rays could be sorted out. Kendrew, however, had to try a number of heavy metals before he could make interpretable pictures; in all he made well over ten-thousand images. When he finally had the laboratory data he wanted, he made his mathematical calculations of electron densities with a computer.

Even after Kendrew obtained his densities, a formidable problem remained. The densities had to be plotted for planar slices through the crystal at intervals of a few angstrom units (one ten-billionth of a meter), and the contours of electron density (like elevations on a topographical map) had to be determined. High density indicated an atom, and certain atoms (like nitrogen and oxygen) could be distinguished by the magnitude of their density. Since computers were not yet capable of these calculations, Kendrick's group had to do all the plotting by hand. They announced their findings in 1960, in the same issue of *Nature* in which Perutz published his preliminary findings on hemoglobin.

Clear Picture of Myoglobin Results in Nobel Prize

The myoglobin molecule proved to be a dense, lumpy structure. It had none of the beauty and regularity that molecular biologists **Francis Crick** and **James Watson** had found in their X-ray work on deoxyribonucleic acid (DNA), for which they received the Nobel Prize in medicine or physiology in 1962—the same year that Kendrew and Perutz were awarded the Nobel Prize in chemistry. One writer commented that the significance of Kendrew's work lay not in the new insights it provided, but in the fact that it could be done at all. Kendrew had risked analyzing a complex structure when many simpler ones had not yet been attempted, and he had succeeded.

Although Kendrew continued his work on the structure of myoglobin after receiving the Nobel Prize, he was increasingly drawn into administration and government advisory positions. The department Kendrew and Perutz created at Cambridge was now known as the Laboratory for Molecular Biology, and Kendrew acted as deputy chairman of the organization from its inception until 1974. The following year he established the European Molecular Biology Laboratory in Heidelberg, Germany, and served as its director until 1982. Earlier in his career he founded the *Journal of Molecular Biology* and acted as its editor-in-chief until 1987. From 1954 to 1968 he was a reader at the Davy-Faraday Laboratory of the Royal Institution, London, and from 1981 to 1987 he was president of St. John's College, Oxford. In addition, he has served as president of the International Organization of Pure and Applied Biophysics, and as both secretary general and president of the International Council of Scientific Unions.

Kendrew has been recognized for his achievements with many awards in addition to his Nobel Prize. He is an honorary fellow of Peterhouse, Cambridge, and St. John's, Oxford. He is also a fellow of the Royal Society, a foreign associate of the National Academy of Sciences in the United States, and a foreign honorary member of the American Academy of Arts and Sciences. He was knighted and given the Order of the British Empire in 1963. He is unmarried.

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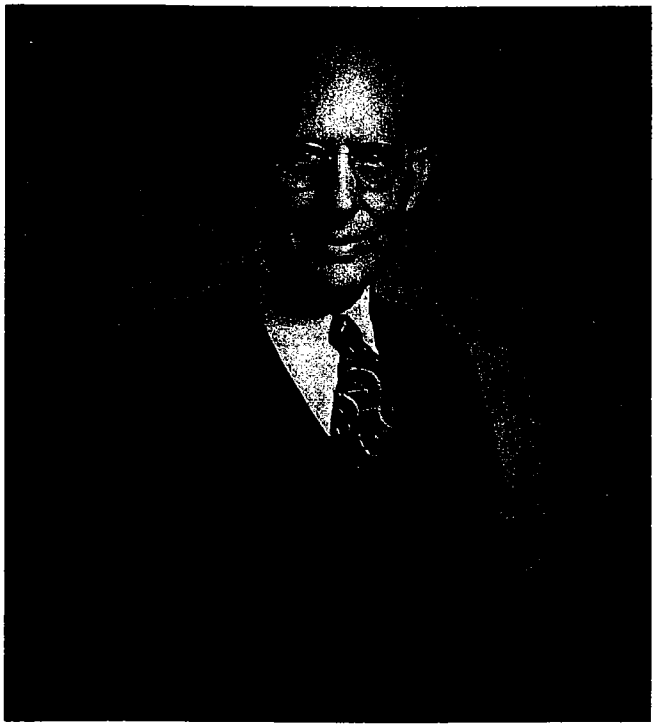
—Sketch by Robert M. Hawthorne Jr.

Charles Franklin Kettering
1876-1958
American engineer and inventor

Charles Franklin Kettering played a major role in the technological advances of the first half of the twentieth century. His research and inventions in the fields of electricity, power systems, and aircraft revolutionized entire industries. Kettering's genius was his ability to develop new technologies with practical applications. His curiosity expanded his research from industrial products into the domains of



Charles Franklin Kettering

plant life, refrigeration, education, and medicine. Kettering's success allowed him to become a generous philanthropist and avid proponent of educational reform in the latter portions of his life.

Kettering, the fourth of five children, was born to Jacob and Martha Hunter Kettering on August 29, 1876, near Loudonville, Ohio. His father ran the family farm and occasionally built barns. Kettering's mother was quiet and stern with an interest in music. Repeated eyesight problems and financial constraints forced Kettering to delay and interrupt his college education at Ohio State University. At one point, he worked in the fledgling telephone industry, whose undeveloped technology provided Kettering the freedom to develop innovative approaches to technological problems. His success stirred his interest in the possible uses of electricity and developed his abilities to spur those around him to assist him in his research.

Kettering developed a personal philosophy of scientific discovery and invention that was unusual in his day: he believed in trying to understand nature by simplifying engineering to fundamental characteristics and relationships. He combined this understanding with a conscious rejection of conventional wisdom and a liberal use of analogous reasoning. His experiments were designed and performed using a trial and error process, and produced slow, incremental, and typically productive results.

Innovates at National Cash Register

National Cash Register (NCR) hired Kettering in 1904 after he graduated from Ohio State University with an electrical engineering degree. His first assignment was to motorize NCR's manually-cranked cash registers. Kettering led a small team of inventors on a year-long journey through technological failures and corporate firings to produce an electric motor that could operate all of NCR's registers. Kettering's team endowed him with his lifelong nickname of "Boss Ket." In the summer of 1905, Kettering married Olive Williams. Their only child, Eugene, was born in 1908.

Kettering stayed at NCR for four years after the electric cash register motor project was completed. He developed a low-priced cash register powered by springs, a phone system linking clerks with the credit office within department stores, and the basis for a successful line of accounting machines.

Starts Delco

Kettering began discussing automobile engines with Edward Deeds, the vice president and general manager of NCR. By 1908, they had decided that reliable power required an ignition system with short, strong sparks instead of the continuous showers of weaker sparks then employed. In their spare time, they started experimenting with a new ignition system in Deeds's garage. In 1909, Kettering left NCR to concentrate on developing a new automobile ignition. Some of his former colleagues became so interested in his work that they volunteered to assist him in his efforts. When the prototype was successfully tested for the chief engineer of Cadillac, the car company's president, Henry Leland, ordered 5,000 ignition sets for his 1910 cars. Kettering and Deeds quickly formed a company, called Dayton Engineering Laboratories Company and known as Delco, to produce the ignitions. The prototype was far from ready for mass production and Kettering rushed to incorporate many refinements into the new ignition to make it ready for the 1910 Cadillacs.

Leland recognized Kettering's genius and assigned him to develop an electric starter to replace the crank used to start automobiles. Many other inventors, including the American **Thomas Alva Edison**, had tried unsuccessfully to develop a self-starter for the automobile. Kettering and his team discovered the correct electrical principle in their first day of experimenting. Their mechanism successfully started the Cadillac engine Leland had donated to the work in Deeds's garage, but the starter was too big to fit in a car. Kettering led marathon sessions to reduce the size of the starter in time for the 1912 line of Cadillacs. Kettering and Deed expanded Delco quickly to produce the self-starters and thereby help Leland and

Cadillac win an industry award for producing the first self-starting automobile.

Delco grew as Kettering improved the automobile components he had invented and experimented with new projects. One of his favorite projects during the early years of Delco was working on an electric lighting system for farms meant to replace kerosene lamps. Kettering had also been interested in the iceboxes used in most kitchens to keep food fresh and was considering how electricity might be used to keep ice frozen when he and Deeds sold Delco to United Motors in 1916.

Leads Research at General Motors

The American industrialist Alfred P. Sloan integrated United Motors with General Motors (GM) a few years after Kettering and Deeds sold Delco and convinced Kettering to lead research at GM from an isolated, well-funded research center near Dayton, Ohio. Kettering's first major opportunity as the head of research was to develop an automobile engine cooled by copper instead of water. He labored over the technology research and new car engine development. Three thousand vehicles were produced and sold in 1922, but the entire line was recalled and canceled because GM's chief engineers considered the engine too radical. By this time, Kettering had been promoted to vice president of GM and elected to the board of directors. The failure of the copper-cooled engine was a severe blow to Kettering; only Sloan's refusal to accept his resignation kept him at GM.

GM research under Kettering concentrated on technological improvements to existing systems that would benefit customers. Advancements were made in brake, gear, spring, and lighting systems, producing safer and more comfortable automobiles. Technological advancements in non-automotive systems were also discovered, such as the use of Freon in cooling systems to replace the toxic gas first used in refrigerators. Kettering strongly endorsed this customer-benefit approach to research and development.

Kettering directed the research to reduce the size of the diesel engine to fit trains and other, more portable uses. He was attracted to the diesel as a power source by its fuel economy and high power production. Kettering's desire to test smaller diesel engines under varied and demanding conditions inspired him to become a yachtsman, using his boats, the *Olive K* and *Olive K II,* as floating laboratories for his lightweight diesels. GM acquired two diesel engine manufacturers and presented their diesel engine at the Century of Progress in Chicago, Illinois, in 1933. The president of the Burlington Railroad was so impressed that he convinced Kettering to test GM's diesels in a lightweight passenger train. The successful non-stop run of the Pioneer Zephyr from Chicago to Denver, Colorado, on May 26, 1934, helped open the door to the next major improvement to the diesel engine. Kettering and GM's expertise allowed them to develop less-polluting diesel engines with increased power, economy, speed, and efficiency. Kettering passed the duty of designing further diesel improvements to his son, also a successful engine designer. GM produced the first diesel-powered freight locomotive in 1939.

One of Kettering's most widely used products is ethyl gasoline, which prevents car engines from knocking. Kettering started the ethyl research by borrowing a theory from his interest in photosynthesis in plants. Because the trailing arbutus plant stored sunlight in its red leaves, he reasoned that the color red could be an indicator of heat absorption. Kettering instructed his researcher to search for a color indicator of heat concentration and resulting knock during engine combustion. The subsequent research took over seven years and was interrupted by World War I, but in 1923 Ethyl Anti-Knock was launched. The next year, the top three finishers in the Indianapolis 500 auto race used the gasoline. In 1925, the new gasoline was withdrawn from the market due to health concerns, but it returned after two years of extensive testing by both federal and private agencies.

Applies Talents to Avocations

Kettering applied his talents for invention to his avocations as well as to his career. He became an avid pilot in the dawn of powered flight. Expanding his work for the government on an unmanned plane, Kettering developed the first practical retracting landing gear, new instrumentation, and improvements to wing structures. He also researched the ability of plants to produce energy with photosynthesis, wanting to find a way to mimic plants' use of solar energy in order to increase the food supply. This work, which started in his own greenhouse and later moved to Antioch College in Ohio, was driven by Kettering's belief that humans should become independent of plant life because of humanity's careless use of available resources.

Kettering's enormous success as a researcher and inventor made him a wealthy and well-known man. Throughout the latter portion of his life, Kettering used the rewards of his success to support numerous charitable causes and to promote his philosophies concerning education and innovation. In 1927, he founded the Charles Kettering Foundation for medical and photosynthesis research, and in 1945 he and Sloan founded the Sloan-Kettering Institute to research cancer in humans, built two years later in New York City as a state-of-the-art facility active in cancer research and treatment. Kettering supported wide-ranging educational reform to replace structured lessons with independent and cooperative learning and applied his leadership skills to support Antioch College for several decades. In 1952, the city of

Kettering, Ohio, named itself after its most famous resident.

In his later years, Kettering became very active as a speaker and advocate for the opportunities available through the use of innovative approaches and the need for continuous technological improvement. He stressed the need for industrial research laboratories and investment in technological advancement. Kettering was often honored for his achievements, including being elected the first president of the Thomas Alva Edison Foundation, winning the Horatio Alger Award in 1952 for personifying the American tradition of rising from rags to riches, and receiving almost forty honorary degrees. Although he retired as head of the GM Research Corporation in 1947, Kettering did not fully retire from research and development until after he turned 80. He remained active until he suffered a stroke while at a GM dinner. He died shortly thereafter on November 25, 1958, at his home near Dayton, Ohio.

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—Sketch by David N. Ford

Bernard Kettlewell
1907-1979
English geneticist and entomologist

Bernard Kettlewell is best known for his research on industrial melanism, or the effects of industrial pollution on pigmentation in insects, particularly moths and butterflies. He specialized in entomological fieldwork and made a significant contribution to the *Lepidoptera* collection at the British Museum of Natural History. Kettlewell's work on industrial melanism at Oxford in the 1950s was considered to be the first rigorous scientific study to confirm Charles Darwin's theory of natural selection.

Henry Bernard Davis Kettlewell was born in Howden, Yorkshire, on February 24, 1907, to Kate (Davis) and Henry Kettlewell, a member of the British Corn Exchange. He attended the prestigious Charterhouse public school from 1920 to 1924, spent a year studying in Paris, then enrolled at Caius College, Cambridge University, in 1926 to study medicine and zoology. He accepted appointments at several hospitals in England, including St. Bartholomew's in London and St. Luke's in Guildford, where he served for a short time as an anesthetist. After receiving his medical degree in 1935, Kettlewell established a general practice in the town of Cranleigh, Surrey. A year later he married Hazel Margaret Wiltshire, with whom he had two children. Kettlewell left his medical practice at the onset of World War II, when he was assigned to Woking War Hospital.

Following the war, the British government instituted the National Health Service program, which significantly changed the profession of medicine in England. Kettlewell left medicine at that time to pursue his lifelong hobby, entomological fieldwork, in a professional capacity. In 1949 he accepted a research appointment at the International Locust Control Center at Cape Town University in South Africa. While in Africa, Kettlewell pursued his passion for fieldwork by making scientific expeditions throughout the continent, including Mozambique, Zaire, the Knysna Forest, and the Kalahari Desert. He was awarded a Nuffield Research Fellowship at Oxford University and returned to England in 1952. Two years later he was appointed senior research officer in the zoology department at Oxford, where he was to perform his most celebrated experiments—those dealing with industrial melanism. Over a span of two decades, Kettlewell worked with a small research team in the laboratory of his good friend Edmund Brisco Ford to link the world of the field naturalist with that of professional biology.

NOTABLE TWENTIETH-CENTURY SCIENTISTS

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