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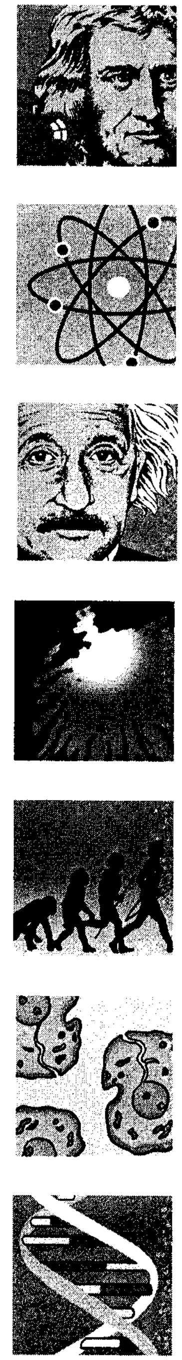

The Science Class You Wish You Had . . .

The Seven Greatest Scientific Discoveries in History and the People Who Made Them

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A Perigee Book

cision. Venice, in 1591, was the most liberal of the Italian states and appeared to be a haven for unorthodox views. Religious tension in Italy and its neighbors had eased after the death of the uncompromising Pope Sixtus V in 1590, and there seemed to be a trend toward religious pacification. Another incentive for returning to Italy was Bruno's hope that he would be appointed to fill the vacancy in the prestigious mathematics chair at the University of Padua. So he began lecturing and writing at Padua in the late summer of 1591, but returned to nearby Venice in early 1592 when it became apparent the chair would be offered to Galileo.

In the spring of 1592, there was a falling out between Bruno and his host Mocenigo, who turned on him unexpectedly and maliciously by denouncing him to the Venetian Inquisition for heresy. In the course of this arrest and trial, Bruno had another opportunity to justify his actions, retract his philosophy, and go on with his life. He admitted errors and pointed out that his theories were philosophy, not theology, and thus were not intended to question the Church's power. Yet, with higher authorities whose memories of Bruno seventeen years earlier were still vivid, the Roman Inquisition demanded his extradition. On January 27, 1593, Bruno became a prisoner of the Holy Office of the Roman palace and began a trial that was to last *seven years.* The charges against him were based primarily on his writings in which he stated that the Earth is not at the center of the universe, the universe is infinite, and the stars are not fixed on a crystal sphere.

The inquisitors informed him that only an unconditional retraction of all his theories would save him. Faced with the choice of uttering lies to indulge his intolerant accusers or maintaining adherence to his principles and losing his life, he declared he had nothing to retract. Pope Clement VIII ordered the death sentence on February 8, 1600, and nine days later, at the Campo di Fiori, Giordano Bruno, bound and his tongue in a gag, was set afire—transforming him from merely a progressive thinker to a martyr for freedom of thought and expression. Bruno's writings later influenced Galileo and became an important source of scientific thought for centuries after his death.

Galileo's Improved Telescope Reveals the Heavens

A Dispute Breaks Out . . . Jupiter's Moons

Born in Pisa, Italy, on February 15, 1564 (two months before Shakespeare's birth), Galileo Galilei was the eldest of seven children and was raised in a household that valued the arts and welcomed new ideas. His father, Vincenzio, was a cloth merchant by trade, and an accomplished musician and composer. In 1574 he moved the family to Florence, where Galileo was sent to the famous Jesuit Monastery school in nearby Vallombrosa when he was 12 years old. He enrolled at the University of Pisa at the age of 17 as a medical student and quickly developed a reputation for obstinately disputing the doctrines handed down from Aristotle and the Greek physician Galen (129–199).

Galileo eventually abandoned his medical studies to pursue mathematics, mechanics, and hydrostatics. His rapid mastery of those subjects can be largely attributed to his mentor and tutor at the University of Pisa, Ostilio Ricci, whose teachings emphasized practical application of math principles, which ideally fit Galileo's developing view of the universe and his prowess as an inventor. In his first year at the university, his attention was drawn to a swinging lamp and the fact that it always seemed to require the same amount of time to complete an oscillation, regardless of the range of the swing. After Galileo verified his observation through experiments, he suggested that the constant regularity of the pendulum could be used to construct a clock that would be highly accurate. He also applied the principle in an invention for measuring the pulse.

Forced to leave school in 1585 for lack of funds, Galileo continued studying on his own and sufficiently developed his knowledge of physics to be appointed a lecturer at the Florentine Academy when he returned to Florence. In 1586, he published an essay describing the invention of the hydrostatic balance (a scale allowing for precise measurements), which brought him to prominence throughout Italy. However, he was still unable to find a steady source of income. But in 1589, at age 25, primarily as a result of a treatise he wrote in 1587 on the center of gravity in solids, Galileo earned the chair of mathematics at the University of Pisa, where he wrote and taught on a variety of subjects, including the laws of motion, for the following two years.

It was at Pisa that Galileo was said to have dropped two balls of unequal weight from the Leaning Tower to prove that they would both fall and accelerate at the same rate, contrary to the writings of Aristotle, who said the heavy ball would reach the ground before the light one. Historians are generally convinced that Galileo never performed that experiment. They surmise that he either conducted a *demonstration* at the Leaning Tower (of a result he already knew) or he performed a "thought experiment" like the following to prove the point: Imagine two unequal balls dropped from the tower at the same time, said Galileo, and also suppose that Aristotle was correct and the heavy ball would fall faster. But now imagine the same experiment with one difference, namely, that the two unequal balls are joined by a string or cable between them. If it were true that the heavy ball moves faster and the light one slower, then the light one will hold back the heavy one. If Aristotle were correct, the two balls tied together would not reach the ground as quickly as the heavy ball alone. But if we assume that the string or cable between the balls has the effect of turning the two balls into a single mass that is *heavier* than either one by itself, the tied balls should drop faster than either one by itself. Whether or not Galileo performed an actual experiment or a thought experiment, his work led to the realization and proof that in a vacuum, where air resistance is not a factor, all objects fall at the same rate. A feather falls as fast as a cannonball.

Galileo was forced to resign from the University of Pisa in the summer of 1592. Historians have various theories concerning his departure. Some maintain that his lectures on his discoveries concerning the motion of falling bodies might have offended and alienated the members of the faculty who still believed in the teachings of Aristotle and who saw their vested interests being threatened by Galileo. Also, he was highly critical of the university's regulations. In another theory, Professor Stillman Drake (translator and biographer of Galileo) suggests that political pressure was used against Galileo by a son of the Grand Duke of Tuscany whom

he'd offended. Whatever the reason, Galileo left Pisa and his native Tuscany to fill the mathematics chair at the University of Padua in the Republic of Venice, having been selected over Giordano Bruno (sixteen years Galileo's senior) for the prestigious position. Galileo remained at Padua for eighteen years (1592–1610), teaching math and astronomy, and at the same time accomplishing much of the work that established Galileo's reputation as a scientist and inventor and that was later used by Isaac Newton to form the foundation of modern physics. During the years at Padua, he lived with Marina Gamba and fathered two daughters (in 1600 and 1601) and a son (in 1606).

Galileo's scientific contribution as the pioneer of modern physics was more significant than his work in astronomy or as an inventor. His research and discoveries in physics, which would later be used by Newton, were set forth in these writings:

- 1585–87: Writes essays on motion and centers of gravity of certain objects.
- 1588: Writes landmark paper on motion, *De motu.*
- 1589: Writes essay on logic, entitled *Demonstrations in Science.*
- 1591: Conceives axial rotation of Earth.
- 1593: Composes summary on branch of physics to be known as mechanics.
- 1595: Explains ocean tides in terms of Copernican motion of Earth.
- 1601: Completes *The World System*, and analyzes Kepler's data.
- 1602: Begins studies on magnetism and pendulum motion.
- 1603–04: Develops theorums on motion and falling objects.
- 1612: Publishes book on the motion of objects in water.
- 1623: Writes *The Assayer*, on the scientific method.
- 1624: Begins *Dialogue on the Tides.*
- 1625–31: Further writing on motion, tides, and falling bodies.
- 1632: Publishes *Dialogue on the Two Chief World Systems.*
- 1638: Publishes *Two New Sciences.*

Of all his discoveries and inventions, his most famous is the telescope. Yet, as with the legend of dropping the balls from the Leaning Tower of Pisa, there is also an element of myth in the story about his telescope. Galileo himself wrote, "We are certain the first inventor of the telescope was a simple spectacle-maker who, handling by chance different forms of glasses, looked, also by chance, through two of them, one convex and the other concave, held at different distances from the eye; saw and noted the unexpected results; and thus found the instrument." Credit for the invention is generally given to a Dutch spectacle-maker named Hans Lippershey, who tried to sell the telescope to the government of Holland in 1608 as a military instrument for its war against Spain. After a special committee recommended the purchase, a dispute broke out in Europe among several people, each claiming he was the inventor. Galileo wasn't among them.

By the end of 1608, telescopes were being made and sold throughout Europe for navigation, military uses, astronomy, and novelty items. When the Venetian senate expressed a desire to buy the new seeing device for maritime military uses, a government official aware of Galileo's expertise in instrument-making asked him to make a telescope of his own design. In July 1609, Galileo began experimenting with ways to make the lenses. In just one month he'd made an instrument three times more powerful than any in existence, and presented one to the senate as a gift. By the end of the year he'd made a 30-power telescope, more than tripling his previous efforts. It was this superior talent as an instrument-maker that resulted in Galileo receiving the primary credit for *inventing* the telescope. His decision to quickly turn the device upward to the heavens resulted in his fame as an astronomer and further enhanced the historical link between Galileo and the telescope. That decision also brought about the tumultuous events that would dominate the rest of his life.

"Our sense of sight," Galileo wrote in March 1610 after looking through the telescope, "presents to us four satellites circling about Jupiter, like the Moon about the Earth, while the whole system travels over a mighty orbit about the Sun . . ." This is from his pamphlet *Sidereus Nuncius* ("The Starry Messenger"), which was the first written account of observations of celestial objects through a telescope. In addition to Jupiter's moons, Galileo described the

mountainous surface of our own Moon, and explained that the Milky Way consists of stars rather than a white cloudy substance, as previously thought. This work with the telescope immediately led to his appointment as philosopher and mathematician extraordinaire to the Grand Duke of Tuscany. He left his position at the University of Padua to fill this lucrative post and devote more time to research. Praise came from all quarters. He was invited to Rome and honored by a meeting with the Pope on April 1, 1611, where he gave a demonstration of the telescope, and on April 14, 1611, the Academy of Lynxes (a scientific society in Rome) held a banquet in Galileo's honor. For several years, Galileo enjoyed the freedom to report his observations publicly and without concern for how they might conflict with the entrenched beliefs of the day. He had no reason to suspect that these observations would soon become seeds of controversy and tragedy.

Galileo Begins to Publicly Support a Sun-Centered Universe as the Church Issues a Warning

Letters to the Duchess on Sunspots . . . God Stops the Sun for the Israelites

As early as April 4, 1597, Galileo had written to Kepler that he'd "become a convert to the opinions of Copernicus many years ago," yet he continued to teach the Ptolemaic system throughout his eighteen years at Padua because he felt more evidence was needed. But in 1610, after his own observations with the telescope, Copernicanism became a clearly supportable and objective truth for him, and he hinted at these views in his book *The Starry Messenger,* though he stopped short of fully endorsing Copernicanism. His discoveries of the moons of Jupiter, the rings of Saturn, and the phases of Venus revealed the reality of this solar system in a way that Copernicus himself could not have known.

The Church advised Galileo that it disagreed with the interpretations and descriptions in *The Starry Messenger,* but did not interfere with his right to express his views or continue those observations. Then began the conflict that would occupy Galileo's remaining years. In 1613, stepping into the unknown chasm of new ground broken by Bruno, Galileo began to publicly support a heliocentric solar system. This is a new theory, Galileo later said, on which "all my life and being henceforth depends." The flames that engulfed Giordano Bruno in 1600 had since burned out, but the political climate of Italy that had ignited the fire was not very different in 1613. Dancing on the edge of the Church's favor and license, Galileo's teachings, writings, and theories were no longer calmly accepted.

In December 1613, Madame Christina of Lorraine, Grand Duchess of Tuscany (mother of the Grand Duke) had engaged Galileo's friend and student Benedetto Castelli, a mathematician and Benedictine abbot, in a discussion over dinner at the Royal Court. Numerous dignitaries were present, including the Grand Duke, but Galileo wasn't there. Castelli found himself under siege and having to defend Galileo's discoveries against the traditional "wisdom" of the group. After Galileo received a letter from Castelli describing the event, he composed the first of a series of letters that came to be called the *Letters on the Sunspots*, discussing the relationship between science and religion, and sent it to Castelli in the hope that it would be useful if he ever found himself in a similar predicament. Following Bruno's ill-fated lead, Galileo wrote that the Bible should be followed for its moral teachings but does not contain the answers to the mysteries of nature.

During most of 1614, opposition to Galileo and his public views was quietly forming among jealous university colleagues and within the Catholic Church. The first public ecclesiastical attack was launched from the pulpit of Santa Maria Novella in Florence on December 21, 1614, when Father Thomas Caccini denounced Galileo. Caccini first referred to the passage in the Bible when Joshua beseeched God to halt the Sun so the Israelites would have sufficient daylight to sustain their momentum and defeat the Amorites. Based on this, Caccini posed the question: "If God stopped the Sun, how could it be that the Sun wasn't moving around the Earth in the first place?" In a vicious and lengthy condemnation, the priest didn't stop at the Copernican system, but indicted Galileo personally as well as mathematics and all mathematicians as religious and political heretics.

In February 1615, an influential Dominican priest named Niccolo Lorini was given a copy of Galileo's private letter to Castelli, and reported Galileo's "heretical views" to the holy office in Rome. Galileo heard of Lorini's action and, wary of the problems the Castelli letter could cause, prepared a modified version of it and sent it to his friend Piero Dini in Rome and asked him to show it to Cardinal Robert Bellarmine, the Church's chief theologian, along with a cover letter, dated February 16, 1615, downplaying some of the points in the original version that were in conflict with the Scriptures. However, in a letter dated March 12, 1615, Castelli informed Galileo that the Archbishop of Pisa had demanded that Castelli relinquish the original letter to him and that the archbishop had said "it was soon to be made known to you, Galileo, . . . that these ideas are all silly and that they deserve condemnation."

The battle lines were becoming clear. While the opposition coalesced, there was also a loyal and growing band of supporters, including a number of Jesuits. One priest, Paolo Antonio Foscarini, had even written a book devoted to defending the Copernican system from charges that it was inconsistent with the Bible, and had sent a copy to Cardinal Bellarmine for his opinion shortly after the Cardinal had received the revised version of the letter to Castelli. However, Bellarmine resoundingly rejected Foscarini's book and implied grave consequences for those who supported the views of Copernicus and Galileo.

Thus, amid this storm of controversy brewing in the spring of 1615, Galileo was faced with the choice of abandoning his position altogether or demonstrating that the Bible can be reconciled with Copernican theory, for he had never actually believed the two to be inconsistent despite the allegations of his detractors. He decided to defend himself in a reasoned and cautious manner. God's Truth, he wrote, is communicated in two forms—the Bible and Nature. "None of the physical effects that are . . . placed before our eyes . . . should ever . . . be placed in doubt by passages of the Scriptures which seemed to have a different verbal import . . . Two