 ROBERT BOYLE: If pressure increases, the volume of a gas decreases.

Robert Boyle (1627–1691) was a British natural scientist and the seventh son of Richard Boyle, the first earl of Cork, and Catherine Fenton. Robert Boyle was born at Lismore Castle in Lismore, Ireland. His mother died when he was three years old, so his very loving father raised him. In 1654, he settled in Oxford, where he did much of his work with Robert Hooke. Boyle then moved to London in 1668. He was deeply religious and, with his older brother, went abroad to be tutored in the scriptures. He remained celibate for his entire life, even though he courted the daughter of Carey, Earl of Monmouth, for a time.

Boyle was a strong proponent of objective observation and experimentation and is considered one of the founders of the scientific method. He wrote in his book, *The Philofophical Works of the Honourable Robert Boyle*, about the many conflicting remedies and various diagnoses of the physicians of his time: "If this were analytically and carefully done, I doubt not but men's knowledge in phyfic [physics] would be more extenfive [extensive], and effectual, than it is at the prefent [present]; and we fhould [should], then, find many probable and promifing [promising] methods of cure, which are now overlook'd" (Shaw ed. 1738, p. 96).

Because of his efforts in recognizing the difference between mixtures and compounds, modern chemistry began to move away from alchemy and rely less on speculations built on little data. He classified substances as acids, bases, or salts. He was the first to collect and isolate a gas and suggested that sound travels through different densities of air at various speeds. He challenged the idea that a vacuum could not exist, but he kept this theory in the background of his work because of the opinions of most 17th-century scientists, who termed it the *horror vacui*.

His book *The Sceptical Cymist* is considered the first modern handbook of chemistry, because it challenged explanations of matter from the Middle Ages. But even with such a cautious approach to scientific discovery based on observation and empirical data, Boyle proposed that all matter in the universe was set in motion by God but then left to behave according to the laws of nature. He believed in the corpuscular theory, which states that atoms make up matter and that they are divisible, unlike many of his contemporaries.

Even with his advanced, more mechanistic view of science, he still at times hoped to solve the mystery of alchemy by dabbling with quicksilver and gold. Another theory that he held for quite a while was the theory of phlogiston. *Phlogiston* is a substance thought to be present in all materials that is released during the process of burning. Boyle experimented with combustion by heating lead and tin in a closed vessel. Antoine Lavoisier, the father of modern chemistry, later disproved this theory by identifying oxygen.

Boyle saw the relationship between weather and the movement of a mercury column in the tube apparatus developed in 1644 by Evangelista Torricelli. Boyle later termed it the *barometer*. It was thought by some 17th-century meteorologists that the Moon could affect the height of a mercury column in the Torricellian apparatus just as it affects the tides. Boyle set up the device in his home in Oxford and monitored the movement of the mercury column, along with the Moon's motions. He disproved the connection between the two but suggested the correlation between the height of the column and the weather. Today we call this *barometric* or *atmospheric pressure*.

To the modern reader, Robert Boyle is best known for his law that explains the relationship between the volume of a gas and pressure. His work led him to the construction of the air pump along with his cohort, the famous biologist Robert Hooke. One day in 1667, Lady Cavendish, Duchess of Newcastle and a self-educated noblewoman in the sciences, watched as the two men weighed air and performed various experiments for her at the Royal Society of London. The Duchess of Newcastle went on to publish several works, debating the eminent scientists of the time and formulating her own theories.

Boyle investigated the relationship of volume and pressure in response to criticism of his publication *New Experiments…Touching the Spring of the Air.* The opposition to his theories came from Linus, a Jesuit father of Liege. Boyle investigated the relationship between volume and pressure by closing the short end of the tube shaped like a *J* that he had designed. He described the apparatus in the following words: "We then took a long glass-tube, which by dexterous hand and the help of a lamp, was in such a manner crooked at the bottom, that the part turned up was almost parallel to the rest of the tube, and the orifice of this shorter leg … being hermetically sealed" (Hart 1924, p. 186). He sealed the short end of the J-tube and calibrated both ends in inches. He allowed the long end to stay open to the atmosphere. He poured mercury into the U-shaped section of the tube so that the level was equal on both sides. Then he poured mercury into the long arm until the air trapped in the short arm of the J-tube was equal. He observed that the air trapped in the short end of the J-tube was able to hold up a column of mercury 29 inches higher than the other. By compressing the air into a smaller volume, he had doubled the atmospheric pressure. He took a series of readings showing the relationship between pressure and volume. He performed another experiment using a large tube filled with mercury, in which he inserted a smaller, heated tube capped with wax. The experiment showed that when the atmospheric pressure is less or greater than one atmosphere due to a change in volume, the height of the mercury column changes as well. Boyle experienced one set back during his observations when his J-tube shattered. Boyle actually credits a fellow scientist, Richard Townley, for making the connection between the pressure of a gas and volume. But after many observations of his J-tube, he confirmed Townley's expectation. Boyle never really understood how significant his law would become as the first quantitative relationship in the field of physics.

Robert Boyle gave us so much more than what he is recognized for in modern physical-science textbooks. He was a philosopher, chemist, and physicist. He died in London in 1691, leaving behind a legacy of knowledge and reshaping the scientific enterprise.

 DANIEL BERNOULLI: Air moving rapidly over a surface reduces the pressure on that surface.

Daniel Bernoulli (1700–1782) was a Swiss mathematician and physicist. He was born in Basel, the son of Johann Bernoulli and Dorothea Faulkner. He made significant contributions to calculus, probability, medicine, physiology, mechanics, and atomic theory. He had an older brother, Nikolaus II, who passed away in 1725, and a younger brother, Johann II. He wrote about problems of acoustics and fluid flow and earned a medical degree in 1721.

Bernoulli was a professor of experimental philosophy, anatomy, and botany at the universities of Groningen and Basel in Switzerland. He was then called to teach botany and physiology at one of the most ambitious scientific institutions of the Enlightenment, the St. Petersburg Academy of Science in the Baltic states. Later in his academic career, he became the physics chair, a position he kept for 30 years. St. Petersburg Academy offered mathematics, physics, anatomy, chemistry, and botany courses. Its buildings included an observatory, a physics cabinet, a museum, a botanical garden, an anatomy theater, and an instrument-making workshop.

Bernoulli's most important publication, *Hydrodynamica*, discussed many topics but, most importantly, advanced the kinetic theory of gases and fluids using the new concepts of atomic structure and atomic behavior. He explained gas pressure in terms of atoms flying into the walls of the containing vessel, laying the groundwork for the kinetic theory. His ideas opposed the theory accepted by many of his contemporaries, including Isaac Newton's explanation of pressure, which was published in his *Principia mathematica*. Newton thought that particles at rest could cause pressure because they repelled each other. Because of the brilliance of Newton's numerous discoveries, it was assumed by most scientists of the time that his explanation was correct, even though it was inaccurate.

In *Hydrodynamica,* Bernoulli took on the task of solving difficult mechanical problems mentioned in Newton's *Principia mathematica*. In the tenth chapter of his book, Bernoulli imagines how gases he called *elastic fluid* were composed of particles in constant motion and describes the behavior of the particles trapped in a cylinder. As he depressed the cylinder's moveable piston, he calculated the increase in pressure, deducing Boyle's law. Then he described how a rise in temperature increases pressure as well as the speed of the atomic particles of the gas, a relationship that would later also become a scientific law.

He attributed the change in atmospheric pressure to gases being heated in the cavities of the Earth's crust, a process that would cause the gases to rush out and rise, increasing barometric pressure. According to Bernoulli, the pressure drops when the internal heat of the Earth decreases and the air contracts.

Bernoulli did not only use his mathematical expertise to contribute to physical science: He also attempted to statistically predict the difference in the number of deaths from smallpox that would occur in a population if people were properly inoculated against the disease.

But in modern physical-science textbooks, Bernoulli is best recognized for his contribution, Bernoulli's principle, or the Bernoulli effect, which describes the inverse relationship between the speed of air and pressure. In 1738, Bernoulli stated his famous principle describing the relationship between the speed of a fluid and pressure in Section XII of *Hydrodynamica.* He deduced this relationship by observing water flowing through tubes of various diameters. Bernoulli proposed that the total energy in a flowing fluid system is a constant along the flow path. Therefore if the speed of flow increases, the pressure must decrease to keep the energy of flow at that constant. Today we apply this relationship to the flow of air over a surface as well. Because of Bernoulli, we are able to build aircraft, fly helicopters, water the lawn, and even pitch a curveball.

Daniel Bernoulli, physicist, mathematician, natural scientist, and professor, died in his native Basel, Switzerland on March 17, 1782 and was buried in the Peterskirche.

 JACQUES CHARLES: The volume of a gas increases as the temperature increases.

Jacques Alexandre Cesar Charles (1746–1823) was a physicist, philosopher, and mathematician born in Beaugency, France. He began his professional career as a clerk in the Ministry of Finance in Paris and was granted a small pension by King Louis XVI. His interest in science began with his fascination for electricity, and he helped popularize Benjamin Franklin's theory. Later in his scientific career, Charles invented the hydrometer, which measures the specific gravity (ratio of mass of a substance of a given volume to that of an equal volume of water or air) of fluids, as well as the aerometer, which measures the weight and density of air.

He was the first to experiment with gas balloons filled with hydrogen instead of hot air. Hydrogen had been isolated by Henry Cavendish in 1766. To produce hydrogen, Charles poured sulfuric acid over scrap iron. On August 27, 1783, Charles sent a silk bag treated with rubber, which measured 13 feet in diameter, from the Champs de Mars in Paris. After rising 3,000 feet, it returned to Earth as the gas leaked away. The balloon landed about 15 miles outside of Paris in a field. The flight was witnessed by 50,000 spectators, including Benjamin Franklin.

In December 1783, Charles and Nicholas Robert, the maker of their balloon, the *Charliere*, mounted its wicker basket and stayed aloft for two hours. The balloon was 26 feet in diameter and had a net covering the fabric to support the basket in which the men stood. It was equipped with a valve at the top, designed by Charles, that released hydrogen gas to descend; the basket contained sand ballast, which was thrown out to ascend. Charles's balloon even carried a barometer so that the aeronaut could measure atmospheric pressure and deduce the balloon's altitude. The two men's voyage took them 27 miles from Paris, to Nesles-la-Vallee. When Charles took a solo flight, he rose to a height of over 9,000 feet.

Much of Jacques work took place during the French Revolution, so the support that he continued to receive from the king made him very unpopular with the revolutionaries. In fact, he narrowly escaped being killed by an angry mob by describing his balloon adventures.

Jacques Charles is most famous in physical-science textbooks for his law, which explains the direct relationship between the temperature and pressure of a gas. In 1787, he created a container whose volume could change. He then measured the volume of the gas in the chamber as he increased the temperature of the gas trapped inside. He observed that for each degree rise in temperature, the volume of the gas expanded by 1/273 of its volume at 0° and for each fallen degree, the volume contracted by the same amount. Eventually this became absolute zero in the Kelvin temperature scale. The law is sometimes referred to as the Gay-Lussac's law because Joseph Louis Gay-Lussac published his work and Charles did not.

Charles was elected to the French Academy in 1795 and later became a professor of physics. Charles married Julie-Francoise Bouchard des Herettes in 1804, who died in 1817 of a long illness. Jacques died six years later in 1823, leaving behind his many contributions, which became building blocks in physics, chemistry, and balloon flight.

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