

origins of petroleum, in questions of fermentative catalysis, and his study of sapropels, proteins, and amino acids.

Zelinskiĭ first encountered the study of the influence of living matter on the formation of nonliving forms after he took part in a scientific expedition, undertaken in 1981 on the initiative of the academician A. O. Kovalevsky, to study the Black Sea. Its primary aim was to establish the reason for the formation of hydrogen-sulfide in deep waters (the absence of life in the sea at great depths was considered to be connected to this). On the basis of the analysis of the gathered specimens in the Black Sea silt, Zelinskiĭ proposed a new theory—which ran counter to the theory of professor Nikolai I. Andrusov—positing a bacterial origin of hydrogen-sulfide. As a result, it seems only logical that he would subsequently turn his attention to the study of sapropels, the basic materials for the formation of which in water reservoirs are microflora and microfauna, which exist in a symbiotic relationship with one another and, in the course of the biochemical process, transform into a sediment saturated with microorganisms. Ultimately this led to study of fermenting catalysis in protein bodies, since it is precisely the latter which play a decisive role in all natural processes of an organism.

The multifaceted nature of Zelinskiĭ's investigations has earned this scientist deserved recognition. Zelinskiĭ's achievements were highly valued both by the scientific community and by the state. He was accepted as a member to the French Chemistry Society and elected honorary member of the London Chemistry Society. In 1924 the Russian Chemistry and Physics Society awarded him the important A. M. Butlerov Prize. In 1926 he was awarded the title of honored scientist. He was a winner of the State Prize of the USSR three times (1942, 1946, and 1948), and he was named Hero of Socialist Labor (1945). He was awarded the Lenin Order four times (1940, 1945, 1946, and 1951), and the Red Banner of Labor twice (1941 and 1943).

Zelinskiĭ was married three times. His first wife, Raisa Ivanovna (née Drokova, b. 1850) died in 1908 after a difficult, long illness. His son, Alexandr is from this marriage. In 1909 he married Evgeniia Pavlovna Kuz'mina-Karavaeva (b. 1881). From this marriage he had a daughter, Raisa (married to A. F. Platě). His wife died after a brief illness in 1934. Zelinskiĭ was married for the third time to Nina Evgenievna Bok (née Zhukovskaia), with whom he had two sons, Andreĭ and Nikolay.

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*Elena Zaitseva*

**ZHAO ZHONGYAO** (Chung-Yao Chao in Wade-Giles; b. Zhuji County, Zhejiang Province, China, 27 June 1902; d. Beijing, China, 28 May 1998), *nuclear physics*.

Zhao was a Chinese experimental nuclear physicist whose research on light-nuclei interactions in the 1930s helped inspire the discovery of the positron and pave the way for the acceptance of quantum electrodynamics. He also helped to found the field of nuclear physics in China and to train generations of Chinese nuclear physicists in the twentieth century.

**Early Years and Education.** Zhao's remarkably long life began at the turn of the twentieth century in an area of southern China known for its strong scholarly tradition. Ironically for a man who would make his reputation as an experimental physicist, Zhao—as the overprotected youngest child and the only son in the family—was forbidden by his elderly parents from engaging in any kind of physical activity. His father, Zhao Jihe, earned a meager living as a schoolteacher and a practitioner of traditional Chinese medicine in the countryside. He did, however, inspire a strong sense of Chinese nationalism in his son and encouraged him to pursue an academic career.

Taking advantages of the educational reform that had commenced during the last days of the Qing dynasty, Zhao went to Zhuji middle school to receive a western-style education in the late 1910s. He excelled in both the sciences and humanities but eventually decided to pursue the former when he went to the Advanced Normal School of Nanjing in 1920. The college, soon renamed the Southeastern University, attracted Zhao because of its free tuition and the high reputation of the faculty, many of whom had recently returned from studying abroad. Finally on his own, Zhao enjoyed hands-on laboratory experiments and decided to major in chemistry, even though he also maintained a strong interest in mathematics and physics. Indeed, he chose to work as an assistant in the Department of Physics even before graduation.

At Southeastern, Zhao came under the influence of Ye Qisun (Chi-Sun Yeh in Wade-Giles), an experimental physicist who had studied at the University of Chicago and received a PhD from Harvard University in 1923 after conducting research on the measurement of the Planck constant and on magnetism with William Duane and Percy Bridgeman. When Ye was offered the chairmanship of the Department of Physics at the newly reconstituted Qinghua University in Beijing in 1925, he brought Zhao with him. Zhao first served as an assistant but soon was promoted to be an instructor, supervising laboratory sessions and making physics instruments. Under Ye's leadership, the department developed into perhaps the best program in the field in China. Following Ye's example, Zhao decided to further his education in the United States. In 1927, after scraping together enough funds by tapping into his own savings, borrowing from relatives and friends, and getting a small grant from the university, he set sail for the California Institute of Technology (Caltech) in Pasadena, leaving behind his newlywed bride, Zheng Yuying, to care for his mother in Zhuji.

What drew Zhao to Caltech was Robert Millikan, the Nobel laureate in physics for 1923 who had taught Ye at Chicago. With quiet determination, Zhao worked hard and made great progress, publishing a theoretical paper on the problem of the ionized hydrogen molecule in the *Pro-*

*ceedings of the National Academy of Sciences* less than two years after his arrival. His performance in the preliminary examinations so impressed Millikan that the latter persuaded the China Foundation for the Promotion of Education and Culture to grant Zhao a three-year fellowship. It was Millikan's practice to assign a thesis topic to each of his students, and to Zhao he prescribed a project related to the use of the optical interferometer. To Millikan's surprise, Zhao demurred, regarding it as too easy. Millikan then suggested the study of the absorption of hard (high energy) gamma rays in matter. When Zhao, still not satisfied, hesitated, Millikan blew up. He said, according to Zhao, that "This is a very interesting and important topic. We have looked at your records and believe that you will be the appropriate person to carry it out. If you don't want to do it, just tell me now. There is no need to put off a decision" (Zhao, 1992, p. 199). Zhao quickly accepted the topic and would realize only later what an excellent choice it was.

**Major Discoveries, 1929–1932.** By the late 1920s, after the triumph of quantum mechanics, physicists increasingly turned their attention to nuclear physics and quantum electrodynamics (QED). The latter, most prominently developed by Paul Dirac, aimed to combine quantum mechanics and relativity in explaining interactions between light (photons) and electrons. When Zhao started his experiment, a major step in QED had just been undertaken in 1929 by two physicists, Oscar Klein of Sweden and Yoshio Nishina of Japan, who—building on Arthur Compton's work—derived a formula on the scattering of photons by electrons. Millikan, sensing the importance of the subject, wanted Zhao to check experimentally the validity of the new theory.

Zhao's experiment proceeded smoothly. Using thorium C" (Thallium-208), a powerful radioactive source, he obtained gamma rays of the highest energy available at that time, 2.65 MeV. Directing the gamma rays through different absorbers in an ionization chamber, he obtained their respective absorption coefficients by measuring the ionic currents caused by the rays with and without the absorbers. To accomplish the latter, he used two measuring instruments: an electroscope devised by Millikan for cosmic ray research and the vacuum electrometer newly invented by the German physicist Gerhard Hoffmann. To his and Millikan's surprise, Zhao found that while the absorption ratios for lighter elements corresponded to the Klein-Nishina formula, there was an abnormally large absorption, by about 40 percent more than the predicted values, of gamma rays by heavy elements such as lead. Puzzled by these results, it was now Millikan's turn to hesitate, in this case about whether to allow Zhao to publish his paper, which he had completed by the end of 1929. Finally, Ira Bowen, a physics professor who was familiar

with Zhao's experiment, came to Zhao's rescue as he vouched to Millikan for the accuracy of Zhao's data. The paper, titled "The Absorption Coefficient of Hard  $\gamma$ -Rays," was then published in the 15 June 1930 issue of *Proceedings of the National Academy of Sciences* with Millikan's recommendation. It turned out to be one of three simultaneous but independent reports—the other two were by scientists working in Britain and Germany, respectively—on the abnormal absorption of gamma rays by heavy elements.

What caused the abnormal absorption of the gamma rays by heavy elements? In his paper, Zhao made several speculations, including the possibility that there might be electrons inside the nucleus that produced additional scattering of the gamma rays. Millikan had earlier suggested the existence of nuclear electrons in connection with his investigation of the scattering of cosmic rays. In any case, Zhao now believed that scattering was the key to understanding the abnormal absorption of the gamma rays. With the approval of Bowen and Millikan, Zhao designed a new experiment to measure the scattering of gamma rays by aluminum and lead, as representatives of light and heavy elements, respectively, at various angles using the Hoffmann vacuum electrometer. The scattering experiment turned out to be much more difficult than the absorption one, demanding great care, patience, and technical ingenuity, which Zhao had acquired partly from his earlier experiment and partly by working on a used car that he had bought for twenty-five dollars. Once again, Zhao made a startling finding: there seemed to be extra "anomalous scattering" of gamma rays by lead, especially in the region behind the scatterer, with energy estimated at about 0.5 MeV, that could not be explained by the Klein-Nishina theory or other existing mechanisms. As the first physicist to record this remarkable phenomenon, Zhao again speculated that, like the abnormal absorption, the anomalous scattering of gamma rays was a nuclear phenomenon.

Naturally, these anomalous phenomena intrigued Zhao and other physicists. He continued to conduct experiments in this area during a tour in Europe after receiving his PhD at Caltech in late 1930. He spent a year with Hoffmann at the University of Halle in Germany and then paid a short visit to the Cavendish Laboratory at Cambridge University in England. There he met the great nuclear physicist, Ernest Rutherford, who encouraged him to continue his research once he returned to China. News of the Japanese invasion and occupation of northeastern China in September 1931 caused Zhao to cut his trip short and quickly return to China. Finding that there was little he could do to contribute directly to national defense, he resumed his teaching and his experiments on hard gamma rays and on neutrons at Qinghua University.

Meanwhile, Zhao's experiments at Caltech had triggered an unexpected sequence of developments that quickly helped to solve the puzzle presented therein. In 1929–1930 Carl D. Anderson, a fellow graduate student, had watched Zhao's experiment with great interest. At one point, he discussed informally with Zhao the possibility of using a cloud chamber, instead of the electroscope, to get a better picture of what happened when the gamma rays were scattered by lead, but nothing apparently was accomplished along this line before Zhao's departure. Afterward, Anderson inherited Zhao's thorium C" and started to design a cloud chamber for this purpose. Millikan, however, persuaded him at this point to use the cloud chamber to study the scattering of cosmic rays, not gamma rays. As he took pictures of the particle tracks in the cloud chamber, Anderson discovered the presence of positively charged electrons—positrons. Subsequent experiments and studies in 1933 by Patrick M. S. Blackett and Giuseppe P. S. Occhialini as well as J. Robert Oppenheimer and others led to the recognition that Anderson's positrons were produced as a result of pair-production: a high energy photon would be transformed into an electron and positron when it entered the coulomb field of a heavy nucleus. Shortly after their creation, however, the electron-positrons would "annihilate" each other while giving off two photons. This interpretation, which corresponded to Dirac's QED theory, also explained the excess absorption and scattering of gamma rays by heavy elements that Zhao was the first or among the first to observe: the former was caused by pair-production and the latter by annihilation.

In retrospect, Zhao's well-designed and beautifully executed gamma ray experiments helped to inspire the discovery of the positron and pave the way for the acceptance of QED. They represented one of the earliest and most significant achievements by a Chinese physicist in the twentieth century. In the exciting and somewhat chaotic atmosphere of nuclear physics in the early 1930s, however, Zhao's contributions were overshadowed by other, more striking discoveries such as the neutron, the positron, and artificial radioactivity. Anderson won his much-deserved Nobel Prize in Physics in 1936, partly upon Millikan's strong recommendation, but it was not until the 1980s when participants such as Anderson and Occhialini more publicly acknowledged the impact of Zhao's work and when historical research by the Chinese and Chinese American physicists Bing An Li and Chen Ning Yang (Yang Zhenning in pinyin), Nobel laureate in physics in 1957 and former student of Zhao's, brought the spotlight to Zhao's accomplishments.

**Experience during the Anti-Japanese War.** When Zhao returned to Qinghua in late 1932, he was an internationally recognized authority in experimental nuclear physics

and the founder of the field in China. As a professor and, for a while, the chairman of the Department of Physics, he quickly organized the first nuclear physics laboratory in China. He assembled a small team of assistants and students, including a skilled technician he hired from Germany, to make instruments, including small cloud chambers and Geiger counters, and conduct research, under primitive conditions, on gamma rays, the resonance levels of neutrons in silver nuclei, and artificial radioactivity, resulting in publications in Chinese physics journals as well as in *Nature*. His colleagues included, besides Ye, other pioneers of modern physics in China such as Wu Youxun (Yui Hsun Woo in Wade-Giles), who had made major contributions to the elucidation of the Compton effects when he studied with Arthur Compton in Chicago in the 1920s, and Zhou Peiyuan (Pei Yuan Chou in Wade-Giles), who had received his PhD at Caltech two years ahead of Zhao. Together they helped train a large number of the leading Chinese nuclear physicists of the twentieth century, including many of those who would become leaders of the Chinese atomic bomb project in the 1960s. Alarmed by the gathering Japanese threat in the 1930s, Zhao was increasingly filled with a sense of national crisis and sought to do something to help strengthen China. Not a revolutionary by temperament, Zhao joined many Chinese intellectuals in advocating the “saving of China” through science, education, and industry. As an example of the latter, he and his colleagues from the Physics Department started a factory to manufacture pencils, first in Beijing and then in Shanghai.

Following the full-scale Japanese invasion of China in July 1937, the Zhaos embarked with the rest of the university on a journey of southward exile. In 1937–1938 he taught at Yunnan University in Kunming in southwestern China but returned to Qinghua when it joined with Beijing University and Nankai University to form the Southwestern Associated University (SAU) in Kunming. Pooling the faculty and resources of the three top universities in China, the SAU became an intellectual powerhouse, producing, among others, Yang and Tsung Dao Lee (Li Zhengdao in pinyin), who went on to receive their PhDs in the United States and to become the first ethnic Chinese to share the Nobel Prize in Physics in 1957. During the eight-year stay in Kunming, Zhao collaborated with another physicist, Zhang Wenyu, to conduct research on cosmic rays. After the end of World War II in 1945, Zhao moved to Chongqing to take up the chairmanship of the Physics Department at the National Central University.

**Second Sojourn in America.** Zhao did not stay in Chongqing long before America beckoned again in the summer of 1946. The U.S. government invited its Chinese ally to send two observers to witness its nuclear test-

ing at Bikini Atoll in the Pacific. Recommended by Sa Bendong (Adam Pen-Tung Sah in Wade-Giles), a former Qinghua colleague who was then serving as executive director of the Academia Sinica, headquartered in Nanjing, Zhao was chosen to be the scientific representative. The first test, conducted in the atmosphere, took place on 1 July 1946, and the second, underwater, went off on 25 July. Following the tests, Zhao did not return to China immediately; he had a special task. Before his departure Sa had given him fifty thousand dollars to purchase instruments in the United States for nuclear physics research at the Academia Sinica. Subsequently, he was entrusted with another seventy thousand dollars to buy instruments for other scientific fields.

With characteristic thoroughness and persistence, Zhao set out to accomplish his mission despite meager resources. The first choice in nuclear physics instrumentation at the time was an accelerator, but even the least expensive of them, the electrostatic generator, invented by and named after the American physicist Robert J. Van de Graaff, would cost more than \$400,000. Zhao decided to design a Van de Graaff of his own, with some of the key components purchased but the rest made by himself in the United States or in China after his return. He spent half a year at the Massachusetts Institute of Technology (MIT), where he learned to design the machine with the help of John G. Trump, a professor of electrical engineering who had teamed up with Van de Graaff to form the High Voltage Engineering Company to commercialize the accelerator. Zhao spent another half year at the Carnegie Institution of Washington, which had two Van de Graaffs and one cyclotron, to continue his design work. He then returned to MIT to work on cosmic rays in Bruno Rossi's laboratory and to purchase the various components for his accelerator as well as the other instruments on his shopping list.

In late 1948 Zhao finished his mission for the Academia Sinica, but amidst the chaos of the Chinese Civil War between the Nationalist government under Jiang Jieshi (Chiang Kai-shek) and the Communist forces under Mao Zedong, Zhao decided to stay in the United States for the time being, both to wait for the political situation to settle and to acquire more experience in using accelerators. Zhao returned to California, where he worked with Thomas Lauritsen and others on nuclear physics at Caltech's Kellogg Laboratory. By late 1949 the Chinese Communists had won the civil war and had driven the Nationalists to Taiwan.

With his wife and three children still in Nanjing, Zhao decided to return to China in early 1950 after first sending his instruments home. In the atmosphere of the cold war and McCarthyism, the journey turned into a saga, with Zhao at the center of an international political dispute. The Federal Bureau of Investigation (FBI), clearly

aware of Zhao's background in nuclear physics, opened and searched Zhao's shipment of instruments. Most of them were released shortly afterward, when Jesse DuMond, a professor of physics at Caltech, told agents that they were not related to nuclear weapons. Thus, except for four sets of electronic circuitry for nuclear physics that Rossi's lab had made for Zhao and which the FBI confiscated (but later returned them to Caltech after Zhao's departure), most of his instruments, packaged into more than thirty cases, made it back to China. Remarkably, for a short period following the Communist takeover in mainland China, it was still possible for shipments and Chinese expatriates to move from the United States to China, often via Hong Kong, despite the lack of diplomatic relations between the two countries. Hundreds of Chinese students and scientists in the United States took advantage of the opportunity to return home. The outbreak of the Korean War in June 1950, however, greatly heightened the tension between the two countries. Unfortunately for Zhao, he did not board the boat *President Wilson* for China via Hong Kong until late August, so FBI agents searched his checked luggage and confiscated some books and journals. More sensationally, they prevented the boarding of his fellow Chinese scientist Qian Xuesen (Hsue-Shen Tsien in Wade-Giles). Qian, the Guggenheim professor of aerodynamics at Caltech, had just lost his security clearance on suspicion of his being a Communist Party member, and the FBI agents detained him on a charge of violating export control. Zhao and other Chinese returnees were alarmed by Qian's arrest but were also relieved that they were allowed to depart on schedule.

It was not, however, smooth sailing all the way for Zhao. When the boat stopped at the port city of Yokohama in Japan, he and two other Chinese from Caltech—Shen Shanjiang, a biologist who had just received his PhD there, and Luo Shijun, an aerodynamic scientist who had completed his PhD under Qian—were hauled off the ship by the U.S. military authorities stationed in the city. Apparently, their connections with Qian had aroused American suspicion. They were led to a Central Intelligence Agency (CIA) office onshore for questioning and were stripped so their clothes could be searched. Inside the CIA office, Zhao, Shen, and Luo demanded a justification for their detention and were told that their checked-in luggage needed to be examined. As the U.S. government flew their luggage to San Francisco for examination, the three were detained in a U.S. Army jail near Tokyo. The Nationalist government in Taiwan tried to convince the trio to go to Taiwan or return to the United States, but they refused, citing the fact that they had families in China. Meanwhile, the news of their detention galvanized a huge outcry by many Chinese and several western scientists in protest of the American action. Finally, on 31 October 1950, they were told that an examination had

found that several items in their luggage violated American export control rules but none was related to national security, and therefore they were to be released. Finally, they boarded *President Wilson* in mid-November and arrived in Hong Kong on 20 November, and then enjoyed a hero's welcome in China.

**Later Years.** In 1951 Zhao joined the newly established Chinese Academy of Sciences, which had been built on the former Academia Sinica but headquartered in Beijing, as director of nuclear physics at its Institute of Modern Physics in Beijing. His colleagues included many of his former students and colleagues from Qinghua, such as Wang Ganchang (Kan Chang Wang in Wade-Giles) who, after graduating from Qinghua, had gone to study with Lise Meitner in Berlin in the 1930s and would later become one of the chief designers of the Chinese nuclear weapons program in the 1960s. In his new position Zhao conducted some research but devoted most of his energy in the 1950s and the first half of the 1960s to building accelerators and training young scientists. When two cyclotrons arrived from the Soviet Union in the late 1950s, Zhao used one of them to study the elastic scattering of neutrons and nuclear reactions involving deuterons. In 1958 he took on the additional responsibility as chairman of the Department of Modern Physics at the newly established University of Science and Technology of China in Beijing, helping make it quickly one of the top programs in China. Yet, despite his patriotic actions, Zhao failed to gain complete political trust by the Communist Party, partly due to his extensive sojourns in the West. He held many honorific positions, but wielded limited influence in science policy and saw few of his proposals for advancing nuclear physics realized. He was only tangentially involved in the Chinese nuclear weapons projects, even though a large number of his colleagues and former students were active participants.

Like most Chinese scientists, the worst for Zhao came during the radical Cultural Revolution (1966–1976). Accused, ironically, of being an American agent (due to his observation of the atomic bomb tests and his detention in Japan) and a capitalist (due to his role in starting the pencil factory), he was detained for a time by the Maoist Red Guards in the Chinese Academy of Sciences. Zhao's conditions improved, as did those of many other senior Chinese scientists, in the early 1970s, when American scientists, especially Chinese American scientists, visited China following President Richard Nixon's groundbreaking trip in 1972. In 1973 Zhao became deputy director of the newly established Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences. When Mao's death in 1976 led to an end of the Cultural Revolution, Zhao reemerged as a senior Chinese nuclear physicist and was much honored by the post-Mao

government and the scientific community. Before his death in 1998 due to an illness, he was especially delighted to see the building and successful operation of the Beijing Electron-Positron Collider in the IHEP in the 1980s and 1990s, the result of a collaboration between the United States and China in high-energy physics.

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*Zuoyue Wang*

**ZHU KEZHEN** (Chu Coching, Chu Co-ching, or Chu K'o-chen in Wade-Giles; *b.* Shaoxing County [now Shangyu County], Zhejiang Province, China, 7

March 1890; *d.* Beijing, China, 7 February 1974), *meteorology, climatology, geography, education, science policy.*

Zhu was a founder of modern meteorology and geography in China who made significant contributions to the studies of typhoons, rainfall patterns, phenology, geographic regions, and, especially, historical climate change of China. He also played a prominent role in science policy, higher education, natural resources surveys, the history of science, and popularization of science in China in the twentieth century.

**Early Years and Education.** Zhu's father, Zhu Jiaxian, was a rice merchant in Shaoxing and his mother Gu Jinniang, a devout Buddhist, ran a busy household with six children. Kezhen was the youngest in the family. Like many of the prominent figures in Chinese history who originated in the region, Zhu was reared in an environment that valued scholarship and a sense of Chinese nationalism. There he received his elementary education in Chinese classics before entering a western-style middle school in Shanghai in 1905. Four years later he enrolled in the Tangshan School of Railroads and Mines in Tangshan, Hebei Province, to study civil engineering. In 1910, he became one of about seventy students from all over China who passed a set of competitive examinations and were selected for study in the United States with the support of the so-called Boxer fellowships, which derived from the returned surplus from the indemnity that China had agreed to pay the United States following the Boxer unrest in 1900.

Arriving at the University of Illinois at Urbana-Champaign, in 1911, Zhu chose to study agriculture due to its importance to China. But he soon realized that the American way of farming—what he perceived to be large-scale and employing African Americans as slavelike plantation workers—would not work back home. Thus he shifted to meteorology as his field of graduate study at Harvard University in 1913, after graduating from Illinois. Working with Robert DeCourcy Ward and Alexander G. McAdie, Zhu quickly demonstrated both his scientific talent and capacity for careful scholarship in the new field. While still a graduate student, he published several papers on Chinese rainfall, typhoons, and Chinese contributions to meteorology. His abiding interest in the history of science in China was in part stimulated by his interactions with the historian of science George Sarton, then at Harvard. Zhu also became a leader in the newly established Science Society of China, with its headquarters first at Cornell University and then at Harvard. He wrote several articles on Chinese meteorology in the society's journal *Kexue* (Science), which was published in Chinese in China as a way to spread scientific knowledge. In 1918, Zhu received his PhD with a dissertation on "A