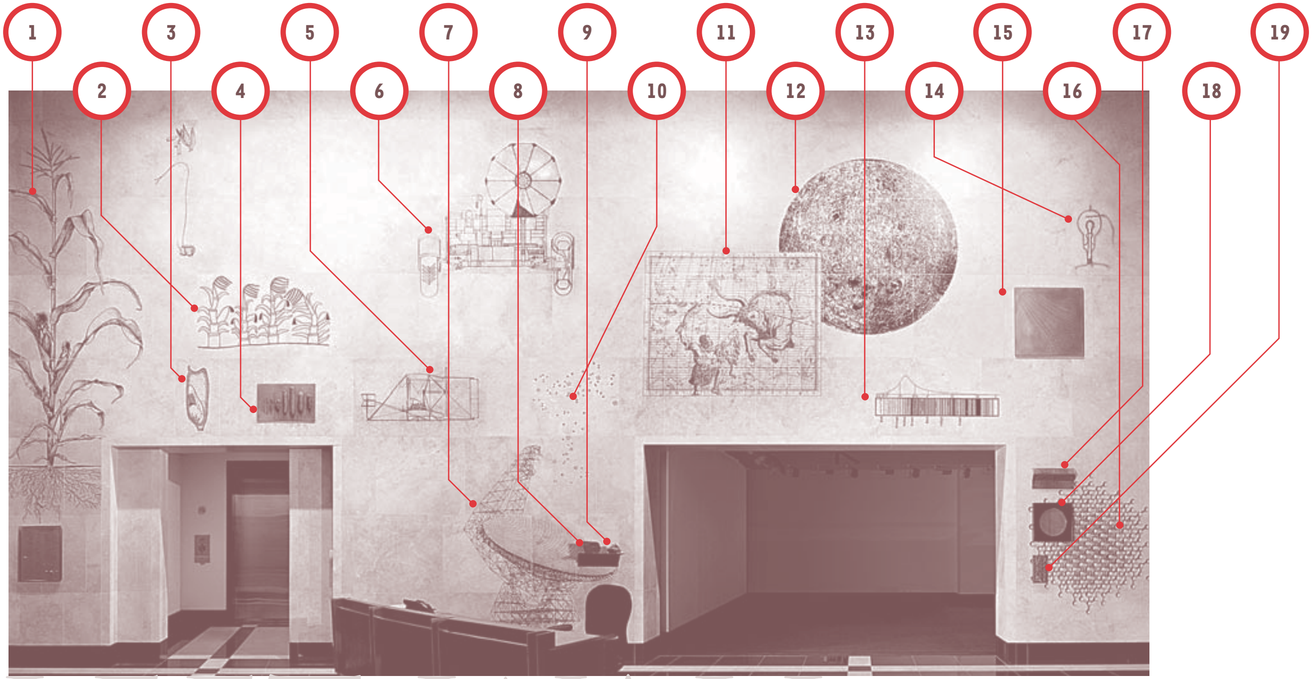
THE NATIONAL ACADEMIES BUILDING

500 FIFTH STREET, NW
WASHINGTON, DC 20001

LOBBY BY LARRY KIRKLAND

How does one convey, at the outset of the 21st century, the origins and evolution of human investigation of the world leading to the contributions to society made by the sciences, medicine, and engineering? This was the task set for artist Larry Kirkland in developing the engraved murals for the lobby of the National Academies building at 500 Fifth Street, NW, in Washington, DC. This visual encyclopedia encompasses investigation past and present, and it includes phenomena from the microscopic to the cosmic.



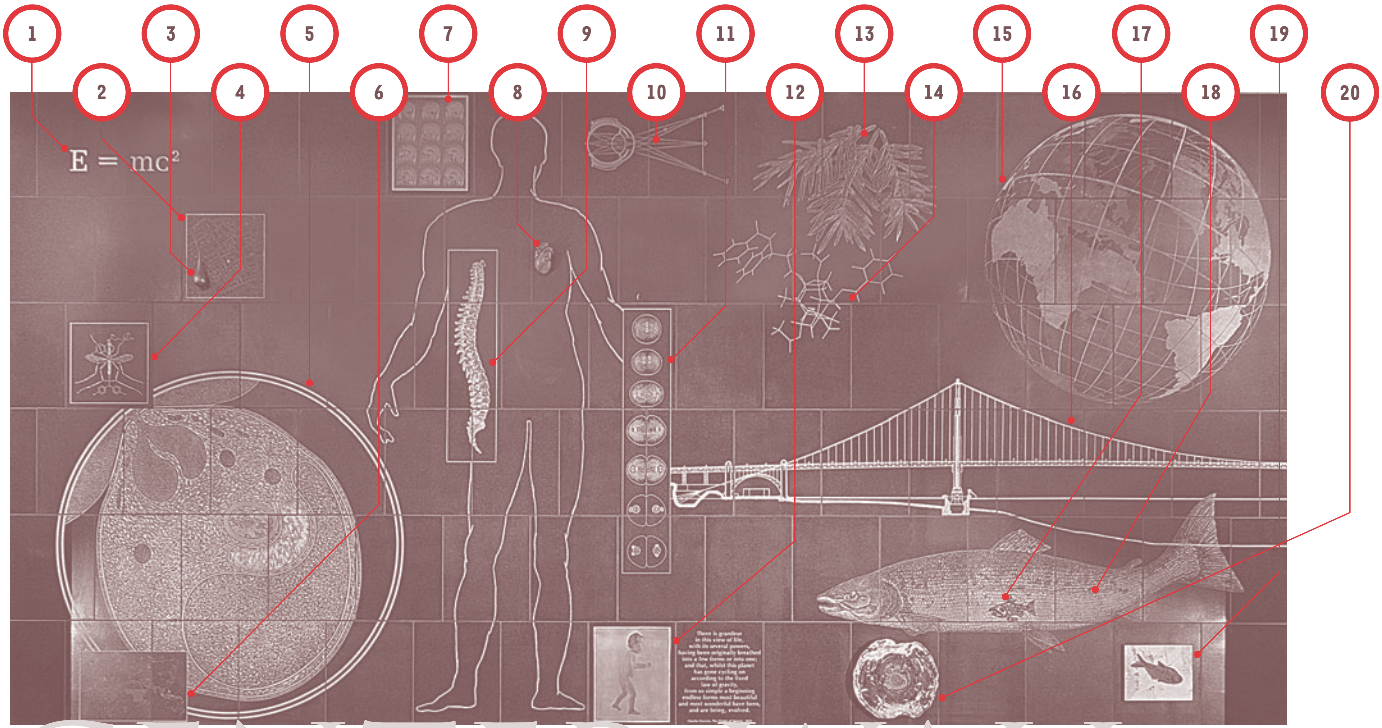
LEFT WALL

Beginning on the far left (as one enters from Fifth Street), there are drawings of maize – one from a pre-Columbian pot from Ancient Peru (ca. 2500 to 1800 BC) and others by a contemporary geneticist. They represent a continuum of human invention spanning forty centuries. This important New World plant, which we know as corn, was produced by the careful breeding of plants by humans. It now feeds a large proportion of the world's population.

Images that follow on the same wall represent attempts to understand the universe – from Galileo's star map of 1610, which includes a detailed study of the moon, to the Lunar Rover designed in 1969 and used during the final three Apollo lunar missions of 1971 and 1972. Attached to the wall is a meteorite and a tidal rhythmite, a sedimentary rock whose stripes record changing tides hundreds of millions of years ago, providing a visual record of the moon's orbit around the earth. Other images illustrate the history of technology. From the abacus and Edison's 1880 design sketch of an incandescent light bulb, to the exploration of computer aided artificial intelligence and nanotechnology, inventors have developed tools that benefit society.

LEFT WALL:

1. The maize plant, commonly known as corn. To the right, the pollination of the corn plant. Courtesy of Dr. Walton Galinat.
2. Maize drawing from a Chicama Valley pot, North Coast of Peru, 2500-1800 BC.
3. Corn embryo. Courtesy of Dr. Walton Galinat.
4. Bronze castings showing stages in the evolution of modern maize from its ancestors: Teosinte, a tall grass native to Mexico and Central America, is compared to the modern hybrids of corn that humans have derived from it through thousands of years of plant breeding. Courtesy of Dr.Walton Galinat.
5. The motorized glider developed by Orville and Wilbur Wright and flown on December 17, 1903, in the first controlled, sustained flight in a power-driven airplane.
6. Lunar roving vehicle. Design by Boeing and General Motors, 1969.
7. The world's largest fully steerable radiotelescope. Robert C. Byrd Green Bank Telescope, National Radio Astronomy Observatory, Greenbank, West Virginia.
8. A tidal rhythmite: A rock produced by sediments in the Precambrian period, at a time between 800 million and 1 billion years ago. Courtesy of Dr. Marjorie Chan.
9. A meteorite: Recovered from a field in Namibia in the early 19th century.
10. First star map recorded with the use of a telescope. Galileo Galilei, 1610.
11. Engraving of the sky from *Atlas Coelestis* (*Celestial Atlas*). John Flamsteed and Sir James Thornhill, 1729.
12. Map of the far side of the moon. Invisible from the earth, this map was created with satellite technology from metric camera photography during the Apollo 15, 16, and 17 lunar explorations of 1971 and 1972.
13. The solar spectrum. The dark lines, first recorded by Joseph Fraunhofer in 1814, were recognized in 1853 to be indicators of specific chemical elements.
14. Incandescent light source patented in 1884. Drawn by Thomas Edison.
15. A double nanotube, a cylindrically shaped large carbon molecule of great strenght and electrical conductivity. Drawing by Matt Frey.
16. Drawing of the crystal structure of silicon: This element provides the basis for constructing the microchips that made possible the computer-telecommunications revolution.
17. Bronze casting of a Jacquard punched card: Developed in the early 19th century by Joseph Jacquard (1752-1834), this card mechanized the weaving of patterns in cloth, and thus some consider it as the first stored intelligence. Courtesy of Gene Valenta.
18. A large wafer of silicon used to produce microchips. Courtesy of the Intel Corporation.
19. An abacus: Developed thousands of years ago as a tool for computation.



CENTER WALL

Two themes dominate the black granite wall: biology and medicine in the service of society and our relationship to our environment. One ongoing focus of medical research is malaria, represented by the parasite that is attacking a human cell in the large circle at the lower left. Spread by mosquitoes, this disease causes 300 million people each year to become ill and more than a million deaths, primarily in children. The malaria parasite continually evades new drugs by becoming resistant and is a major target for efforts to create a vaccine. The map of London (1854) represents the investigations of John Snow, known as the father of public health, who discovered the source of a cholera epidemic to be contaminated water – delivered by a public pump marked here with a gold dot. The tree branch is that of a Pacific yew, a low growing evergreen that is a natural source for taxol, which has proved beneficial in the treatment of some cancers. The large Atlantic salmon and the small Northwest Coast Native American drawing of a Pacific salmon reflect the complex issues relevant to this valuable fish. The problems include transformation of their natural habitat by dams, farming, and forestry practices, overfishing, decades of stocking of hatchery fish, and the comingling of farm-raised fish with native species.

CENTER WALL

1. *E=mc²*: Albert Einstein's famous equation relating energy (*E*), mass (*m*), and the speed of light (*c*).
2. Map of the incidence of cholera in London, 1854. Through observation of the spread of cholera, Dr. John Snow discovered its source: water from the Broad Street pump, here indicated by a gold dot.
3. Bronze casting of a drop of water: Contaminated water spreads cholera.
4. The *Anopheles* mosquito that spreads malaria, illustrated along with the structures of chloroquine, used in the treatment of malaria, and of DDT, used to kill the mosquitoes.
5. A human cell being infected with the malaria parasite: In this drawing of an electron micrograph, the parasite fills nearly the entire space, with the human red cell that is being attacked visible only at the upper left. Courtesy of Trudy Nicholson.
6. Map showing where the drug chloroquine has become ineffective in the treatment of malaria: In the shaded areas, this parasite has evolved a resistance to chloroquine.
7. A brain scan produced by magnetic resonance imaging: This scan is of a brain tumor patient after an operation.
8. Bronze casting of a human heart.
9. Drawing of a human spine. Leonardo da Vinci, 1489.
10. Analysis of light entering the eye. From *La Dioptrique*, by René Descartes, 1637.
11. Drawing of the stages of mitosis, or cell division. From *The Cell in Development and Heredity*, by Edmund B. Wilson, 1925.
12. A child taking its first steps. Photo by Jerry Hart.
13. A branch from a Pacific yew. This evergreen tree, indigenous to the northwestern United States, is the source of the drug taxol used in the treatment of cancer.
14. The molecular structure of taxol.
15. Wire frame view of the earth. Drawing by Matt Frey.
16. The Golden Gate Bridge, San Francisco. Architect Irving F. Morrow.
17. A Pacific salmon, according to a Northwest Coast Native American image.
18. An Atlantic salmon: This species has been endangered by overfishing, habitat destruction, and pollution.
19. A 20-million-year-old fossil of a fish. From the Green River fossil beds spanning Wyoming, Utah, and Colorado.
20. A 40-million-year-old petrified Douglas fir tree ring.

RIGHT WALL

The theme of our relation to the environment continues in the third wall. The Golden Gate Bridge celebrates both a feat of engineering, as well as the human will to shape the environment. The internal combustion engine benefits society but raises myriad problems by burning fossil fuels. The graph shows the continuing increase in atmospheric carbon dioxide, as measured by Charles Keeling, who began taking measurements in the 1950s. A chemical model of octane, a major component of gasoline, casts a shadow on the graph. Other images celebrate our evolving knowledge of the storage and replication of hereditary information, recognizing Darwin, Mendel, and 20th-century research on DNA. By observing the beaks of the finches shown, Charles Darwin concluded that the species had evolved to accommodate the varieties of available food. Among the images inscribed on the double helix of DNA are a chimpanzee (whose DNA is closest to humans), a gingko leaf, and a fruit fly. The bronze pea pod commemorates the experiments by the Austrian monk Gregor Mendel (1822-84), which led to the conclusion that inherited traits are determined by a combination of genes. The metal plate on the far right is an X-ray photograph of crystalline DNA obtained by Rosalind Franklin (1920-58), whose research was crucial in helping James Watson and Francis Crick to discover the double-helical structure of DNA in 1953.

RIGHT WALL

1. The Golden Gate Bridge, San Francisco. Architect Irving F. Morrow.
2. Satellite image showing the polar ice cap and the depletion of the earth's ozone layer. Courtesy NASA and Dr Richards McPeters.
3. A molecular model of octane, a major component of gasoline.
4. A plot showing the changes in atmospheric carbon dioxide concentration over time. Courtesy of Charles D. Keeling and Timothy Whorf.
5. An internal combustion engine: The Offenhauser cylinder block was used in race cars. This image is taken from a 1952 illustration.
6. Finches from the Galapagos Islands, showing the adaptation of their beaks to the food supply of various environments. Charles Darwin, 1839.
7. The molecular structure of the double helix of DNA (deoxyribonucleic acid), superimposed with:
   - **a.** A chimpanzee, whose DNA most closely approximates that of humans.
   - **b.** A fruit fly. The extensive genetic analysis of *Drosophila melanogaster* in the 20th century has revealed many details of DNA function.
   - **c.** A gingko leaf. Sometimes called a "living fossil," this plant has remained essentially unchanged for 200 million years.
   - **d.** The Mamo bird, an extinct Hawaiian species.
   - **e.** The Destroying Angel fungus, *Amanita virosa*.
   - **f.** A tube worm from the bottom of the ocean. Living in a unique ecosystem, these worms get their nourishment from bacterial symbionts that harness chemical energy from minerals in the hot vent water.
   - **g.** Bronze cast of a pod of the pea plant. This organism was studied by Gregor Mendel (1822-84) to reveal the basic principles of heredity.
   - **h.** A tortoise and a hare: The fable reminds the artist of the nature of the scientific process.
   - **i.** Bronze cast of a lab rat: This organism is frequently used to study biological mechanisms common to humans.
8. An X-ray photograph of crystalline DNA. Rosalind Franklin, 1952.

EQUATIONS

Wall:

$$E = mc^2$$

Einstein's Equation *E = mc²*

The fundamental relationship connecting energy, mass, and the speed of light emerges from Einstein's theory of special relativity, published in 1905. Showing the equivalence of mass and energy, it may be the most famous and beautiful equation in all of modern science. Its power was graphically demonstrated less than four decades later with the discovery of nuclear fission, a process in which a small amount of mass is converted to a very large amount of energy, precisely in accord with this equation.

Floor:

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

1. Heisenberg's Uncertainty Principle

Werner Heisenberg's matrix formulation of quantum mechanics led him to discover in 1927 that an irreducible uncertainty exists when simultaneously measuring the position and momentum of an object. Unlike classical mechanics, quantum mechanics requires that the more accurately the position of an object is known, the less accurately its momentum is known, and vice versa. The magnitude of that irreducible uncertainty is proportional to Planck's constant.

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

2. Einstein's Field Equation

Einstein's elegant equation published in 1916 is the foundation for his theory of gravity, the theory of general relativity. The equation relates the geometrical curvature of space-time to the energy density of matter. The theory constructs an entirely new picture of space and time, out of which gravity emerges in the form of geometry and from which Newton's theory of gravity emerges as a limiting case. Einstein's field equation explains many features of modern cosmology, including the expansion of the universe and the bending of star light by matter, and it predicts black holes and gravitational waves. He introduced a cosmological constant in the equation, which he called his greatest blunder, but that quantity may be needed if, as recent observations suggest, the expansion of the universe is accelerating. A remaining challenge for physicists in the 21st century is to produce a fundamental theory uniting gravitation and quantum mechanics.

$$i\hbar \frac{\partial \Psi}{\partial t} = H\Psi$$

3. Schrödinger Equation

In 1926, Erwin Schrödinger derived his nonrelativistic wave equation for the quantum mechanical motion of particles such as electrons in atoms. The probability density of finding a particle at a particular position in space is the square of the absolute value of the complex wave function, which is calculated from Schrödinger's equation. This equation accurately predicts the allowed energy levels for the electron in the hydrogen atom. With the use of modern computers, generalizations of this equation predict the properties of larger molecules and the behavior of electrons in complex materials.

$$i\hbar \frac{\partial \Psi}{\partial t} = [c\vec{\alpha} \cdot (\vec{p} - e\vec{A}) + \beta mc^2 + e\Phi]\Psi$$

4. Dirac Equation

In 1928, Paul Dirac derived a relativistic generalization of Schrödinger's wave equation for the quantum mechanical motion of a charged particle in an electromagnetic field. His marvelous equation predicts the magnetic moment of the electron and the existence of antimatter.

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$$\vec{\nabla}\cdot\vec{D}=\rho \quad \vec{\nabla}\times\vec{H}=\vec{J}+\frac{\partial\vec{D}}{\partial t}$$

$$\vec{\nabla}\times\vec{E}+\frac{\partial\vec{B}}{\partial t}=0 \quad \vec{\nabla}\cdot\vec{B}=0$$

5. Maxwell's Equations

The fundamental equations explaining classical electromagnetism were developed over many years by James Clerk Maxwell and finished in his famous treatise published in 1873. His classical field theory provides an elegant framework for understanding electricity, magnetism, and the propagation of light. Maxwell's theory was a major achievement of 19th century physics, and it contained one of the clues that was used years later by Einstein to develop special relativity. Classical field theory was also the springboard for the development of quantum field theory.

$$S=k\ln W$$

6. Boltzmann's Equation for Entropy

Ludwig Boltzmann, one of the founders of statistical mechanics in the late 19th century, proposed that the probability for any physical state of a macroscopic system is proportional to the number of ways in which the internal states of that system can be rearranged without changing the system's external properties. When more arrangements are possible, the system is more disordered.

Boltzmann showed that the logarithm of the multiplicity of states of a system, or its disorder, is proportional to its entropy, and the constant of proportionality is Boltzmann's constant **k**.

The second law of thermodynamics states that the total entropy of a system and its surroundings always increases as time elapses. Boltzmann's equation for entropy is carved on his grave in Vienna.

$$E = h\nu$$

7. Planck-Einstein Equation

The simple relation between the energy of a light quantum and the frequency of the associated light wave first emerged in a formula discovered in 1900 by Max Planck. He was examining the intensity of electromagnetic radiation emitted by the atoms in the walls of an enclosed cavity (a blackbody) at fixed temperature. He found that he could fit the experimental data by assuming that the energy associated with each mode of the electromagnetic field is an integral multiple of some minimum energy that is proportional to the frequency. The constant of proportionality, **h**, is known as Planck's constant. It is one of most important fundamental numbers in physics. In 1905 Albert Einstein recognized that Planck's equation implies that light is absorbed or emitted in discrete quanta, explaining the photoelectric effect and igniting the quantum mechanical revolution.

$$u=\frac{8\pi h}{c^3}\nu^3\left[e^{\frac{h\nu}{kT}}-1\right]^{-1}$$

8. Planck's Blackbody Radiation Formula

In studying the energy density of radiation in a cavity, Max Planck compared two approximate formulas, one for low frequency and one for high frequency. In 1900, using an ingenious extrapolation, he found his equation for the energy density of black body radiation, which reproduced experimental results. Seeking to understand the significance of his formula, he discovered the relation between energy and frequency known as the Planck-Einstein equation.

$$T_{BH} = \frac{\hbar c^3}{8\pi GMk}$$

9. Hawking Equation for Black Hole Temperature

Using insights from thermodynamics, relativistic quantum mechanics, and Einstein's gravitational theory, Stephen Hawking predicted in 1974 the surprising result that gravitational black holes, which are predicted by general relativity, would radiate energy. His formula for the temperature of the radiating black hole depends on the gravitational constant, Planck's constant, the speed of light, and Boltzmann's constant. While Hawking radiation remains to be observed, his formula provides a tempting glimpse of the insights that will be uncovered in a unified theory combining quantum mechanics and gravity.

$$\rho\frac{\partial\vec{v}}{\partial t} + \rho\left(\vec{v}\cdot\vec{\nabla}\right)\vec{v} = -\vec{\nabla}p + \mu\nabla^2\vec{v} + (\lambda+\mu)\vec{\nabla}\left(\vec{\nabla}\cdot\vec{v}\right) + \rho\vec{g}$$

10. Navier-Stokes Equation for a Fluid

The Navier-Stokes equation was derived in the 19th century from Newtonian mechanics to model viscous fluid flow. Its nonlinear properties make it extremely difficult to solve, even with modern analytic and computational techniques. However, its solutions describe a rich variety of phenomena including turbulence.

$$L_{QCD} = -\frac{1}{4}F_a^{\mu\nu}F_{a\mu\nu} + \sum_f \overline{\Psi}_f\left[i\nabla\!\!\!/ - gA\!\!\!/_a t_a - m_f\right]\Psi_f$$

11. Lagrangian for Quantum Chromodynamics

Relativistic quantum field theory had its first great success with quantum electrodynamics, which explains the interaction of charged particles with the quantized electromagnetic field. Exploration of non-Abelian gauge theories led next to the spectacular unification of the electromagnetic and weak interactions. Then, with insights developed from the quark model, quantum chromodynamics was developed to explain the strong interactions. This theory predicts that quarks are bound more tightly together as their separation increases, which explains why individual quarks are not seen directly in experiments. The standard model, which incorporates strong, weak, and electromagnetic interactions in a single quantum field theory, describes the interaction of quarks, gluons, and leptons and has achieved remarkable success in predicting experimental results in elementary particle physics.

$$T_{BH} = \frac{\hbar c^3}{8\pi GMk}$$

$$T_c = 1.13\Theta e^{-\frac{1}{N(0)V}}$$

12. BCS Equation for Superconductivity

Superconductors are materials that exhibit no electrical resistance at low temperatures. In 1957 John Bardeen, Leon N. Cooper, and J. Robert Schrieffer applied quantum field theory with an approximate effective potential to explain this unique behavior of electrons in a superconductor. The electrons are paired and move collectively without resistance in the crystal lattice of the superconducting material. The BCS theory and its later generalizations predict a wide variety of phenomena that agree with experimental observations and have many practical applications. John Bardeen's contributions to solid state physics also include inventing the transistor, made from semiconductors, with Walter Brattain and William Shockley in 1947.

$$\frac{d(\Delta\varphi)}{dt} = \frac{2eV}{\hbar}$$

13. Josephson Effect

In 1962 Brian Josephson made the remarkable prediction that electric current could flow between two thin pieces of superconducting material separated by a thin piece of insulating material without application of a voltage. Using the BCS theory of superconductivity, he also predicted that if a voltage difference were maintained across the junction, there would be an alternating current with a frequency related to the voltage and Planck's constant. The presence of magnetic fields influences the Josephson effect, allowing it to be used to measure very weak magnetic fields approaching the microscopic limit set by quantum mechanics.

$$x^n + y^n = z^n$$

14. Fermat's Last Theorem

While studying the properties of whole numbers, or integers, the French mathematician Pierre de Fermat wrote in 1637 that it is impossible for the cube of an integer to be written as the sum of the cubes of two other integers. More generally, he stated that it is impossible to find such a relation between three integers for any integral power greater than two. He went on to write a tantalizing statement in the margin of his copy of a Latin translation of Diophantus's *Arithemetica*: "I have a truly marvelous demonstration of this proposition, which this margin is too narrow to contain." It took over 350 years to prove Fermat's simple conjecture. The feat was achieved by Andrew Wiles in 1994 with a "tour de force" proof of many pages using newly developed techniques in number theory.

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