diagram permeates evolutionary thought, and his statistical theory of inbreeding is standard in evolutionary genetics. Wright was the recipient of numerous awards, including the Weldon Medal of the Royal Society of London in 1947, the National Medal of Science in 1966, and the Medal of the Royal Society of London in 1980. And many of those who worked with Wright, including James Crow, Motoo Kimura, Janice Spofford, and Michael Wade, staked out careers that are a testament to his stature. Wright the man was described by his friends and associates as shy, but warm, and unflinching when discussion turned to his interests.

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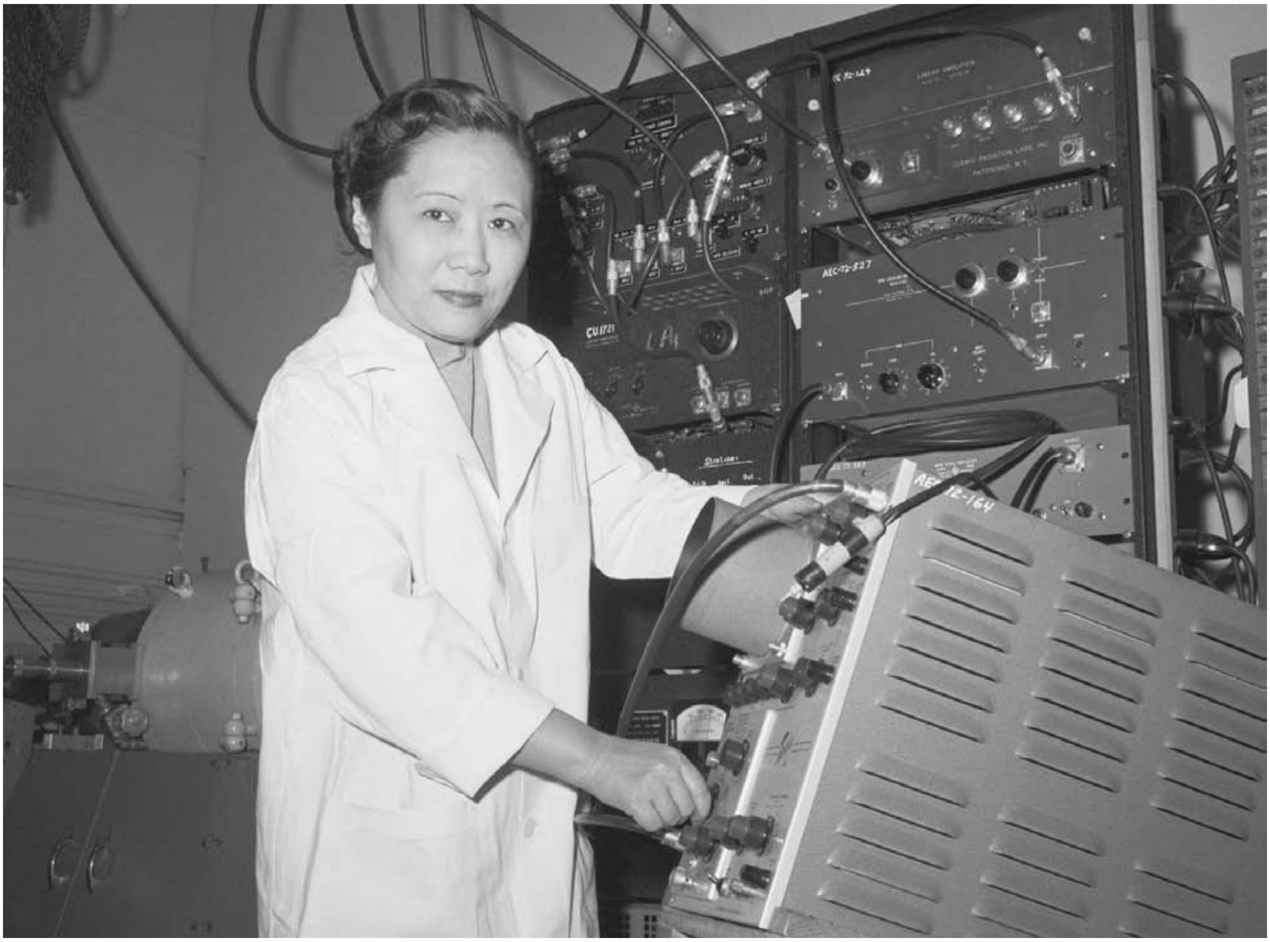
Robert A. Skipper Jr.

WU CHIEN-SHIUNG

WU CHIEN-SHIUNG (Wu Jianxiong in pinyin) (*b.* Shanghai, China, 31 May 1912; *d.* New York, New York, 16 February 1997), *nuclear and particle physics.*

Wu was one of the leading experimental physicists of the twentieth century and a recognized authority on the nuclear phenomenon of beta decay whose research helped overturn the notion of parity conservation in weak interactions. As the first female and Chinese American president of the American Physical Society (APS), she fought for equal opportunities for women in science and inspired women and girls in the United States, China, and all over the world to pursue scientific careers.

Early Years and Education. Wu grew up in one of the most turbulent periods in modern Chinese history, but fortunately for her, she enjoyed a happy childhood due primarily to the encouragement and support of an enlightened father, Wu Zhongyi. Among the first Chinese to receive a western-style education, Wu Zhongyi not only acquired technical training but also an understanding and appreciation of democracy, human rights, and equality for women. A passionate Chinese nationalist, he participated in Shanghai in both the Republican revolution in 1911 to overthrow the Qing dynasty and the unsuccessful 1913 revolt against Yuan Shikai, a military strongman who had



Wu Chien-Shiung. © BETTMANN/CORBIS.

seized power and become the first president of the new republic. Thereafter, Wu Zhongyi returned to his family in the town of Liuhe near Shanghai to open Mingde, the first school for girls in the region. To overcome the traditional resistance to educating girls, he enlisted his wife, Fan Fuhua, to visit families and persuade them to allow their daughters to attend the school.

Chien-Shiung, whose name means "a strong hero" in Chinese, went to Mingde for her elementary education up to the fourth grade. She apparently first became fascinated with the wonders of modern learning and technology when her father reportedly built the first radio sets in town. As perhaps the most important influence in her life, Wu Zhongyi instilled in his daughter a pride in Chinese culture, a love of science, and a belief in herself. "Ignore the obstacles … and keep walking forward," he told her (McGrayne, 1993, p. 255).

In 1923, after passing a competitive entrance examination, Chien-Shiung, then eleven years old, left home for the Suzhou Women's Normal School in Suzhou, where she trained to be an elementary school teacher. There she excelled in all her classes but became attracted especially to physics, inspired partly by what she learned about Nobel Prize–winner Marie Curie. Much of the science that she acquired came through self-study late at night, revealing, even at this early stage, a remarkable capacity for passionate and self-disciplined intellectual pursuit that would become her trademark. At the school she also had the chance to hear lectures by well-known Chinese and foreign scholars. Among these, Hu Shi, the Chinese philosopher who had studied in the United States, especially impressed her. As a leader of the May Fourth Movement, Hu sought to reform traditional Chinese culture into what was called a New Culture with the introduction of democracy, science, and an easy-to-learn vernacular Chinese language. Her admiration for Hu deepened when she enrolled in his class on modern Chinese history at a school in Shanghai following her graduation from Suzhou in 1929. On his part, Hu recognized Chien-Shiung's superior intellect and would provide crucial encouragement to her to pursue her scientific ambitions during their lifelong friendship.

In the fall of 1930, Wu entered the National Central University in Nanjing, then the capital of China under Nationalist rule. She majored in mathematics for the first year apparently because she recognized its importance to her chosen field of physics. At the time that she switch to physics as a sophomore, China entered into an era of intensified sense of national crisis triggered by the Japanese invasion of northeastern China on 28 September 1931. Students at the National Central, for example, staged demonstrations urging the government under Jiang Jieshi (Chiang Kai-shek in Wade-Giles) to take stronger actions against Japanese aggression. Wu, not a radical activist, nevertheless harbored a strong sense of Chinese nationalism and was made a leader in some of these agitations. It was said that her excellent academic records and sterling revolutionary family background would afford her protection that other students did not have. Occupying the courtyard of the presidential mansion one snowy night, she and her comrades actually succeeded in gaining an audience with Jiang himself. But physics remained her true love and Curie her role model. In this regard, she especially enjoyed taking classes with Professor Shi Shiyuan, who returned from Curie's lab in Paris in 1933 after receiving his PhD under her direction and who often told stories about Curie's intellectual curiosity and perseverance in a field dominated by men. She completed her senior thesis with Shi concerning crystal structure, investigating nuances of the twenty-year-old Bragg's law on x-ray diffraction.

After graduating in 1934, Wu first worked as an teaching assistant in the Physics Department at Zhejiang University in Hangzhou for a year before taking up a research assistant position in the Academia Sinica's Institute of Physics in Shanghai upon Shi's recommendation. There she worked on x-ray crystallography under Gu Jinghui (Zing Whai Ku), who had received her PhD in physics from the University of Michigan in Ann Arbor in 1931. In August 1936, with Gu's encouragement, financial support from her businessman uncle, and some preparation in English, Wu boarded the ship *President Hoover,* bound for the United States to pursue graduate study at Gu's alma mater.

Graduate Education at Berkeley. Wu changed her mind about Michigan, however, shortly after landing in San Francisco. She decided, instead, to enroll in the University of California at Berkeley, partly because of stories she heard about the discrimination against women students at Michigan, partly due to the attraction of the Physics Department at Berkeley, especially Ernest Lawrence's Radiation Laboratory. In addition, Luke Chia-Liu Yuan (Yuan Jialiu in pinyin), a fellow Chinese student in physics at Berkeley who preceded Wu by only a couple of weeks, did his best to persuade Wu to stay. Only later did she find out that Yuan was a grandson of Yuan Shikai, whose rule her own father had fought against in the early 1910s. At Berkeley, Wu's fellow students included, besides Yuan, Robert R. Wilson and Willis Lamb. Her main advisor was Lawrence, but she also worked closely with J. Robert Oppenheimer and Emilio Segrè. She quickly impressed them all not only with her intellectual and experimental talent but also her charm and elegance. Despite constant worries about her family and fellow countrymen in a war-torn China, she thrived scientifically at Berkeley.

In 1938–1940 Wu completed two separate experiments in nuclear physics for her PhD thesis. The first one, assigned by Lawrence, was on bremsstrahlung (braking radiation), which refers to the radiation that comes from a charged particle when it decelerates. At the suggestion of Enrico Fermi, the eminent Italian American physicist, Wu chose to focus on a comparative study of the internal and external x-ray radiation excited by electrons shooting out of the nucleus during the process of beta decay. "Internal" here refers to the x-rays produced by the deceleration of electrons when they come out of the nucleus itself and "external" to x-rays caused by electrons' deceleration when they move through the nucleus's electromagnetic field. Using artificially radioactive phosphorus ^{32}P, Wu's experiment offered some of the earliest confirmations of theories regarding these phenomena. When a report from others contradicted her results, she successfully undertook, with characteristic confidence and meticulousness, not only to repeat her own experiment, but also to determine the errors in the one that contradicted hers. This project demonstrated Wu's ability to relate her experimental discoveries to theoretical advances. It also marked her entrance into beta decay, a field that she soon would make her own. The second part of Wu's thesis reported her experiments with Segrè, using Berkeley's 37-inch and 60-inch cyclotrons, on the production of radioactive xenon from iodine as a product of the fission of uranium. The work initiated Wu into the new field of nuclear fission research and would later bring her into the Manhattan Project to make atomic bombs. In four short years, Wu had transformed herself at Berkeley from an ambitious student to a confident and competent young scientist making contributions at the frontier of her field. In June 1940, after Wu received her PhD, she stayed at Lawrence's lab as a research fellow for two years, working on fission. Despite Lawrence's and Segrè's glowing recommendations, she could not find a stable position at a research university; being a woman and a Chinese alien may have been held against her.

On 30 May 1942, the day before her thirtieth birthday, Wu and Yuan were married in the courtyard of Robert Millikan, head of the California Institute of Technology (Caltech) at Pasadena, where Yuan had transferred and received his PhD in 1940. Afterward, they moved to the East Coast, he obtaining a job designing radar at RCA laboratories in Princeton, New Jersey, and she becoming an assistant professor at Smith College in Northampton, Massachusetts. Dissatisfied with the lack of opportunities for research and feeling out of touch with the scientific world at Smith, Wu moved to Princeton University in 1943 as an instructor of physics for naval officers upon Lawrence's recommendation, making her the first woman instructor in the university's history. In March 1944, however, after only a few months at Princeton, she moved once again, recruited by the Division of War Research at Columbia University in New York to develop radiation detectors for the Manhattan Project. Perhaps of equal importance to the success of the atomic bomb, her earlier research at Berkeley on xenon now found unexpected applications in solving the so-called xenon-poisoning problem in the plutonium-producing reactors at Hanford, Washington. (Xenon, as a by-product of uranium fission, was absorbing neutrons and shutting down the chain reactions.)

Recognized Authority in Beta Decay. The end of the war in 1945 brought welcome news from several fronts: Wu heard from her family in China, learning that they had survived the Japanese invasion; Columbia invited her to stay as a senior scientist with a lab of her own; and Yuan found a position designing accelerators at the newly established Brookhaven National Laboratory on Long Island. In 1947 their son, Vincent Wei-chen Yuan, was born (and later followed his parents' footsteps to become a physicist). Meanwhile, their intention to return to China was frustrated first by the civil war between the Nationalists and the Communists and then by the cutoff of Sino-American relations following the Communist victory in 1949 and the outbreak of the Korean War in 1950. Finally, in 1954 they decided to become naturalized U.S. citizens, joining thousands of other Chinese students and scholars who settled in the United States permanently in this period.

Scientifically, Wu focused, in 1946–1952, on the problem of beta decay, an important area of nuclear physics. As one of the three kinds of radiation to come out of a radioactive nucleus (the other two are alpha rays of protons and gamma rays of photons), beta decay was understood to be made up of electrons and neutrinos, but the mechanism for their production was in dispute. According to Fermi's influential theory, for example, electrons should come out of the nucleus with higher energies than what were commonly reported from experiments. In a series of ingeniously designed experiments with Richard David Albert at Columbia in 1948–1949, Wu proved that the discrepancy derived not from theoretical flaws but from the uneven thickness of the radioactive materials used in earlier experiments by others. Electrons that came out of one nucleus but had to travel through the electromagnetic fields of others would necessarily be slowed down. Thus, she invented an innovative but simple process to prepare an extremely thin and even source that yielded results in remarkable agreement with Fermi's predictions. This and other experiments of Wu's around the same time not only made her a recognized authority in beta decay, but also cemented her reputation for accuracy and technical sophistication. These successes also helped her to overcome resistance to women in Columbia's Physics Department—chiefly by Isidor I. Rabi—and brought her a promotion to associate professor with tenure in 1952.

Triumph: The Parity Experiment. For a few years after 1952, Wu's interest gradually shifted from beta decay to other topics. But a conversation with her Columbia colleague and fellow Chinese American physicist Tsung Dao Lee (Li Zhengdao in pinyin) in the spring of 1956 rekindled her passion for beta decay. At the time, Lee and Chen Ning Yang (Yang Zhenning in pinyin), another Chinese American physicist at Princeton's Institute of Advanced Study, were investigating the possibility that particles involved in weak interactions—beta decay was one example—might not follow the law of parity. Simply stated, the law of parity—or the conservation of parity—meant that nature did not discriminate between right and left; if a process is possible, its mirror imaged counterpart should be equally possible. But in order to explain several mysteries in the behaviors of elementary particles, Lee and Yang were forced to suspect that perhaps the widely accepted law of parity was violated in weak interactions. While most physicists—theoretical and experimental—were highly skeptical of any such speculation, Wu took it seriously. What Lee and Yang found, with Wu's assistance, was that no one had ever tested the law in weak interactions. So Wu reasoned that even if the law held, an experiment to prove it would be significant and worthwhile. Her choice of a reaction for testing parity was the beta decay of radioactive cobalt ^{60}Co.

Wu's idea was to line up the spins of the ^{60}Co nuclei and then detect the direction of the beta particles (electrons) that were emitted from the nuclei. If the law of parity held, electrons should come out in both directions—along and opposite the direction of the spin of the nuclei—in equal numbers. Otherwise, parity would be broken. Conceptually simple, the experiment was technically extremely difficult. A big challenge was to cool the ^{60}Co to 0.01 degree Celsius above absolute zero (-273.14^{0}C[-459.65^{0}F]) to reduce background noise. Fortunately, Wu found a group of capable collaborators, headed by Ernest Ambler, with low-temperature facilities at the National Bureau of Standards (NBS) to carry out the experiment, with additional assistance from her graduate student Marion Biavati. Overcoming many obstacles they found, by late 1956 and early 1957, that indeed, as Lee and Yang had suggested, the law of parity was violated in beta decay: more beta particles were emitted in the direction opposite that of the nuclear spin than along it. Two groups of physicists—Richard Garwin, Leon Lederman, and Marcel Weinrich at Columbia and Jerome Friedman and Valentine Telegdi at the University of Chicago—quickly confirmed the breaking of parity in other processes of weak interactions.

The fall of parity came as a shock to many physicists, including Wolfgang Pauli, the sharp-tongued Austrian-Swiss physicist (and Wu's close friend), who could not believe that God was "left-handed" (in weak interactions). As one of the most dramatic episodes in modern physics, the investigation on parity overthrew one of the fundamental laws of nature and heralded, in Wu's own words, a "sudden liberation of our thinking on the very structure of the physical world" (Wu, 1973, p. 118.) It led to new advances in many directions and paved the way, eventually, for the unification of the weak and electromagnetic forces. Columbia's Physics Department called a press conference on 15 January 1957, which was presided over by a proud Rabi, to announce the breakthrough by Wu and her colleagues. The next day the *New York Times* carried the news on its front page and spread it to the rest of the world.

The significance of the research by Lee, Yang, Wu, and her NBS collaborators was immediately recognized by the physics community, but when the Nobel Prize in Physics for 1957 was announced, it went only to Lee and Yang, not Wu. While she felt happy for her friends, who were the first Chinese to ever win the prize, and she never conducted research just to win the prize, she clearly was disappointed by her exclusion, as were many others, including Lee, Yang, and Rabi, who felt that she deserved the honor. Over the years Wu received just about every other award for a scientist, mainly for her parity experiment but also for her other achievements. She was given an honorary doctorate of science by Princeton University, elected a member of the National Academy of Sciences, promoted—finally—to full professorship at Columbia, and named recipient of the Research Corporation Award, all in 1958. From the National Academy she also received the Comstock Award in 1964. In 1972 she was made the first Michael I. Pupin Professor of Physics at Columbia and elected a member of the American Academy of Arts and Sciences. Three years later she became the president of the APS and received the National Medal of Science from President Gerald Ford. Then, in 1978, she received the first Wolf Prize in physics from the Wolf Foundation of Israel. For many of these awards, she was the first woman or one of the first women so honored.

Later Research and Activities. Wu maintained a strong track record following her parity triumph, as best exemplified by her experiment on the conservation of vector current (CVC) in beta decay in 1963. In the late 1950s, particle theorists Richard Feynman and Murray Gell-Mann at Caltech, whose thinking had been liberated by the breaking of parity, had proposed the CVC theory in a major step toward the unification of two of the four fundamental forces in nature: the electromagnetic and weak forces (the other two are strong and gravitational forces). When initial experiments failed to confirm the CVC hypothesis, Gell-Mann turned to Wu, reportedly pleading: "How long did Yang and Lee pursue you to follow up on their work?"(McGrayne, 1993, p. 278). When she finally did the experiment with two graduate students, the results unequivocally confirmed the theory. Other experiments that Wu conducted with students and collaborators in the 1960s and 1970s upheld her reputation for being both accurate and hard-driving. These included investigations on double-beta decay, carried out half a mile underground in a salt mine near Cleveland, Ohio on the so-called muonic atoms in which muons take the place of electrons in normal atoms; on Mössbauer spectroscopy and its application in the study of sickle-cell anemia; and on Bell's theorem, with results confirming the orthodox interpretation of quantum mechanics.

Taking advantage of her parity celebrity, Wu began to speak out on social and political issues, especially on equality for women in science. At a Massachusetts Institute of Technology symposium in 1964, for example, she lamented the lack of women in science due to both cultural biases and professional discrimination. "I sincerely doubt that any open-minded person really believes in the faulty notion that women have no intellectual capacity for science and technology" (Wu, 1965, p. 45). Counting proudly the achievements of women nuclear physicists such as Marie Curie and Lise Meitner, she declared that "never before have so few contributed so much under such trying circumstances!" (p. 47). In 1975, from the platform of the APS presidency, she urged the federal government to increase funding for education and basic research.

During the later stage of Wu's life, her Chinese heritage and connections began to take on growing importance for her. She had always maintained contact with the scientific community in Taiwan, even though the parity experiment in 1956 prevented her from taking a prearranged around-the-world trip that had included a stop there. In 1962 she finally traveled, with her husband, to Taiwan for a meeting of the Academia Sinica, of which she was elected the first woman member in 1948 and of which her beloved teacher Hu Shi was then president. While apolitical in general, around this time she signed petitions against the arrests of political dissidents and advised Jiang Jieshi against launching a project to make atomic bombs. The reopening of U.S.-China relations in the early 1970s made possible her first return to the mainland, again with her husband, in 1973. On this bittersweet and nostalgic journey, Wu mourned the fact that she never got to see her parents and brothers again before they died in the 1950s and 1960s. She was, however, delighted by a six-hour meeting with Premier Zhou Enlai, whom she admired as a moderate leader pushing for the modernization of China. With the flexibility that came with her retirement from Columbia in 1981, Wu traveled more frequently to both sides of the Taiwan Strait to advise the governments on science policy, promote education and science, and receive many honors and awards. In 1989, when the Chinese government cracked down on students demanding democracy and political reform in Beijing's Tiananmen Square, she voiced her disapproval. Nevertheless, she was elected one of the first foreign academicians of the Chinese Academy of Sciences in 1994. A household name in mainland China, Taiwan, and Hong Kong, Wu, as a "Chinese Curie," became a role model for many Chinese students, especially girls and women, with scientific aspirations. When Wu died, her ashes were buried, according to her will, in the courtyard of her father's Mingde school, joined several years later by that of her husband.

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Zuoyue Wang

WU JIANXIONG

SEE **Wu Chien-Shiung**.

WUNDT, WILHELM

(*b.* Neckarau, Baden, Germany, 16 August 1832; *d.* Grossbothen, Germany, 31 August 1920), *psychology.* For the original entry on Wundt see *DSB,* vol. 14.

In studies of the history of psychology, nothing could likely be more illustrative of how dynamic, fluid, and changing the study of history can be than the topic of Wilhelm Wundt and his system of psychology. In one generation, scholars such as Edward Titchener and E. G. Boring were caught up in looking through historical filters that created a particular view of that individual and his time. Then in a later generation, those filters began to dissolve as scholars such as Kurt Danziger and Arthur