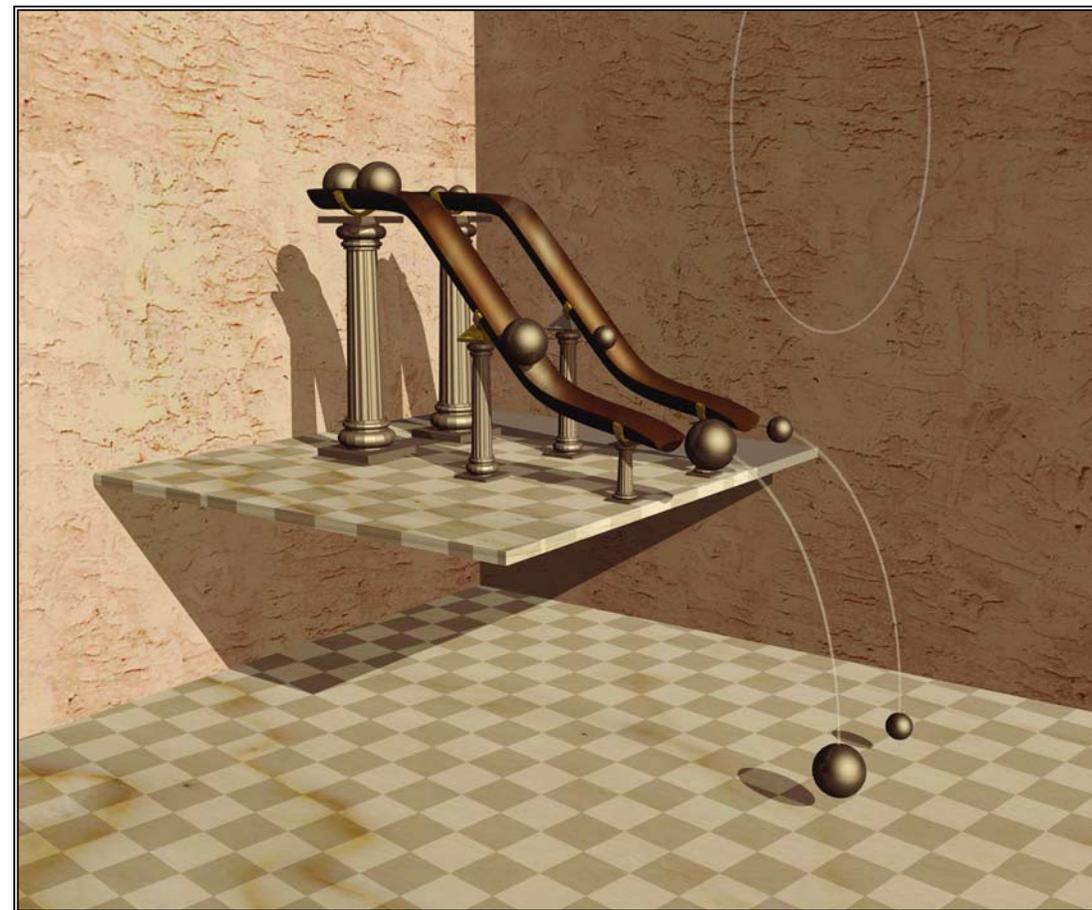
## OPPOSITE PAGE

Galileo rolled balls of different weight down a slope. His measurements showed that each body increased its speed at the same rate. He also showed that the trajectory of the final fall out onto the floor was elliptical.

mology is only weakly defended by its simpleminded supporter and is viciously attacked by the forceful and persuasive Copernican. The book achieved a great success, despite being the subject of massive protest upon publication. By writing it in vernacular Italian rather than Latin, Galileo made it accessible to a broad range of literate Italians, not just to churchmen and scholars. Galileo's Ptolemaic rivals were furious at the dismissive treatment that their scientific views had been given. In *Simplicio*, the defender of the Ptolemaic system, many readers recognized a caricature of Simplicio, a sixth-century Aristotelian commentator. Pope Urban VIII, meanwhile, thought that Simplicio was meant as a caricature of himself. He felt misled by Galileo, who apparently had neglected to inform him of any injunction in the 1616 edict when he sought permission to write the book. Galileo, on the other hand, never received a written injunction, and seemed to be unaware of any violations on his part.

By March 1632, the Church had ordered the book's printer to discontinue publication, and Galileo was summoned to Rome to defend himself. Pleading serious illness, Galileo refused to travel, but the pope insisted, threatening to have Galileo removed in chains. Eleven months later, Galileo appeared in Rome for trial. He was made to abjure the heresy of the Copernican theory and was sentenced to life imprisonment. Galileo's life sentence was soon commuted to gentle house arrest in Siena under the guard of Archbishop Ascanio Piccolomini, a former student of Galileo's. Piccolomini permitted and even encouraged Galileo to resume writing. There, Galileo began his final work, *Dialogues Concerning Two New Sciences*, an examination of his accomplishments in physics. But the following year, when Rome got word of the preferential treatment Galileo was receiving from Piccolomini, it had him removed to another home, in the hills above Florence. Some historians believe that it was upon his transfer that Galileo actually said "Eppur si muove," rather than at his public abjuration following the trial.

The transfer brought Galileo closer to his daughter Virginia, but soon she died, after a brief illness, in 1634. The loss devastated Galileo, but eventually he was able to resume working on *Two New Sciences*, and he finished the book within a year. However, the Congregation of the



Index, the Church censor, would not allow Galileo to publish it. The manuscript had to be smuggled out of Italy to Leiden, in Protestant northern Europe, by Louis Elsevier, a Dutch publisher, before it could appear in print in 1638. *Dialogues Concerning Two New Sciences*, which set out the laws of accelerated motion governing falling bodies, is widely held to be the cornerstone of modern physics. In this book, Galileo reviewed and refined his previous studies of motion, as well as the principles of mechanics. The two new sciences Galileo focuses on are the study of the strength of materials (a branch of engineering), and the study of motion (kinematics, a branch of mathematics). In the first half of the book, Galileo described his inclined-plane experiments in accelerated motion. In the second half, Galileo took on the intractable problem of



that a stone of twenty pounds moves ten times as rapidly as one of two; but I claim that this is false and that, if they fall from a height of fifty or a hundred cubits, they will reach the earth at the same moment.

Simp. Perhaps the result would be different if the fall took place not from a few cubits but from some thousands of cubits.

Salv. If this were what Aristotle meant you would burden him with another error which would amount to a falsehood; because, since there is no such sheer height available on Earth, it is clear that Aristotle could not

have made the experiment; yet he wishes to give us the impression of his having performed it when he speaks of such an effect as one which we see.

Simp. In fact, Aristotle does not employ this principle, but uses the other one which is not, I believe, subject to these same difficulties.

Salv. But the one is as false as the other; and I am surprised that you yourself do not see the fallacy and that you do not perceive that if it were true that, in media of different densities and different resistances, such as water and air, one and the same body moved in air more rapidly than in water, in proportion as the density of water is greater than that of air, then it would follow that any body which falls through air ought also to fall through water. But this conclusion is false inasmuch as many bodies which descend in air not only do not descend in water, but actually rise.

Simp. I do not understand the necessity of your inference; and in addition I will say that Aristotle discusses only those bodies which fall in both media, not those which fall in air but rise in water.

Salv. The arguments which you advance for the Philosopher are such as he himself would have certainly avoided so as not to aggravate his first mistake. But tell me now whether the density [*corpulenza*] of the water, or whatever it may be that retards the motion, bears a definite ratio to the density of air which is less retardative; and if so fix a value for it at your pleasure.

Simp. Such a ratio does exist; let us assume it to be ten; then, for a body which falls in both these media, the speed in water will be ten times slower than in air.

Salv. I shall now take one of those bodies which fall in air but not in water, say a wooden ball, and I shall ask you to assign to it any speed you please for its descent through air.

Simp. Let us suppose it moves with a speed of twenty.

Salv. Very well. Then it is clear that this speed bears to some smaller speed the same ratio as the density of water bears to that of air; and the value of this smaller speed is two. So that really if we follow exactly the assumption of Aristotle we ought to infer that the wooden ball which falls in air, a substance ten times less-resisting than water, with a speed of twenty would fall in water with a speed of two, instead of coming to the



**OPPOSITE PAGE**

*An astronaut dropped a lead ball and a feather in the near vacuum of the Moon and both dropped at the same rate.*

**OPPOSITE PAGE**

*The Hubble space telescope. This is the twenty-first century version of Galileo's telescope and continues the nature of observation that exemplifies the theoretical models created in his time and thereafter.*

This desire at times induces them to unite against these truths, although at heart believing in them, merely for the purpose of lowering the esteem in which certain others are held by the unthinking crowd. Indeed, I have heard from our Academician many such fallacies held as true but easily refutable; some of these I have in mind.

Sagr. You must not withhold them from us, but, at the proper time, tell us about them even though an extra session be necessary. But now, continuing the thread of our talk, it would seem that up to the present we have established the definition of uniformly accelerated motion which is expressed as follows:

*A motion is said to be equally or uniformly accelerated when, starting from rest, its momentum (celeritatis momenta) receives equal increments in equal times.*

Salv. This definition established, the Author makes a single assumption, namely,

*The speeds acquired by one and the same body moving down planes of different inclinations are equal when the heights of these planes are equal.*

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**END OF THE THIRD DAY**

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