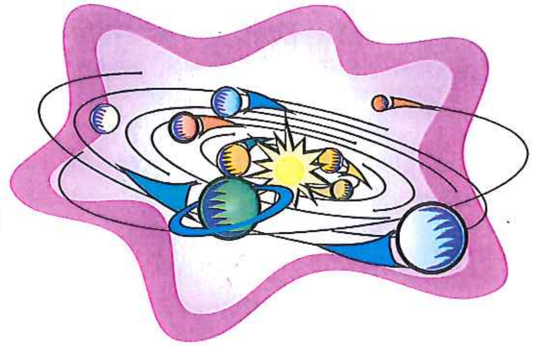
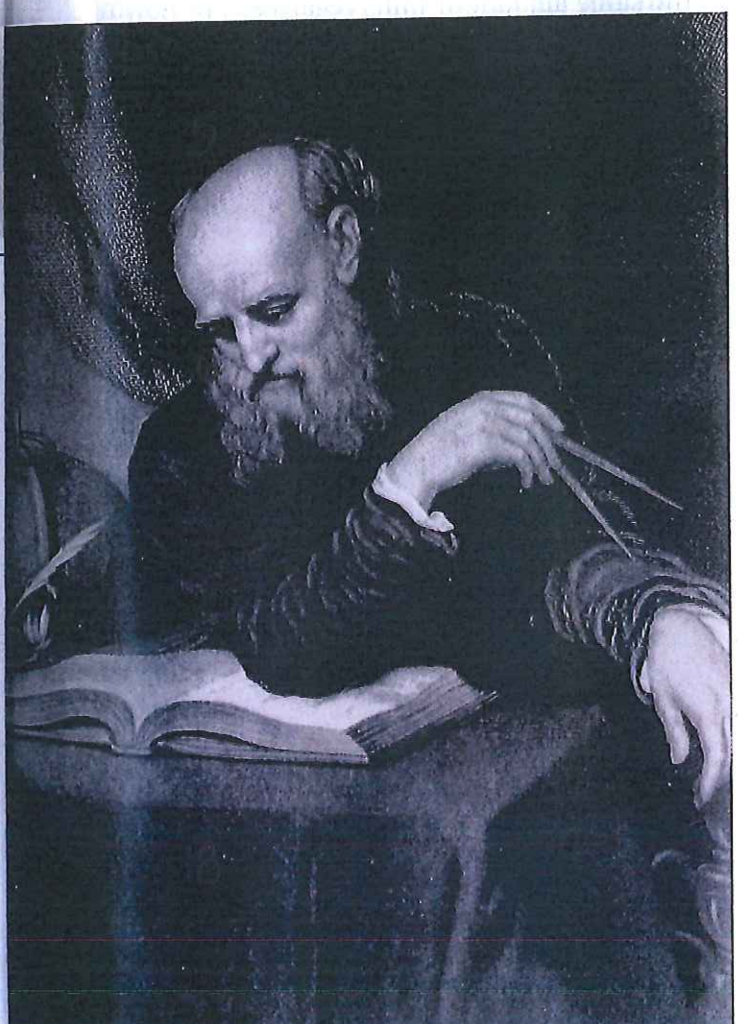
# Galileo and EXPERIMENTAL SCIENCE





**GALILEO GALILEI**
PHOTO: Library of Congress, Prints & Photographs Division, LC-USZ62-47604

1 In Lesson 1, you made observations, took measurements, recorded and analyzed data, and discussed your findings with your classmates. This probably seems like the logical way to do science—but it hasn't always been the case.

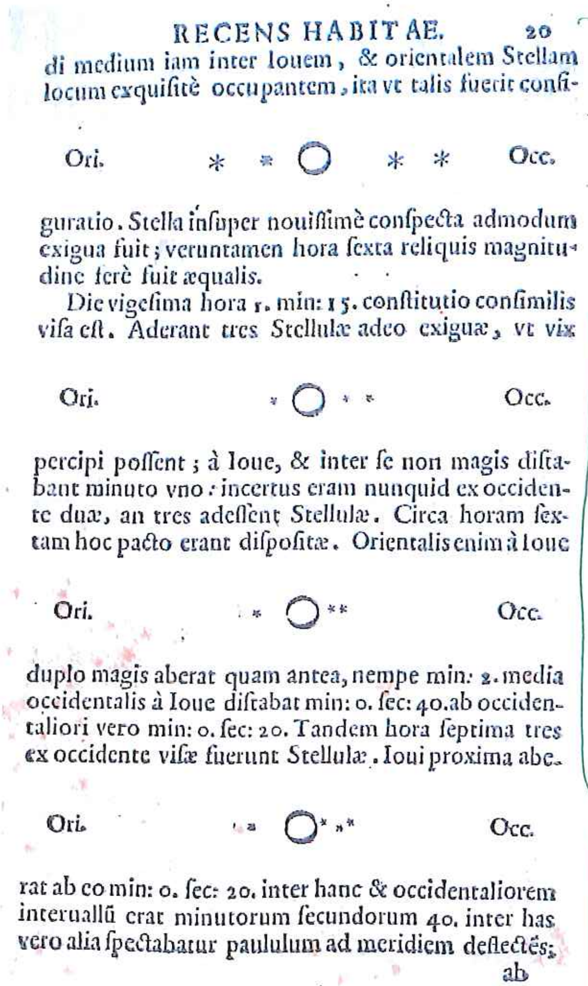
2 In ancient times, scientists were curious about the world around them. These early scientists often relied too much on general observations and on what previous scientists had done. They were often reluctant to question authority.

3 About 400 years ago in Western Europe, things changed. A number of scientists began to explore the world around them with a fresh eye. Everything interested them. They looked at things in a new way. They did not just observe things and record information; they experimented to see if their ideas were correct. One of the most famous of these scientists was an Italian named Galileo Galilei.

4 Galileo was born in Pisa, Italy, in 1564. At the age of 17, he entered the University of Pisa. He planned to become a doctor, but he soon became sidetracked. Galileo began to observe things that were happening around him, and he found

# READING SELECTION

## EXTENDING YOUR KNOWLEDGE



RECENS HABITAE. 20

di medium iam inter Iouem, & orientalem Stellam locum exquiſitè occupantem, ita vt talis fuerit confi-

Ori. * * O * * Occ.

guratio. Stella inſuper nouiſſimè conſpecta admodum exigua fuit; veruntamen hora ſexta reliquis magnitudine ferè fuit æqualis.

Die vigeſima hora 1. min: 15. conſtitutio conſimilis viſa eſt. Aderant tres Stellulæ adeo exiguæ, vt vix

Ori. * O * * Occ.

percipi poſſent; à Ioue, & inter ſe non magis diſtabant minuto vno: incertus eram nunquid ex occidente duæ, an tres adeſſent Stellulæ. Circa horam ſextam hoc pacto erant diſpoſitæ. Orientalis enim à Ioue

Ori. * O ** Occ.

duplo magis aberat quam antea, nempe min: 2. media occidentalis à Ioue diſtabat min: 0. ſec: 40. ab occidentaliori vero min: 0. ſec: 20. Tandem hora ſeptima tres ex occidente viſæ fuerunt Stellulæ. Ioui proxima aberat ab eo min: 0. ſec: 20. inter hanc & occidentaliorem interuallū erat minutorum ſecundorum 40. inter has vero alia ſpectabatur paululum ad meridiem deflectēs; ab

Ori. * O * * * Occ.

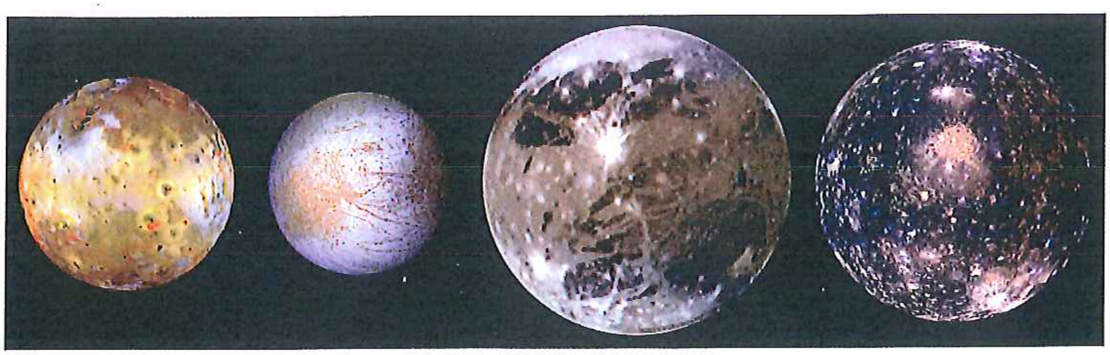
WITH HIS TELESCOPE, GALILEO SAW FOUR MOONS ORBITING JUPITER. HE STUDIED THEIR MOTIONS FROM NIGHT TO NIGHT AND RECORDED THE POSITIONS OF THE MOONS IN HIS NOTEBOOK.

PHOTO: Courtesy of Smithsonian Institution Libraries, Dibner Library of the History of Science and Technology, Washington, D.C.

them much more interesting than what he heard in the lecture hall.

5 Even the simplest things could be fascinating. For example, Galileo sat in church and watched a lamp swing from the ceiling. He soon realized that its movements were regular. He could time them with his pulse beat. When Galileo watched different lamps, he discovered that there was a relationship between the time it took for a lamp to swing back and forth and the length of the chain from which it was suspended. He also discovered that a lamp swung back and forth in the same amount of time, regardless of how broad or narrow the swing.

6 Galileo did not find any immediate application for his observations of the swinging lamp; that would come later, with the invention



CLOSE-UP PHOTOS OF JUPITER'S MOONS, TAKEN BY THE *GALILEO* SPACE PROBE.

PHOTO: NASA Jet Propulsion Laboratory

of a pendulum clock. But it didn't matter. The experience was important because he had identified and documented a mathematical relationship in a universal event—the swinging of a lamp.

7 As Galileo became more involved in science, he began to record his observations in notebooks. This was another important distinction between him and earlier scientists. These notebooks, in which he frequently made sketches, enabled Galileo to share his ideas with other people of his time. The notebooks, which still exist today, give us insight into his imaginative and creative mind.

8. Galileo was also a famous inventor. One of his most astounding devices was a military compass that could aim cannonballs at the enemy. He achieved his greatest fame as an astronomer, however. He built his own telescope. With it, he made observations that revolutionized our understanding of the universe. He saw craters on the moon and thousands of stars in the Milky Way galaxy.

9 In 1609, Galileo looked at the planet Jupiter and saw four small points of light circling it. At first, he thought they were distant stars. As he continued to observe and record what he saw, he finally concluded that those points of light were actually moons in orbit around the planet. Today, these moons are called the Galilean moons.

10 Galileo's ideas sometimes got him into trouble. For example, his observations convinced him that the planet Earth revolves around the sun. (For centuries, people had thought that Earth was the center of the solar system.) This idea was very controversial, especially to the leaders of the Church, who put Galileo on trial for heresy and threatened him with torture. To keep Galileo quiet, the Church leaders put him under house arrest for the rest of his life. Galileo could no longer speak in public, but he remained convinced that his beliefs about the solar system were correct (and, of course, they were).

11 The *Galileo* space probe, launched by the National Aeronautics and Space Administration (NASA) in 1989, honored this famous Italian scientist. Its mission was to observe Jupiter and send information back to Earth. The space probe also sent back information about the four moons that Galileo saw.

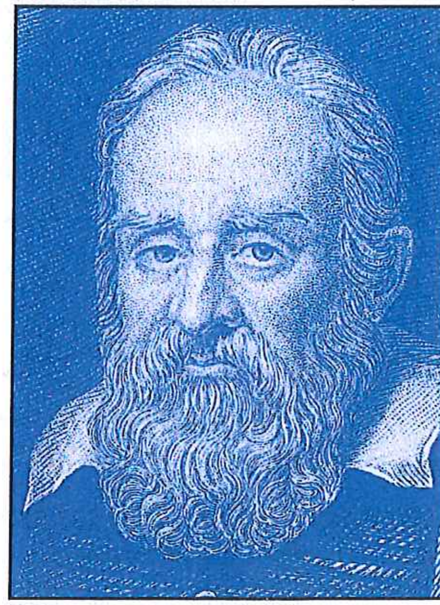
12 To Galileo, these moons were four tiny points of light. Take a look at the pictures from the space probe on page 10. Do you think Galileo would be pleased to see his moons in such detail? ■

## DISCUSSION QUESTIONS

1. What process did Galileo use to come to his conclusions?
2. What other famous scientists have gotten in trouble for their ideas? Why?

Scientist's Notebook

# Falling for Gravity



Between 1589 and 1592, the great scientist Galileo Galilei (1564–1642) taught geometry and astronomy at the University of Pisa in Italy. During those years, the young teacher also began writing a book he titled *On Motion.* That book was never published, but many of Galileo's ideas and experiments from that work, concerning gravity and falling bodies, were included in his later works.

Galileo lived more than a century before Sir Isaac Newton, the man who developed the laws of motion and gravity. Like Newton, Galileo had beliefs about the nature of the universe that were not accepted at the time. Throughout his life, Galileo made enemies of people in authority by questioning their scientific beliefs—beliefs handed down over the centuries and accepted without question. For Galileo, any truth had to be proved.

In this historical fiction, the writer has Galileo pondering the relationship between falling bodies and gravity. The italicized words are direct quotes from Galileo.

**Pisa, 1589:** How foolish is the mob who blindly follows past teachings of ancients such as Aristotle or Ptolemy! The study of our world must be done with one's own eyes. *In science, the opinion of thousands is not worth the thoughtful reasoning of a single individual.*

**Pisa, 1590:** I have long questioned Aristotle's teachings on the motion of falling bodies. Most accept his statement that the speed of a falling body remains the same throughout the fall. This troubles me. Even more troubling is the acceptance of his teaching that the weight of a falling body determines the speed of its fall.

Following that line of reason, let us suppose that two objects—one with a weight of 22 pounds (10 kg), the other 11 pounds (5 kg)—were dropped from the same height. According to Aristotle, the heavier object would reach Earth twice as fast as the lighter object. Though it might seem logical—and indeed it has been accepted for generations—I cannot accept Aristotle's teaching without experiment. For me, a truth cannot be reached unless *we measure what is measurable and make measurable what is not.*

Were it possible, I would present the esteemed Greek with the following hypothesis: Suppose I were to ascend to the top of the tower here in Pisa with the two objects I previously described. Now suppose I were to connect the two with a string and drop the new joined object. By attaching the lighter, slower-falling weight, would I in fact slow the fall of the new object? Or would the linking of the two make the new object—now 15 kilograms in total—fall one and one-half times faster than the 10-kilo object and three times faster than the 5-kilo object? For Aristotle's teaching to hold true, the answer to both questions would have to be yes. Yet common sense tells us that the answer to both questions is no.

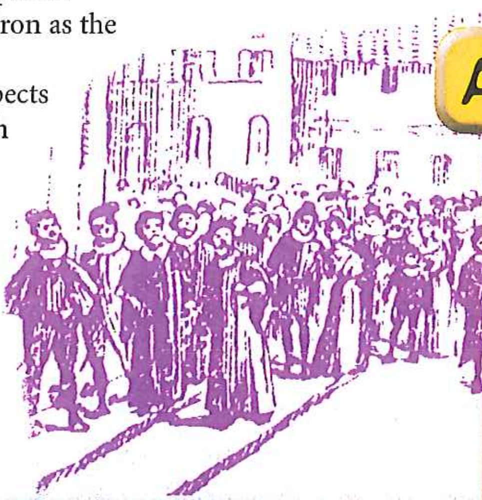
This division between unthinking belief and thoughtful reason is but one example of the failure of our society today. *For who can deny that the worst disorders occur when we are told* *to deny our senses and submit to an outside will?*

7 **Pisa, 1591:** My mind has been consumed with proving my theories of falling bodies. In direct disagreement with Aristotle, I contend that when two objects of differing weights are dropped, the lighter object will move ahead of the heavier body in the initial moments of the fall. Next, it is my claim that the speed of a falling object increases over the time of its fall. Further, I contend that all objects fall at the same speed, regardless of their weight, drawn downward by the force of the ground beneath our feet.

8 **Pisa, 1592:** Many hours of work and thought have helped to redirect my hypotheses of falling bodies. My students have assisted in performing, observing, and measuring my experiments. From Pisa's leaning tower, we repeatedly dropped two spheres of identical size, one of wood and one of iron. We observed that indeed the wooden spheres moved ahead of the iron as the fall began.

9 As to the other aspects of my theory, the iron object did indeed strike ground before the wooden sphere. However, the iron sphere had a weight ten times greater than that of wood. Observers agreed that the heavier object did not fall at a rate ten times greater than the lighter object. Though my theory that all objects fall at the same speed was not proved, that of Aristotle was disproved. Finally, my third contention involving the increase of speed over the time of a fall was one that resisted mathematical measurement and thus remains unproved. Though I have no doubt of its truth, *the laws of the universe cannot be read until they are written in mathematical language, without which they are impossible to comprehend.*

10 **Florence, 1636:** As I complete my latest work, *Two New Sciences,* I am at last able to advance my theory of falling bodies: In a setting without the resistance of air, all bodies fall at the same speed and gain equal amounts of speed during the time of the fall.



## Activity

**SPEED CONTROL** **After his experiments at Pisa, Galileo realized that the resistance of air made it impossible to prove his theory that all objects fall at the same rate of speed. Now that we have traveled into the airless and weightless environment of space, his theory has been tested. What variables must be controlled when testing gravity's effect on the rate of speed of different objects? Design an experiment that controls these variables and could be implemented on the Moon.**

**DISCOVERY EDUCATION SCIENCE CONNECTION**

EYEWITNESS ACCOUNT

### *Greece, 384-322 B.C.*

**During his lifetime the Greek philosopher Aristotle thinks and thinks. Finally he decides that Earth is the center of all existence and that the other heavenly bodies revolve around it in perfect circles. People are happy. We just love this idea of a geocentric (Earth-centered) universe. It makes us feel important.**

### *Alexandria, Egypt, A.D. 127-145*

**Claudius Ptolemaeus, known as Ptolemy, refines Aristotle's ideas but agrees that everything revolves around the earth. People remain happy. After all, it's only right that everything should travel around us. We're that special. Besides, there are references in the Bible that seem to back up geocentricity.**

### *Poland, 1543*

**Astronomer Nicolaus Copernicus develops a theory that Earth and the other planets orbit the Sun, that they are heliocentric (Sun-centered). What? We're not the center of attention? People are angry. Copernicus doesn't feel their wrath; he dies right after his ideas are published.**

### *Padua, Italy, January 7, 1610*

# HAS GALILEO GONE LOONY?

BY SIGNORE SCOOP

1 It's a beautiful night. You look up at a bright round shiny moon. A perfect sphere, right? Wrong. Or so said Galileo Galilei today in Padua.

2 Professor Galileo says our pure moon is not perfect. He claims he has seen peaks and valleys on the moon—and that they are bigger than Earth's! That would mean the moon might be more special in some ways than Earth.

3 But wait, there's more! Galileo also says that four little stars circle Jupiter. Stars circling another planet? But everything is supposed to circle around us, the Earth! Has Galileo not learned the lessons of Ptolemy? The Church and all other scholars tell us all the stars orbit our noble planet. It's us, us, us! Everything is about us! After all, anyone can plainly see the Sun and stars cross our sky each day and each night!

4 But Galileo Galilei says he has proof in the form of an amazing instrument. It's called the telescope, and objects seen through it are magnified more than a thousand times. Planet Earth, we must now consider, might be more ordinary than extraordinary.

## From "The Starry Messenger," by Galileo Galilei, 1610

5 Let me speak first of the surface of the Moon. The brighter part and the darker part are plain to everyone, and every age has seen them. Other spots, smaller in size, sprinkle the whole surface of the Moon. These spots have never been observed by anyone before me.

6 From my observations, I feel sure that the surface of the moon is not perfectly smooth and exactly spherical, as a large school of philosophers considers. On the contrary, it is uneven, like the surface of the Earth itself. The boundary that divides the part in shadow from the enlightened part is marked by an irregular, uneven, and very wavy line.

7 There appear very many bright points within the darkened portion which gradually increase in size and brightness. After an hour or two, they become joined to the rest of the bright portion.

8 Now, is it not the case on the Earth before sunrise, that while the plain is still in shadow, the peaks are illuminated by the Sun's rays? Does not the light spread further and, when the Sun has risen, do not the illuminated parts of the plains and hills join together?

9 The grandeur of such prominences [peaks] and depressions [valleys] in the Moon seems to surpass the ruggedness of the Earth's surface.

### Jupiter Has Company

10 On the 7th day of January in the present year, 1610, the planet Jupiter presented itself to my view. I noticed . . . three little stars, small but very bright, were near the planet. They seemed to be arranged exactly in a line and to be brighter than the rest of the stars. On the east side there were two stars, and a single one towards the west.

11 At first I believed them to be fixed stars. But on January 8th, I found a very different state of things. There were three little stars, all west of Jupiter, and nearer together than on the previous night.

12 I became afraid lest the planet might have moved differently from the calculation of astronomers. But on January 10th, there were two stars only, and both on the east side of Jupiter. The third, as I thought, [was] hidden by the planet.

13 I knew that changes of position could not by any means belong to Jupiter, but to the stars. I therefore concluded that there are three stars moving about Jupiter. [Further] observations established that there are not only three, but four.

## Activity

**SCOPE IT OUT** **Galileo's telescope was very advanced for its day, but primitive compared to what we have today. Circling in space is the Hubble Space Telescope. You can log onto its web site at www.sci.edu/public.html for some incredible close-ups of the planets and stars.**

**DISCOVERY EDUCATION SCIENCE CONNECTION**