James C. Wang
1936-
Chinese-born American biochemist

James C. Wang is a biochemist who trained as a chemical engineer before turning to biophysical chemistry and molecular biology. Wang discovered deoxyribonucleic acid (DNA) topoisomerases (or local enzymes) and proposed a mechanism for their operation in the 1970s. He also studied the configuration (or topology) of DNA, an approach that proved fruitful in helping to explain how the structure of the double helix coils and relaxes.

Wang was born in mainland China on November 18, 1936. Less than a year later the Sino-Japanese War began. Wang lost his mother during the conflict, and shortly after it ended, his older sister also died. His father remarried, moving the family to Taiwan in 1949. Because of the war, Wang received only about two years of elementary education before starting junior high school in Taiwan. As a child, he wanted to study medicine, but his father encouraged him to become an engineer. A high school teacher inspired him to follow his interest in chemistry. Chemical engineering became Wang's course of study, and he earned a B.S. in 1959 from National Taiwan University. Continuing his studies in the field of chemistry, he earned a masters from the University of South Dakota in 1961, and a doctorate from the University of Missouri in 1964.

In the same year that Wang received his doctorate, he became a research fellow at the California Institute of Technology, remaining there until 1966. He then taught at the University of California in Berkeley from 1966 until 1977, when he joined the faculty at Harvard University. He was named the Mallinckrodt Professor of Biochemistry and Molecular Biology at Harvard in 1988.

Study of DNA Topology Leads to Revelations

Wang once noted that his interest in DNA topology came about by chance. His training in engineering and chemistry had led him to study the physical basis of chemical processes. He began to think about the questions raised by the double helix structure of DNA soon after its discovery by molecular biologists **James Watson** and **Francis Crick**. His own study of DNA confirmed the unique structure. But it was not clear how the two tightly intertwined strands could unravel at the speed at which the biochemical processes were thought to occur. Topologically, it did not seem possible for the strands to unravel at all. Wang studied supercoiling in *E. coli* bacteria and found that the rotation speed of an unraveling DNA strand is 10,000 revolutions per minute. He also found that the same enzyme, a DNA topoisomerase, is responsible for both breaking and rejoining the DNA strands.

Wang believed that the topological characteristics of the double helix affected all its chemical transformations, including transcription, replication, and recombination. In a 1991 interview in *Cell Science,* Wang remarked that he relied on intuition to further his scientific understanding, particularly when trying to make sense of "bits and pieces of information" that didn't obviously fit together. "There are times," he told the interviewer, "when results that seem to make no sense are key to new advances."

Wang has served on the editorial boards of several scholarly journals, including *Journal of Molecular Biology, Annual Review of Biochemistry,* and *Quarterly Review of Biophysics.* He was a Guggenheim fellow in 1986, and was elected to the U.S. National Academy of Sciences in 1984. In 1961 Wang married a former classmate; they have two daughters.

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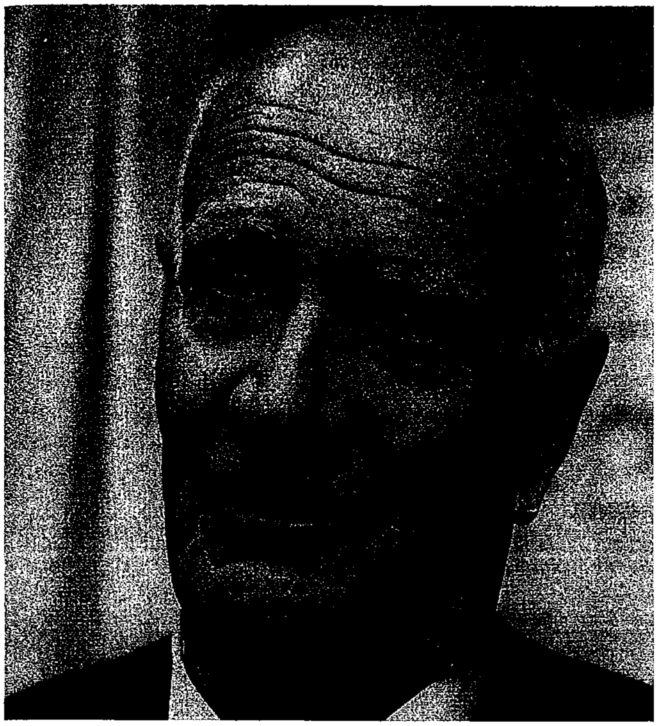
—Sketch by Valerie Brown

Felix Wankel
1902-1988
German inventor

The distinction for designing the first practical rotary engine belongs to Felix Wankel, who experimented for years to properly integrate the necessary systems. Although concepts for an engine with pistons that spin rather than move back and forth had existed for centuries, Wankel was the first to develop the technologies required for its use in internal combustion engines. He became the leading developer of engine improvements based upon rotation and engine sealing systems, and Wankel engines are still used in thousands of automobiles manufac-



Felix Wankel

Wankel continued to perform experiments and develop new projects until his death in Lindau, Germany, on October 9, 1988.

Felix Heinrich Wankel was born to Rudolf Wankel and Gerty Heidlauff Wankel on August 13, 1902, in the town of Lahr, located in the Black Forest region of Germany. Wankel's father, a forest commissioner, was killed at the beginning of World War I when Wankel was twelve years old. As a result, Wankel worked to support himself and his mother after he finished high school. This prevented him from pursuing an apprentice position in foreign industry, the route often followed by men of his day who were talented in mechanics. Instead, Wankel moved to Heidelberg and worked in the print shop of a university book store until illness forced him to move from the print shop to the stock room. While there, however, he devised an improved method of stacking books for storage.

After work, Wankel attended night school and took correspondence courses. At the age of twenty-two he opened a machine shop in Heidelberg, quickly learning the important aspects of machining, production, and precision shaping and finishing of parts. Wankel began to experiment with improvements to automobile engines, specifically with reciprocating internal combustion engines, which use pistons and valves that move in a back-and-forth motion.

Wankel was aware of the shortcomings of reciprocating engines. Many parts were required to achieve the back-and-forth motion, which in turn caused a high degree of vibration and noise. In addition, as the speed of the engine increased, power losses occurred more frequently. Wankel believed that a rotary engine, one based on pistons which move in a circular motion, could perform much better than engines based upon reciprocating motion, and he began sketching designs of internal combustion engines with rotary pistons as early as 1924. He knew that ideas for rotary engines had been proposed since the sixteenth century, but a model that could withstand the heat, pressure, and wear created by internal combustion engines had not yet been developed. Wankel's own evaluations of his earliest designs led him to the conclusion that they did not justify further pursuit.

Designs Innovative Leak-Proof Valves

Wankel initially experimented with adapting rotary valves for motorcycle engines. His work in 1926 included improvements to the valve seals to prevent leakage of gas from the cylinders that house the pistons. He recognized that the lack of such seals in previous rotary valve designs was a primary cause of their failure. He began experimenting with a disc valve, rotating valves which turned on top of the engine cylinders, and by 1933 Wankel had successfully operated a disk valve engine on a motorcycle. His innovations in sealing became one of the most important steps in Wankel's development of a rotary engine.

In 1928 Wankel met Wilhelm Keppler, who later became the business consultant to Adolf Hitler. At their meeting Wankel expressed his desire to help Germany maintain her position as a great nation by building his technologically superior rotary engine. Keppler played a central role in Wankel's work on the engine during World War II and for several years after the war.

In 1933 Wankel contracted with Daimler-Benz A.G., an auto manufacturer, to research sealing, rotary valves, and engines. After a year he began conducting similar research for another automobile maker, Bayerische Motoren Werke (BMW). As a result of this work, Wankel obtained a patent for "packing bodies" in 1936. Packing bodies were specially-designed materials that were attached to primary components to achieve the seal. This customized approach provided much tighter seals than previous sealing attempts by precisely finishing primary components and pressing them tightly together in direct contact. Wankel also used the pressure of the gases in the engine to help tighten the seals. Wankel received many patents for his work on sealing systems, and by 1936 all possible rotary valve applications to internal combustion engines and compressors were covered by his patents. Wankel developed his first rotary piston internal combustion engine, one with rotating instead of reciprocating pistons, during this period. This first engine was impractical, but Wankel's unique solution to sealing the cylinders proved critical to future development.

War Research Provides Avenue for Improved Rotary Technology

As Germany became involved in the Second World War, Wankel's work toward the development of a practical rotary engine slowed. He was branded a traitor and imprisoned by then-State Chancellor Hitler for his assistance in uncovering an embezzlement operation run by members of Hitler's party. Hans Nibel, the chief engineer at Daimler-Benz, learned of Wankel's circumstances and convinced Wilhelm Keppler to have Wankel released. Keppler acted as Wankel's protector throughout World War II.

Upon his release from prison in 1935, Wankel moved his workshop closer to his home in Lahr. The following year Hermann Goering, the head of Germany's air force, heard of Wankel's work and invited him to conduct his research in Berlin. Wankel declined to move to Berlin, but convinced Goering to establish a separate research facility for him on Lake Constance near his home. Goering's air ministry invested millions of dollars in Wankel's facility and the development of a rotary valve airplane engine. By 1939 Wankel's rotary disk valve was part of the new Daimler-Benz DB601 aircraft engine. The outbreak of World War II prevented a scheduled speed flight that was expected to break records, but by 1942 the DB601 engine was in production for use in many German fighter planes and light bombers.

During the war, another company, Junkers, began using Wankel's rotary valves in the designs for their torpedo engines. The valves were critical to the development of Junkers's product because they greatly reduced the amount of space required by the engine. Junkers designed and tested several engines using Wankel's valves. The final design was for an engine that fit inside a twenty-one inch diameter torpedo.

Wankel was in Berlin performing research for Goering's air ministry from 1940 through 1944. He was able to use the successful DB601 engine as a springboard for further development of rotary valves. In 1944 Wankel built a rotary compressor, and by 1945 he had contracts with several government agencies and automobile and railroad corporations to develop rotary parts.

At the conclusion of World War II, the politics of war again interrupted Wankel's work. French occupation forces jailed the inventor from 1945 to 1946 as a war criminal for his work on German airplane engines. His research facility on Lake Constance was dismantled, and he was forbidden to conduct research or experiments. Wankel used this time to review his work, write papers, and work on designs for engines that included his rotary valves and pistons and sealing system.

Develops Practical Rotary Engine in Partnership with NSU

In 1951 Wilhelm Keppler helped Wankel open a new research and development facility on Lake Constance, not far from the site of his wartime laboratories. Keppler had influence in German industry and guided Wankel into a working relationship with NSU Werke, the motorcycle manufacturer. Some of Wankel's early work at NSU included the development of sealing systems for air compressors and conventional pistons. Wankel carefully developed his relationship with NSU, never becoming a company employee. Instead he contracted with NSU for the company's use of his motorcycle engines and future research. In addition, Wankel negotiated his contracts so that he was free to work with other clients and run his own shop.

NSU funded the development of Wankel's compressor into a supercharger for their racing motorcycles. The supercharger, completed in 1954, pushed the mixture of gas and air into the cylinder of a small NSU moped engine, increasing the power by more than 800 percent. For three and a half years Wankel and NSU experimented with ways to develop a rotary engine from the supercharger's fundamental design. The shape of the chamber in which a rotary piston spins is particularly critical to a practical rotary engine. Wankel identified the shapes for his early engines empirically. Only later would Professor Othmar Baier of the Technical College in Stuttgart employ geometric principles. Professor Baier's work greatly facilitated the analysis of Wankel's engine and simplified manufacturing by allowing the application of analytic mathematics to the shape of the Wankel engine.

During this time Wankel was assisted by a team of NSU engineers led by Dr. Walter Froede. On February 1, 1957, the group successfully tested their first rotary engine. A second, larger test engine was built and tested that same year. It produced no mechanical vibration, proving the ability of the Wankel engine to overcome a primary disadvantage of reciprocating engines. However, the engine required additional modifications before it could be used for such practical applications as the power plant in an automobile. In this early design, while the triangular shaped piston spun inside the chamber, the chamber itself rotated as well. A stationary housing would be required to protect the engine for use in practical applications, but instead of adding the cost and weight of an additional housing to the engine, Dr. Froede redesigned it so that the chamber remained stationary instead of turning. This allowed the chamber to act as the engine's protective housing. Froede's design resulted in the KKM engine, which made the Wankel engine truly practical. Wankel initially opposed the KKM on technical grounds, but after testing the improved engine design, his research and experimentation with NSU progressed.

Wankel was forced to divert some of his attention away from the development of his engine during its long technological progression. Financial difficulties at NSU forced him to find additional funding in order to continue his research. Wankel joined forces with Ernst Hutzenlaub, an architect turned inventor who provided $250,000 to market licenses for Wankel's engine. In order to use the Wankel engine in their airplanes, in 1958 Curtiss-Wright became one of the first companies to purchase a license. NSU continued to have a volatile financial status, but Wankel was able to conduct further research.

Wankel and the NSU engineers improved and modified the design of the KKM engine over the course of several years until a production model of the Wankel engine was ready. The KKM became the basis for numerous applications, including a water cooled version for boats. Wankel and NSU were very interested in using the engine for automobiles. In 1963 Toyo Kogyo (Mazda) produced the Cosmo Sports, the first prototype car using a Wankel engine. Several other corporations with licenses for Wankel engines, including Mercedes-Benz and General Motors, developed improvements to Wankel's basic design. In 1970 the first publicly available automobile powered by a Wankel engine arrived in the United States from Japan. Wankel's dream of a rotary piston engine for automobiles had finally become reality. After the development of a practical version of the engine, Wankel continued to experiment with new seals and geometric applications. He also performed extensive research into adapting the engine for diesel power and large rotary compressors.

Wankel showed unusual innovation and persistence in the pursuit of his dream of a practical rotary engine, and in 1969 the Technical Institute of Munich awarded him an honorary doctorate. Based upon an idea that is centuries old, Wankel's efforts have resulted in the development of valuable innovations in power systems.

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—Sketch by David N. Ford

Otto Warburg
1883-1970
German biochemist

Otto Warburg is considered one of the world's foremost biochemists. His achievements include discovering the mechanism of cell oxidation and identifying the iron-enzyme complex, which catalyzes this process. He also made great strides in developing new experimental techniques, such as a method for studying the respiration of intact cells using a device he invented. His work was recognized with a Nobel Prize for medicine and physiology in 1931.

Otto Heinrich Warburg was born on October 8, 1883, in Freiburg, Germany, to Emil Gabriel Warburg and Elizabeth Gaertner. Warburg was one of four children and the only boy. His father was a physicist of note and held the prestigious Chair in Physics at University of Berlin. The Warburg household often hosted prominent guests from the German

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