ATOMIC PIONEERS

Book 3

From the Late 19th to the Mid-20th Century

by Ray and Roselyn Hiebert


The Authors

Mrs. Roselyn Hiebert received her B.A. degree from the University of California. She and her husband, Dr. Ray Hiebert, have written the following books for children, *Franklin Delano Roosevelt: President for the People,* 1968; *Thomas Edison: American Inventor,* 1969; and *The Stock Market Crash of 1929,* 1970, Franklin Watts, Inc.

Dr. Ray Hiebert received his B.A. degree from Stanford University, his M.S. degree from Columbia University, and his M.A. and Ph.D. degrees from the University of Maryland. He is Professor and Head of the Journalism Department at the University of Maryland. Dr. Hiebert is editor of *Books in Human Development,* Agency for International Development, 1965, *The Press in Washington,* Dodd, Mead and Company, 1966, and a series of textbooks on government and communications for John Wiley and Sons, Inc. He is the author of a biography, *Courtier to the Crowd,* Iowa State University Press, 1966.

The Cover

Top, Albert Einstein, second from top, James Franck; first row, left to right, Wolfgang Pauli, Niels Bohr, Erwin Schrödinger; second row, Irène Joliot-Curie, Ernest O. Lawrence, Enrico Fermi.

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

PREFACE

Books 1 and 2 of "Atomic Pioneers" traced the history of atomic science through the lives of 51 scientists who lived from ancient Greek times to the great physicists and chemists of the early 20th century.

This book takes up the dramatic story of the development of atomic science where we left off in the 20th century. The new discoveries that Michael Faraday and Wilhelm Roentgen and other scientists had made in the knowledge of electromagnetism and X rays had resulted in the great theories of Max Planck, Albert Einstein, and Ernest Rutherford.

Now as the 20th century unfolded, these building blocks of atomic knowledge would be used as a foundation for creating even greater knowledge of atomic science. Men such as Niels Bohr with his work on atomic structure, James Chadwick and his discovery of the neutron, and others like Enrico Fermi, Leo Szilard, and E. O. Lawrence made possible the ultimate development of atomic energy before the middle of the century.

This book carries on the story of the atom by presenting a brief account of the lives and work of 24 atomic scientists who brought the world into the complex Age of the Atom by mid-20th century.

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ALBERT EINSTEIN

Albert Einstein, German-born and naturalized American physicist, was one of the greatest scientists of all time. An aspect of his theory of relativity, among many other scientific contributions, became the foundation for the development of atomic energy. He won a Nobel Prize in physics in 1922. He was born in Ulm, Germany, on March 14, 1879, and died in Princeton, New Jersey, on April 18, 1955.

Biographical Details

Einstein attended public school in Munich, and at the time he showed little promise of the genius that would develop later. As a child he was extremely slow in speech development, and it was feared that he was retarded.

Einstein's father was an unsuccessful manufacturer. After a particularly bad year, he decided to move to Switzerland. Einstein

Albert Einstein and his sister Maja.

was left behind to finish school. After several months he became so disgusted with school that he decided to quit. In parting, one of his teachers said, "You will never amount to anything, Einstein." Other teachers complained that his disinterested attitude disrupted their classes. So he left school and joined his family in Switzerland.

Of his early education Einstein said, "I soon learned to scent out that which was able to lead to fundamentals and to turn aside from everything else, from the multitude of things which clutter up the mind and divert it from the essential. The hitch in this was, of course, the fact that one had to cram all this stuff into one's mind for the examinations, whether one liked it or not. This coercion had such a deterring effect on me that, after I had passed the final examination, I found the consideration of any scientific problems distasteful to me for an entire year."

While he attended school in Switzerland he was lucky enough to have a friend, Marcel Grossmann, who, he said, "attended the lectures regularly and who worked over their content conscientiously. This gave one freedom in the choice of pursuits until a few months before the examination, a freedom which I enjoyed to a great extent and have gladly given into the bargain the bad conscience connected with it as by far the lesser evil.

"It is, in fact nothing short of a miracle that the modern methods of instruction have not entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in need of

Einstein in 1905.

freedom; without this it goes to wreck and ruin without fail."

After he graduated he had a difficult time finding a job. Finally Marcel Grossmann's father obtained a post for him at the Swiss Patent Office in Berne. Einstein's duties included reading the patent applications and writing condensations of them for his boss. The work was not difficult and often he came upon interesting devices that stimulated his imagination. Also he could finish in 4 or 5 hours and spend the rest of the day on his theories and calculations. These he scribbled on slips of paper, which he quickly hid in a drawer if anyone walked toward his desk. He retained this job from 1902 to 1909 and became a Swiss citizen in 1905.

During these years he made three of his greatest contributions to scientific knowledge. In 1905 he published three papers, each of which involved a development of major importance to physics. The first dealt with the photoelectric effect. In the second he worked out a mathematical analysis to show that if water in which particles were suspended was composed of molecules in random motion, then these suspended particles would jiggle as scientists had observed. The equation he developed could be used indirectly to figure out sizes of the molecules and of the atoms that composed the molecules. Einstein's third paper was his Special Theory of Relativity.

Many years later Einstein, commenting on these three theories, said to Robert Oppenheimer, "When it has once been given you to do something rather reasonable, forever afterward your work and life are a little strange."

These theories were published when he was 26, and before he had even acquired a formal academic position. It was not until 1909 that he became professor of theoretical physics at the University of Zurich.

In 1914 he assumed German citizenship again when he accepted a professorship at the University of Berlin and became director of the Kaiser Wilhelm Physics Institute where he remained until 1933.

Increasingly apprehensive over the rise of Hilter in Germany, Einstein was visiting the United States in 1933 when the Nazis confiscated his property and took away his job and citizenship.

He had already been offered the directorship of the school of mathematics in the newly created Institute of Advanced Study in Princeton, New Jersey. He accepted the position and remained there until his death. In 1940 he became an American citizen.

Einstein was a humanist as well as a physicist. He gave many days of his life to helping individuals and mankind in general.

The following excerpts from a book* written by Leopold Infeld in 1941 reveal a little about Einstein's personality:

"Einstein wrote about himself: 'My passionate interest in social justice and social responsibility has always stood in curious contrast to a marked lack of desire for direct association with men and women. I am a horse for single harness, not cut out for tandem or teamwork. I never belonged wholeheartedly to country or state, to my circle of friends or even to my own family. These ties have always been accompanied by a vague aloofness and the wish to withdraw into myself increases with the years.

'Such isolation is sometimes bitter, but I do not regret being cut off from the understanding and sympathy of other men. I lose something by it, to be sure, but I am compensated for it in being rendered independent of the customs, opinions and prejudices of others and am not tempted to rest my peace of mind upon such shifting foundations.'

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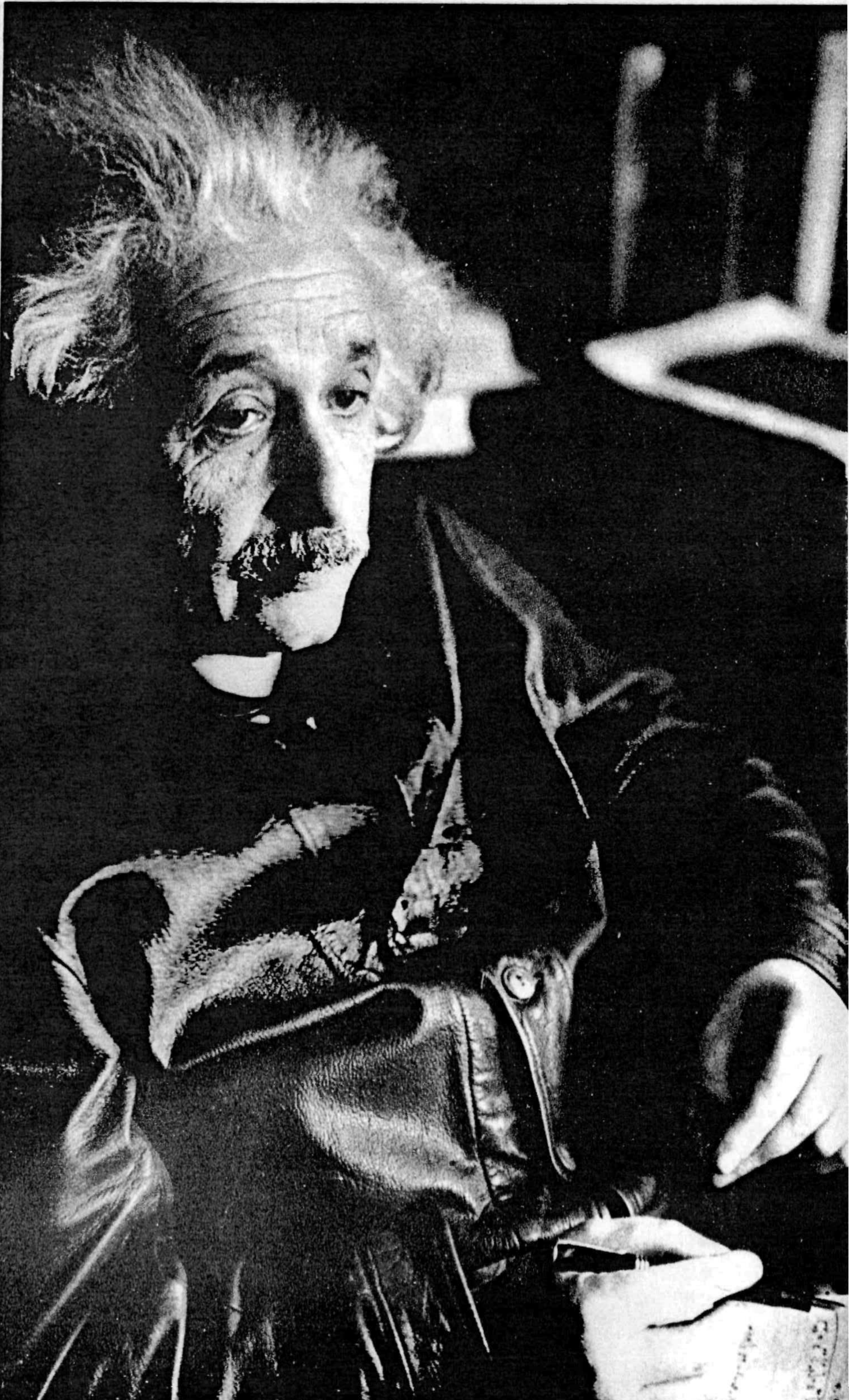
*From *Quest*, Leopold Infeld, Doubleday and Company, New York, 1941. Copyright by Mrs. Helen Infeld. Reprinted by permission.



"... fame has had no effect on Einstein.... Fame bothers him when and as long as it impinges on his life, but he ceases to be conscious of it the moment he is left alone.... He once told me, 'I envy the simplest working man. He has his privacy.' Another time he remarked, 'I appear to myself as a swindler because of the great publicity about me without any real reason.'

"One of my colleagues in Princeton asked me: 'If Einstein dislikes his fame and would like to increase his privacy, why does he not do what ordinary people do? Why does he wear long hair, a funny leather jacket, no socks, no suspenders, no collars, no ties?'

"The answer is simple and can easily be deduced from his aloofness and desire to loosen his ties with the outside world. The idea is to restrict his needs and, by this restriction, increase his freedom. We are slaves of millions of things, and our slavery progresses steadily ... We are slaves of bathrooms, frigidaires, cars, radios and millions of other things. Einstein tried to reduce them to the absolute minimum. Long hair minimizes the need for the barber. Socks can be done without. One leather jacket solves the coat problem for many years. Suspenders are superfluous, as are nightshirts and pajamas. It is a minimum problem which Einstein has solved, and shoes, trousers, shirt, jacket, are the very necessary things; it would be difficult to reduce them further.

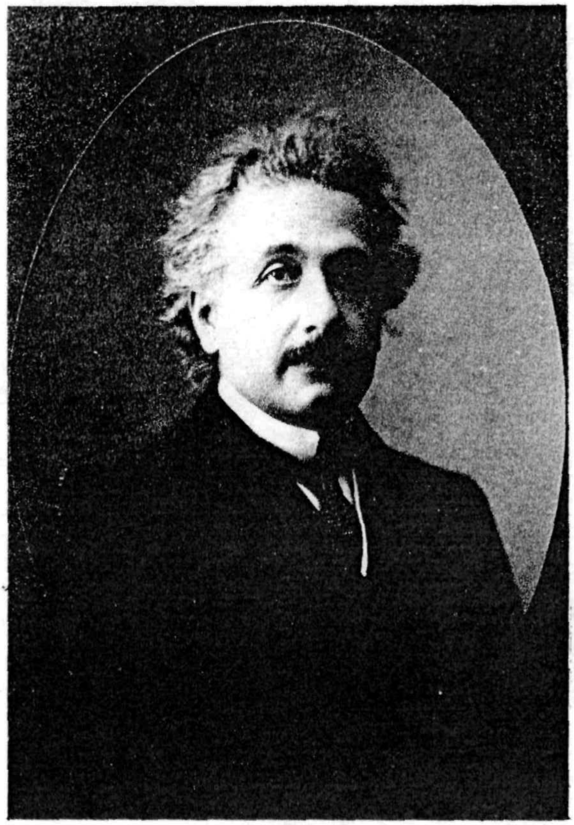
"There is no fear of death in Einstein. He said to me once: 'Life is an exciting show. I enjoy it. It is wonderful. But if I knew that I should have to die in three hours it would impress me very little. I should think how best to use the last three hours, then quietly order my papers and lie peacefully down.' "

Scientific Achievements

At the age of 26 in 1905 Einstein published his three history-making papers. In the first, he used the quantum theory of Max Planck to explain the photoelectric effect. This effect takes place when light hits certain metals with sufficient energy to release electrons. Einstein said that when quanta or packets of light energy strike metal, they force it to release electrons. He helped justify the quantum theory and the photoelectric effect, which could not be done while scientists believed that light traveled only in waves.

In Einstein's famous Special Theory of Relativity, involving a new view of the universe, he worked out the equivalence of mass and energy. He began with the assumption that the velocity of light in a vacuum is always constant despite any motion of its source or of the individual measuring the light. An important fact of Einstein's work was that he extended Planck's theory. According to Planck, light (radiation) was emitted and absorbed in "packets" (quanta). Einstein suggested that light was also propagated in quanta. All motion is relative to a frame of reference and the laws of nature are the same in all frames of reference. Because of this idea that all motion is relative, the theory is called relativity.

He developed the equation $E = mc^2$, where E is energy, m is mass, and c is the velocity of light. This equation explained the energies given off by radioactive elements as a consequence of the slight loss of mass involved. The interrelationship of mass and energy proved to be valid and it was used to work out some of the basic problems of atomic energy.



Einstein in 1922, the year he won the Nobel Prize in physics.

Another paper that same year concerned the Brownian movement, an irregular movement of microscopic particles suspended in a liquid or gas. With it he showed in mathemati-

Einstein with his wife and their daughter Margot in 1929.

cal detail that if the water in which the particles were suspended was composed of molecules in random motion as was the current belief, then the suspended particles would move just as they were observed to move.

After these three great papers, Einstein expanded the Special Theory of Relativity into his General Theory of Relativity in 1915. The equations developed by this theory allowed grand conclusions to be drawn about the universe as a whole, and in 1917 he applied this theory to the problem of the shape and the size of the universe, opening up a huge new field of research.

The final years of Einstein's life were spent trying to combine electromagnetic and gravitational equations into a single theory, which he called the unified field theory in 1929. This he was not able to do although he never gave up the attempt.

Einstein did not agree with all the theories that were revolutionizing physics. He especially disliked theories such as Heisenberg's Uncertainty Principle, which contain probabilities and indeterminates and seemed to leave the fate of the universe to chance. He was fond of saying in response to these theories, "God may be subtle, but He is not malicious" or "I cannot believe that God is playing a game of dice with the world."

Contribution to Atomic Science

Einstein's great relativity theory revolutionized scientific thought with new conceptions of time, space, mass, motion, and gravitation. By treating matter and energy as interchangeable rather than distinct, he laid the groundwork for the release of energy by splitting the atom. The concept of the equivalence of mass and energy was considered by others before Einstein, but he put the subject on a firm mathematical basis.

JAMES FRANCK

James Franck, German-American physicist, shared the Nobel Prize in physics in 1925 with Gustav Hertz for experiments testing Planck's quantum theory and laws for electron-atom collision. He was born in Hamburg, Germany, on August 26, 1882, and died in Göttingen on May 21, 1946.

Biographical Details

Franck studied at universities in Heidelberg and Berlin. He fought for Germany in World War I and won an Iron Cross. In 1920 he became professor of physics at Göttingen. At this university he created a superb center for nuclear studies. He resigned his university post in 1933 in protest over Hitler's rise to power and in 1935 was forced to leave Germany.

Franck came to America where he was appointed professor at Johns Hopkins University. In 1938 he joined the faculty of the University of Chicago and eventually became a U. S. citizen.

During World War II he, like so many other atomic physicists, worked on the Manhattan Project.

Scientific Achievements

Franck worked with Gustav Hertz on research which proved that the electron must have a certain amount of energy to *excite* an atom, i.e., to bring it to a state of higher (electronic radiation) energy. Then it can emit the excess energy as light. They proved this by bombarding atoms of a gas with electrons of various energies. Franck found that an atom needs an exact amount of energy, or quantum, to change its energy state and that it emits, in the form of light, the exact amount of energy it absorbed from the electron.

Contribution to Atomic Science

Franck's research proved through experiment the validity of Max Planck's quantum theory and Niels Bohr's concept of the atom, i.e., that an atom can absorb internal energy only in specific amounts that transform it from one state to another one.

At a social gathering in Berlin in 1920 are, standing, left to right, Hugo Grotrian, Wilhelm Westphal, Otto von Baeyer, Peter Pringsheim, and Gustav Hertz. Seated, left to right, are Hertha Sponer, Albert Einstein, Ingrid Franck, James Franck, Lise Meitner, Fritz Haber, and Otto Hahn.

MAX BORN

Max Born, German-British physicist, shared the 1954 Nobel Prize in physics with Walther Bothe for their statistical interpretation of the quantum mechanical wave function. He was born in Breslau, Germany, on December 11, 1882, and died on January 5, 1970, in Göttingen.

Biographical Details

Born's family were well-educated members of German society. His father was an anatomist and embryologist. Born studied at the University of Göttingen and later at Cambridge University under J. J. Thomson.

In 1907 he received his doctorate from Göttingen and then taught there and at other universities. His papers on the relativity theory of the electron caught the attention of the American physicist Albert A. Michelson, who invited him to lecture at the University of Chicago in 1912.

After serving in World War I he became a professor at the University of Frankfurt am Main. One of his assistants was Otto Stern. It was there that Stern began his experiments to determine the spin and magnetic moment of the atom for which he received a Nobel Prize.

In 1921 he accepted the much sought-after chair of theoretical physics at the University of Göttingen. Along with James Franck, Born contributed much toward making this a great center for nuclear studies. Some of the physicists who worked with him were John von Neumann, Eugene Wigner, Werner Heisenberg, J. Robert Oppenheimer, P. A. M. Dirac, and Wolfgang Pauli.

In 1933 Born went to Cambridge as a lecturer. In 1936 he became professor of natural philosophy at the University of Edinburgh where he remained until his retirement in 1953.

Scientific Achievements

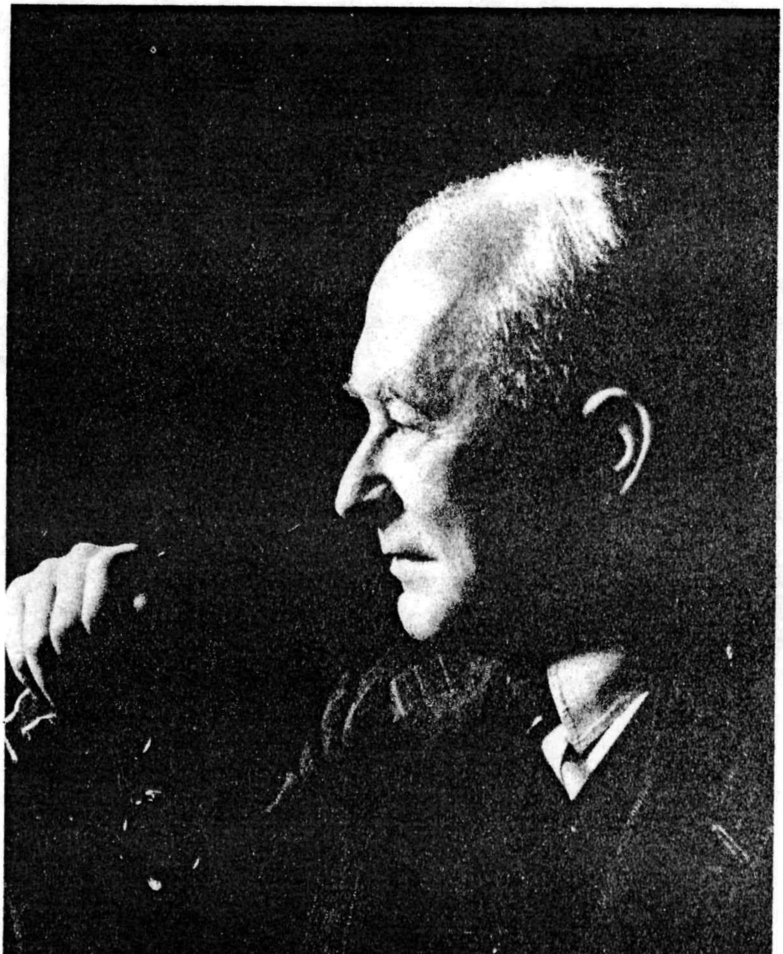
Born helped clear up a problem in quantum mechanics. Erwin Schrödinger had suggested that a particle's wave function should be considered to the exclusion of its function as a particle. This meant that the particle spread through all space.

Born did not believe that this could be true because of the various counters—Geiger counters, cloud chambers, etc.—that registered individual particle counts. He subsequently worked out the statistical meaning of the wave function. This has been used in all nuclear procedures ever since.

Born and Franck also confirmed Louis Victor de Broglie's theory. C. J. Davisson in 1925 wrote to Born about his, Davisson's, experiments with the reflection of electrons from metallic surfaces. Born and Franck discovered that Davisson's wavelength pattern matched de Broglie's formula for the wavelengths of an electron moving at a certain speed.

Contribution to Atomic Science

Born, along with such men as de Broglie, Schrödinger, and Heisenberg, contributed to atomic science the mathematical basis of quantum mechanics.



PETER J. W. DEBYE

Peter Joseph Wilhelm Debye (dee-bigh), Dutch-American physical chemist, won the Nobel Prize in chemistry in 1936 for his contributions to the knowledge of molecular structure. He was born in Maastricht, Netherlands, on March 24, 1884, and died November 2, 1966, in Ithaca, New York.

Biographical Details

Debye received his doctor's degree in physics at the University of Munich. He was a professor of physics at the Universities of Zurich, Leipzig, and Berlin until he was appointed to head the Kaiser Wilhelm Institute for theoretical physics in Berlin in 1935.

He left Germany in 1940 and came to the United States to teach at Cornell University. There he served as head of the chemistry department until 1950. He became an American citizen in 1946 and remained in Ithaca, New York, for the rest of his life.

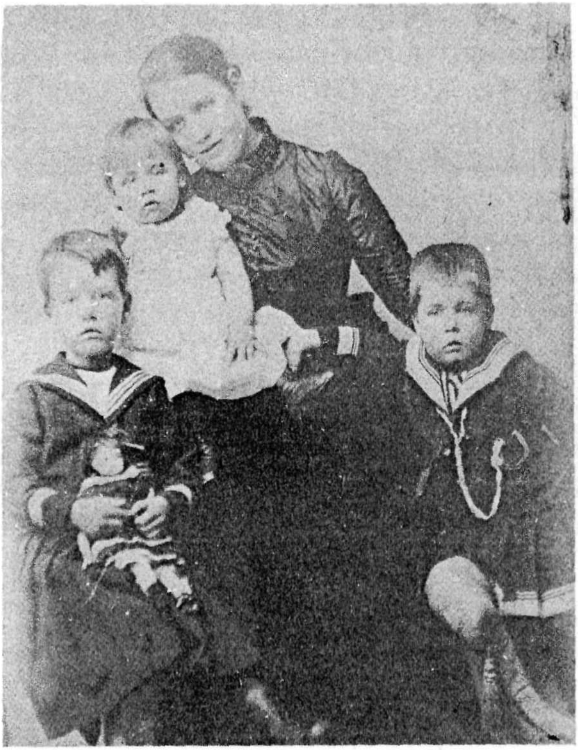
Scientific Achievements

Debye's research included the dipole moments, which determine what an electrical field will do to a molecule with a positive and a negative charge. The dipole moment unit is called a debye.

He also broadened Arrhenius' research on ions in solution. Arrhenius had believed that electrolytes broke up into positive and negative ions in solution, but that the ionization was not always 100%. Debye believed that the ionization was complete because X rays demonstrated that the electrolytes had been in an ionic form before they were dissolved. Debye thought that every negative ion was surrounded by a group of mostly positive ions and vice versa. Such a situation would have caused Arrhenius to conclude that the ionization was not complete. Debye formed a mathematical basis for this which is still used in present-day work.

Contribution to Atomic Science

Debye's work on the theory of electrolyte solutions is the foundation of the modern interpretation of the properties of such solutions. His work on electrical polarity in molecules led to an improvement in picturing molecular structure.

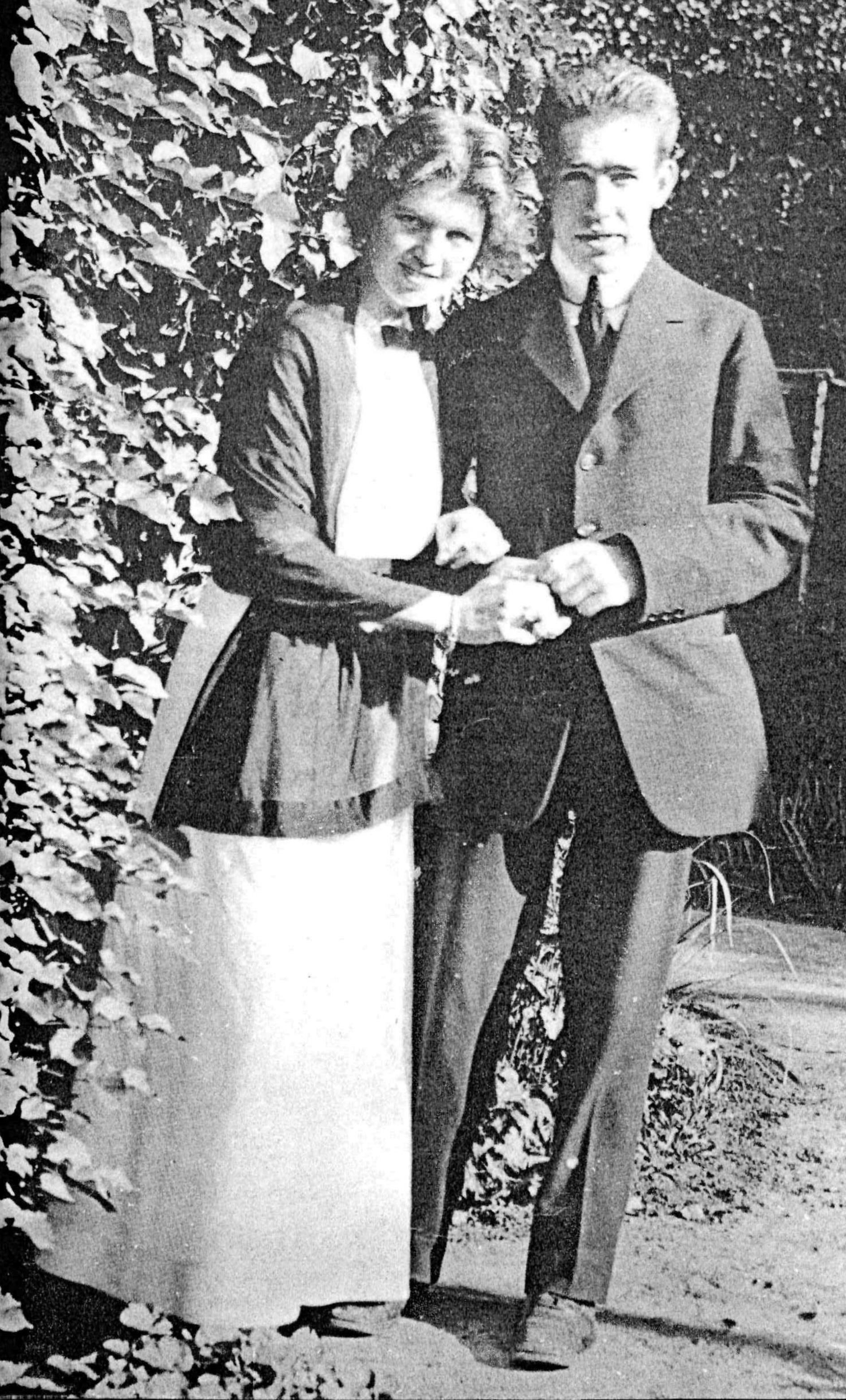


Niels Bohr at the age of four, right, with his mother, his brother Harald (in mother's lap), and his sister Jenny (left) in 1889.

NIELS BOHR

Niels Bohr, a Danish physicist who helped develop the field of quantum physics, was awarded the Nobel Prize in physics in 1922 for his atomic theory which laid the groundwork for later atomic research. He was born on October 7, 1885, in Copenhagen, Denmark, and died there November 18, 1962.

Margrethe Norlund and Niels Bohr happily hold hands at the time their engagement was announced. The photograph was taken at Margrethe's home.

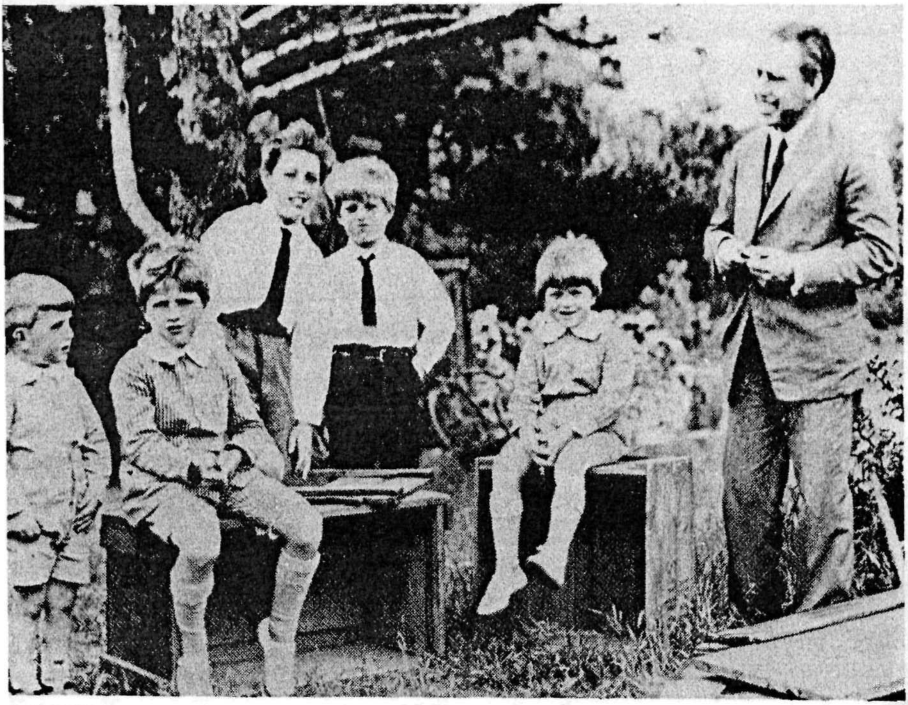


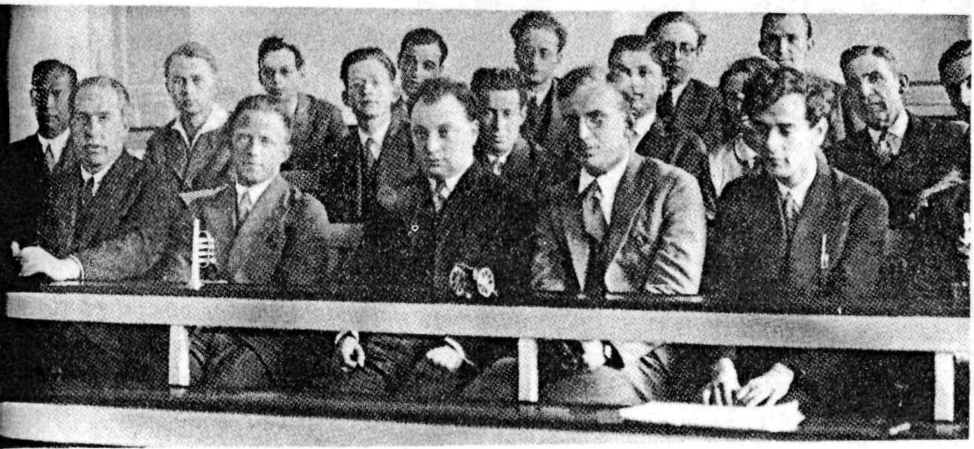
Biographical Details

Bohr studied physics at the University of Copenhagen and received a doctorate in 1911. He went to Manchester University and worked under Rutherford and returned to the University of Copenhagen as a physics professor.

In 1920 Bohr became head of the newly created Institute of Theoretical Physics in Copenhagen, and he held this position until his death. By the 1920s his institute had become a world center of atomic physics, and it was there that he developed his interpretations of quantum theory.

Bohr with his five sons, left to right, Ernest, Erik, Christian, Hans, and Aage.





A group at Bohr's institute about 1930. First row, Oskar Klein, Niels Bohr, Werner Heisenberg, Wolfgang Pauli, George Gamow, Lev Landau, Hans Kramers. Second row, Waller, Piet Hein, R. E. Peierls, W. Heitler, Felix Bloch, Miss Ehrenfest, Colby, Edward Teller. Third row, first man unidentified, B. Wintner, C. Møller, Alexander Pihl, W. W. Hansen.

However, Bohr and the young students at the institute were not solely occupied with physics. For example, they devised a system for rating the beautiful girls in Copenhagen:

1. You can't stop looking.
2. You can stop but it hurts.
3. It doesn't make any difference whether you look or not.
4. It hurts to look.
5. You couldn't look if you wanted to.

In 1940 Denmark was occupied by the Germans, and Bohr fled by fishing boat to Sweden. When he escaped, he carried with him his Nobel medal made of gold, which he had melted down in order to carry it inconspicuously. After the war he had the medal recast to its original form.

From Sweden, Bohr came to the United States where he participated in the Los Alamos atomic bomb project.

He helped organize the first United Nations Atoms-for-Peace Conference in Geneva in 1955 and received the first Atoms-for-Peace award 2 years later.

Scientific Achievements

Bohr showed an early talent for physics. At the age of 22 he won a gold medal for determining the surface tension of water.

Working with Rutherford, Bohr studied that scientist's nuclear model of the atom. In 1913 he combined the Rutherford nuclear atom with the quantum theory of Max Planck to explain how atoms emitted and absorbed radiant energy.

Studying the hydrogen atom, he concluded that electrons move in orbits around the atomic nucleus. As long as an electron remains in a given orbit, no energy is radiated. However, if a suitable energy source causes the electron to jump to an orbit of *higher* energy, then the *extra* energy is liberated as a single quantum of light or other electromagnetic radiation.

Each type of radiant energy is transmitted in waves that are in a certain range of frequencies. Bohr tried to derive theoretical equations for calculating the frequencies (or wavelengths) of the lines in the spectrum of the hydrogen atom.

Bohr was unable to apply his theory to *calculate* the spectrum of atoms more complex than hydrogen, but he pointed out that where more electrons existed in the atom, they existed in shells, and the electron content of the outermost shell determined the chemical properties of the atoms of an element.

After Meitner's and Frisch's theory of uranium fission was announced in 1939, Bohr correctly predicted that the isotope, uranium-235, was the fissionable isotope.

Niels and Margrethe Bohr (right) with Lord Rutherford in Rutherford's garden about 1930.

Contribution to Atomic Science

Bohr applied quantum theory to explain the hydrogen spectrum. Later he prepared a scheme for the arrangement of the electrons in various atoms based on their observed spectra.

J. Robert Oppenheimer summed up Bohr's contribution in this way: "Our understanding of atomic physics, of what we call the quantum theory of atomic systems, had its origins at the turn of the century and its great synthesis and resolutions in the nineteen-twenties. It was a heroic time. It was not the doing of any one man; it involved the collaboration of scores of scientists from many different lands, though from first to last the deeply creative and subtle critical spirit of Niels Bohr guided, restrained, deepened, and finally transmuted the enterprise. It was a period of patient work in the laboratory, of crucial experiments and daring action, of many false starts and many untenable conjectures. It was a time of earnest correspondence and hurried conjectures, of debate, criticism, and brilliant mathematical improvisation. For those who participated, it was a time of creation; there was terror as well as exaltation in their new insight. It will probably not be recorded very completely as history. As history, its re-creation would call for an art as high as the story of Oedipus or the story of Cromwell, yet in a realm of action so remote from our common experience that it is unlikely to be known to any poet or historian."

GEORGE VON HEVESY

George von Hevesy (hey'veh-shee), Hungarian-Danish chemist, was co-discoverer of the element hafnium and won the Nobel Prize for chemistry in 1943 for developing radioactive isotopes as laboratory tracers in research on chemical processes. He was born in Budapest, Hungary, on August 1, 1885, and died in Freiburg, Germany, on July 5, 1966.

Biographical Details

Hevesy was educated in Budapest and in Germany. He became a professor in Budapest in 1918 and in 1920 moved to Copenhagen to become a professor there.

In 1926 he moved to Freiburg, Germany, as professor of physical chemistry. In 1943 he became a refugee and fled to Stockholm to teach. The Atoms-for-Peace award was given to him in 1959.

Scientific Achievements

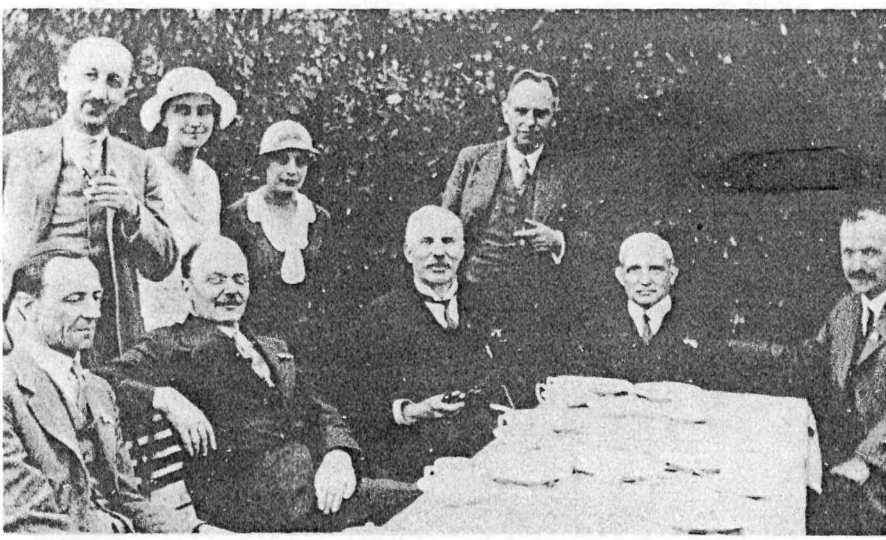
In Copenhagen in 1922 Hevesy studied zirconium minerals with Dirk Coster, using X rays in his research. He discovered element 72 on Mendeléev's Periodic Table and named the newly discovered element hafnium, the Latinized name for Copenhagen.

Hevesy's lifework lay in developing methods of using radioactive isotopes as tracer elements to study chemical processes in the body.

In 1935 when radioactive isotopes of phosphorus became available, he used them to trace physiological and chemical processes of the body. Phosphorus was an isotope that would act like a normal part of living tissue and was not poisonous to humans as were radioactive isotopes of lead, which he had used earlier.

Contribution to Atomic Science

Hevesy's use of a radioactive isotope to study various physiological processes by tracing the course of substances through the body contributed a greater understanding to knowledge of body chemistry. Radioactive tracer techniques have also been applied to increase knowledge of plant and animal growth.



At the Bunsen Congress on Radioactivity in Münster in 1932 are, standing, left to right, George von Hevesy, Mrs. Hans Geiger, Lise Meitner, and Otto Hahn. Seated, left to right, are James Chadwick, Hans Geiger, Ernest Rutherford, Stefan Meyer, and Hans Przibram.

HENRY G.-J. MOSELEY

Henry Gwyn-Jeffreys Moseley, English physicist, was born in Weymouth, England, on November 23, 1887, and died in Gallipoli, Turkey, on August 10, 1915.

Biographical Details

Moseley's father was professor of human and comparative anatomy at Oxford University. He had also served as a naturalist on the ship *Challenger*, which carried the first expedition to study life in the sea.

Moseley won a king's scholarship to Eton at 13. In 1906 he attended Oxford University also on a scholarship. He was accepted as one of Rutherford's staff at Manchester before he graduated from Oxford. In a letter to Rutherford at the time he said, "It will be a great pleasure for me to work in your laboratory and . . . I consider myself very lucky to have got the opening which I coveted. I would like to be guided entirely by you on the subject which I attempt, since until I have had a year or two for reading of a different kind from that useful for [college] examinations, I cannot profitably choose for myself. I will spend August in Oxford, and will then read up Radioactivity in the hope that your suggestion may be in that direction. My present knowledge extends little way beyond your books."

Moseley was 23 and the youngest on the staff. A. S. Russell, another member of Rutherford's team, wrote of Moseley, "I felt that he was so reserved that I could neither like him nor not like him. In the lab we did not realize that he was one of those colts, unrecognized even by his trainers, destined to outstrip the others on the racecourse."

Moseley worked in the laboratory until 1913 when he was awarded a fellowship, which allowed him to give up lecturing and give all his time to research. He left Manchester and went to work at the Electrical Laboratories in Oxford.

When World War I broke out, Moseley enlisted in the British Army. In 1915 he was killed at Gallipoli, Turkey, at the age of 27. Robert Millikan, an American physicist, wrote of his death, "In a research which is destined to rank as one of the dozen most brilliant in the history of science a young man twenty-six years old threw open the windows through which we can glimpse the sub-atomic world with a definiteness and certainty never dreamt of before. Had the European War had no other result than the snuffing out of this young life, that alone would make it one of the most hideous and most irreparable crimes in history. . . ."

Scientific Achievements

Moseley's main research centered around the X-ray spectra of the elements. He discovered that the X-ray wavelengths became smaller as the atomic weight of the elements that emitted them became larger. He thought that this was due to the fact that the number of electrons increased as the atomic weight grew larger and to the growing amount of positive charge. Later this charge was discovered to be due to the number of protons, which are positively charged, in the nucleus.

Moseley arranged Mendeléev's periodic chart in order of the charge of the nucleus. This charge was the number of protons in the nucleus and was later called the atomic number. In the old table a number of elements might separate elements next to each other. With the new arrangement the atomic number had to be a whole number and therefore no intervening elements could exist. Also with Moseley's X-ray process, the undiscovered elements could be placed in the table. When new elements were announced, the Moseley technique could be used to verify or refute them.

Contribution to Atomic Science

His development of the atomic number system of arranging and identifying elements was a major step in element research. Professor Georges Urbain of the University of Paris wrote of Moseley, "I was most surprised, on my visit to Oxford, to find a very young man capable of doing such remarkable work . . . . Moseley's law, for the end as well as for the beginning of the group of rare earths, has established in a few days the conclusions of my efforts of 20 years of patient work. However, it is not only that which makes me admire Moseley's work. His law replaced the somewhat imaginative classification of Mendeléev with one which was scientifically precise. It brought something definite into a period of hesitant research on the chemical elements. It ended one of the finest chapters in the history of science."

GUSTAV HERTZ

Gustav Hertz, German physicist, was born in Hamburg, Germany, on July 22, 1887.

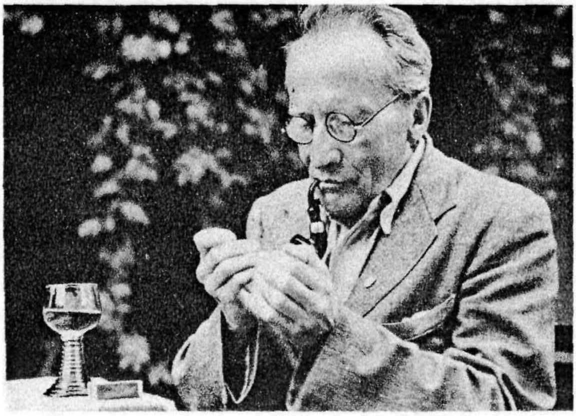
Biographical Details

Hertz studied physics and won his doctorate at the University of Berlin. He was appointed as an assistant there in 1913 but World War I intervened. He fought and was severely wounded in battle.

After the war, he became a physics professor, and from 1928 until 1934 taught at Berlin University. During the 1930s the Nazi takeover in Germany forced him to resign since he was Jewish, but he remained in Germany during the war. When the Russians marched into Berlin in 1945, they took Hertz to the Soviet Union and to East Germany. There at the University of Leipzig he became a professor of physics.

Scientific Achievements and Contribution to Atomic Science

Hertz and James Franck received the Nobel Prize in physics in 1925 for experiments testing Planck's quantum theory and laws for electron-atom collisions. See pages 15 and 16 for a description of this work.



ERWIN SCHRÖDINGER

Erwin Schrödinger (shroi-ding-er), Austrian physicist, shared the Nobel Prize in physics in 1933 with P. A. M. Dirac for their new atomic theory, including wave mechanics and prediction of the positron. He was born on August 12, 1887, in Vienna, Austria, and died there on January 4, 1961.

Biographical Details

Schrödinger was educated at the University of Vienna. When World War I broke out, he fought as an artillery officer and then settled in Germany after the war.

He taught physics at several universities and in 1927 succeeded Max Planck as professor of theoretical physics at the University of Berlin.

When the Nazis rose to power in Germany in the early 1930s, Schrödinger returned to Austria. While still in Germany he interceded during a Nazi raid on a Jewish ghetto. The Storm Troopers would have beaten him to death if one of them hadn't recognized him and prevented the attack.

When Germany usurped control of Austria, too, Schrödinger fled to Ireland to teach at the Institute of Advanced Studies in Dublin.

In 1956 he returned to Vienna and remained there until his death in 1961.

Scientific Achievements

Schrödinger in his research wanted to combine the Bohr atom model with de Broglie's matter waves. In Schrödinger's model, the electron could exist in any orbit. Around each of these electrons, matter waves spread out in a specified number of wavelengths. Only certain orbits existed. Schrödinger derived the mathematical basis for this idea, and these equations, which are called wave or quantum mechanics.

Contribution to Atomic Science

De Broglie postulated the concept of wave-particle duality for all particles. Based on this idea, Schrödinger expressed the behavior of a particle by a mathematical equation used to describe the behavior of wave motion. By combining this with the quantum theory, the Schrödinger equation of wave mechanics was derived.

The Schrödinger equation has many applications in the study of the behavior of small particles. In particular it was used to explain the spectrum of atomic hydrogen more exactly than Bohr had been able to do and without introducing the assumptions that Bohr had found it necessary to make.

OTTO STERN

Otto Stern, German-American physicist, received the Nobel Prize in physics in 1943 for the molecular ray method and the measurement of the proton magnetic moment by this method. He was born in Sohrau, Germany, on February 17, 1888, and died in Berkeley, California, on August 19, 1969.

Biographical Details

After studying physics at the University of Breslau, Stern went to work under Einstein in 1912. In 1914 he became a professor at the Universities of Frankfurt and Hamburg where he remained until 1933 except for a short military service during World War I.

Along with many other scientists, Stern left Germany in 1933 when Hitler rose to power. He fled to the United States where he accepted a professorship at the Carnegie Institute of Technology in Pittsburgh. In 1945 he was made professor emeritus at Carnegie and retired to Berkeley, California.

Scientific Achievements

Some of Stern's work concerned molecular beams. In a laboratory experiment he watched gases exit from a compartment in a vacuum. They left in a straight line because there were no other molecules with which they could interact.

Because these molecules contain negatively and positively charged particles, Stern noted that they acted like little magnets.

Contribution to Atomic Science

Stern's important work, done in conjunction with Gerlach, was to prove that the atomic magnets can only take up certain specific directions in a magnetic field. This was required by the quantum theory of the electron, whereas classical theory permitted all directions. In other words Stern proved that certain atoms behaved like very small magnets which pointed in particular directions in a magnetic field.

JAMES CHADWICK

James Chadwick, English physicist, won the 1935 Nobel Prize in physics for his discovery of the neutron. He was born in Manchester, England, on October 20, 1891.

Biographical Details

Chadwick graduated from the University of Manchester in 1911. He worked with Rutherford at Manchester and received his Master of Science degree there. On a scholarship he went to Germany to study under Hans Geiger. Because of World War I he was interned in Germany until the war ended.

In 1919 he went to the Cavendish Laboratory to work with Rutherford again. In 1923 he became assistant director of research at the laboratory and in 1935 he went to the University of Liverpool as professor of physics.

In World War II he worked on the Manhattan Project in the United States. He returned to England in 1948 to become master of Gonville and Caius College at Cambridge University.

Scientific Achievements

In 1931 Chadwick began the experiments that were to result in the discovery of the neutron. Frédéric and Irène Joliot-Curie had reported that when beryllium was bombarded with alpha particles, the resulting radiation from the beryllium could cause protons to be emitted from paraffin wax or anything else that contained hydrogen. The kind of radiation produced was unknown, but Chadwick concluded that the alpha particles were ejecting neutral particles that were causing the protons to be emitted from the paraffin.

Chadwick then performed the Joliot-Curie experiments and analyzed the results using the Geiger counter, the high-pressure ionization chamber, and the expansion chamber. With these instruments he discovered the neutron in 1932.

Contribution to Atomic Science

The discovery of the neutron was of great importance since this particle was to be used several years later to initiate a chain reaction.

ARTHUR H. COMPTON

Arthur Holly Compton, American physicist, won the Nobel Prize in physics in 1927 for his discovery of the Compton effect in X-ray research. He was born in Wooster, Ohio, on September 10, 1892, and died in Berkeley, California, on March 15, 1962.

Biographical Details

Compton went to school in Wooster, Ohio, and received his Ph.D. at Princeton University. In 1919 he went to Cambridge University to work with Rutherford. He became head of the physics department at Washington University in St. Louis, Missouri, in 1920. In 1923, he went to the University of Chicago to serve as chairman of the physics department and dean of the division of the physical sciences.

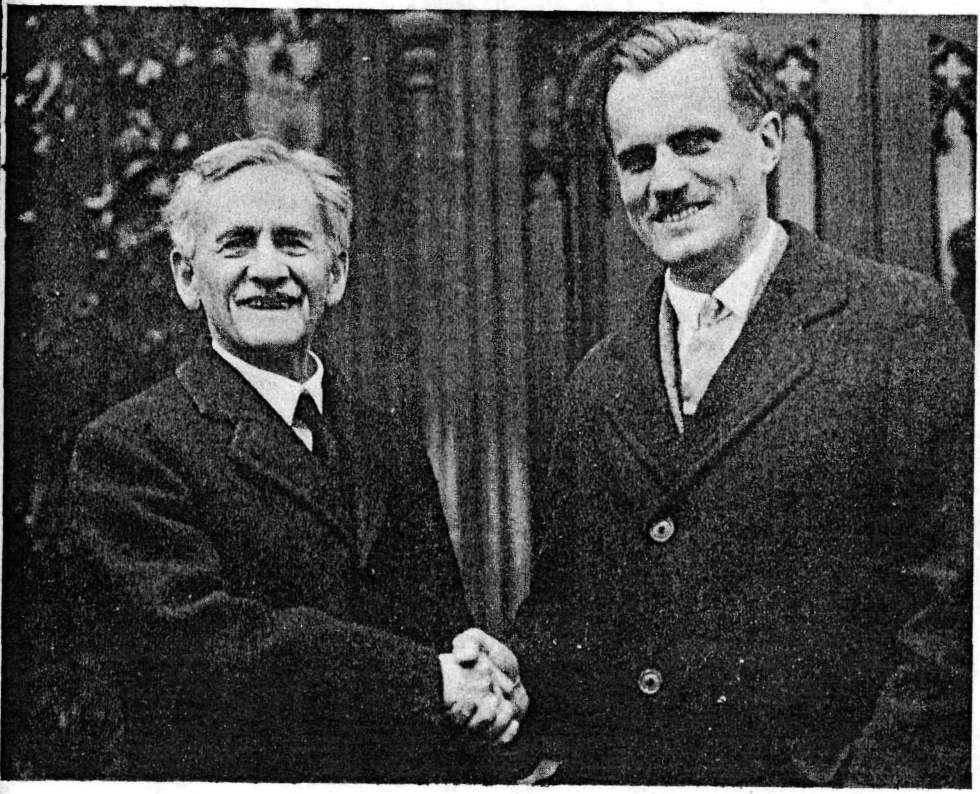
Later he returned to Washington University, serving as chancellor from 1945 to 1953. At that time, he became special professor of natural philosophy. He retired to Berkeley, California, in 1961.

Scientific Achievement

At the University of Chicago, Compton performed research on the scattering of X rays and measured their wavelengths. He found that some of the X rays had increased in wavelength after being scattered. This phenomenon was named the Compton effect after its discoverer.

The change in quality of the radiation depended on the angle through which the rays were scattered, and the change was found to be greater for larger angles.

Compton said that radiation had a corpuscular nature in which each photon or quantum possessed momentum as well as



Albert A. Michelson, the American physicist, with Compton about 1931.

energy. He proposed that when an X ray was scattered, it shared its energy and momentum with an electron.

Then Compton presented a theory that X rays were corpuscular photons or quanta, which was similar to the ideas in Einstein's explanation of the photoelectric effect.

Compton presented a theory to physicists who had believed in the wave properties of radiation. As quantum mechanics developed, it was found that radiation and matter as well possess both wave and particle aspects.

Contribution to Atomic Science

The Compton effect brought important new knowledge to the field of physics. Now scientists would increasingly realize that electromagnetic radiation had both a particle and a wave aspect.

LOUIS VICTOR DE BROGLIE

Prince Louis Victor de Broglie (broh-glee), French physicist, won the Nobel Prize for discovering the wave nature of electrons. He was born in Dieppe, Seine-Marne, on August 15, 1892.

Biographical Details

De Broglie descended from a family of the French nobility. He was educated in history at the Sorbonne. After serving in World War I, he became interested in science and worked in the field of theoretical physics. After World War II, he served as advisor on atomic energy to the French Government.

Scientific Achievements

The year before he received his Ph.D., de Broglie made his significant contribution to nuclear physics. He studied the inconsistencies of the quantum theory of radiation. On the one hand the particle theory could not be entirely accepted because of the wave characteristics of the particle. On the other hand the wave theory could not be accepted completely because of the particle characteristics.

So, using the Einstein mass-energy formula and Planck's frequency energy formula, he demonstrated that there is a wave accompanying every particle and vice versa. The wavelength of these matter waves is related to the momentum of the particle which is related to its mass and velocity. De

Broglie derived an equation that illustrated this relationship.

Contribution to Atomic Science

De Broglie's wave-particle theory was the beginning of wave mechanics which was to change the physicist's idea of matter.

HAROLD C. UREY

Harold Clayton Urey, American chemist, won the 1934 Nobel Prize in chemistry for his discovery of heavy hydrogen. He was born in Walkerton, Indiana, on April 29, 1893.

Biographical Details

Urey attended rural schools in Indiana and taught in them from 1911 to 1914. Then he attended Montana State University and graduated with a B.S. degree. After working for 4 years, he returned to school and earned his Ph.D. at the University of California at Berkeley.

For 5 years Urey served as associate professor at Johns Hopkins University and then as professor at Columbia University from 1929 until 1945. During that time, he won the Nobel Prize in physics in 1934 and assisted on the wartime Manhattan Project to develop the atomic bomb.

In 1945 he moved to the new Institute for Nuclear Studies of the University of Chicago. In 1952 he returned to his alma mater to become a professor at the University of California.

Scientific Achievements

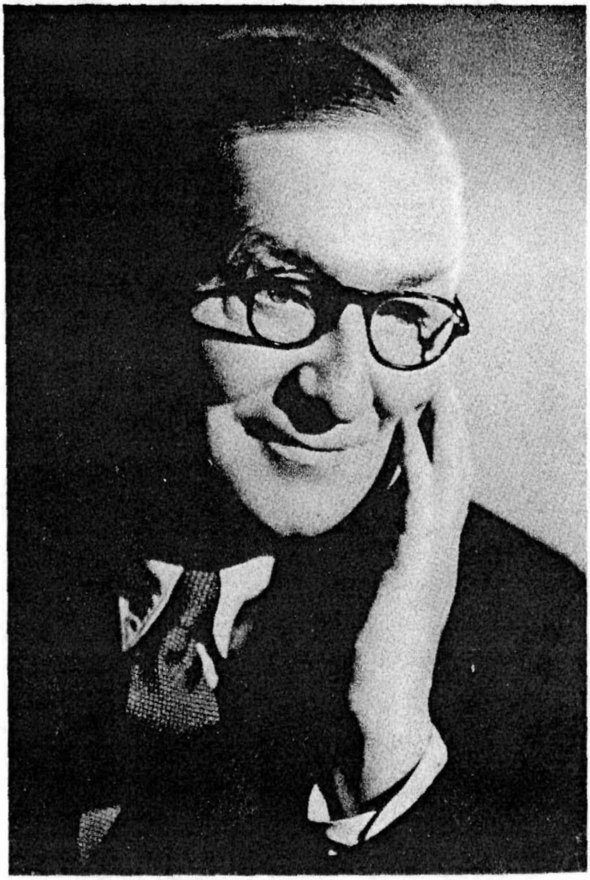
In 1931 Urey became interested in finding a form of hydrogen with atoms twice the mass of ordinary hydrogen, or heavy hydrogen. He decided that there should be differences in the vapor pressures of hydrogen and its heavy isotope. He distilled liquid hydrogen in order to investigate the spectral lines of the electrons, and discovered the heavy isotope of hydrogen, which he named deuterium. This isotope of hydrogen is twice as heavy as ordinary hydrogen and is a component of "heavy water".

Urey learned how to separate isotopes of different elements and discovered that heavier isotopes reacted more slowly than lighter ones. He used this knowledge to devise new techniques to prepare heavy isotopes such as carbon-13 and nitrogen-15.

After the war Urey applied his knowledge of isotopes to the study of geophysics and geochemistry. He proposed a method for calculating the temperatures of ancient oceans and prepared a table that gave an idea of origins of elements and the abundance of elements in the sun and stars.

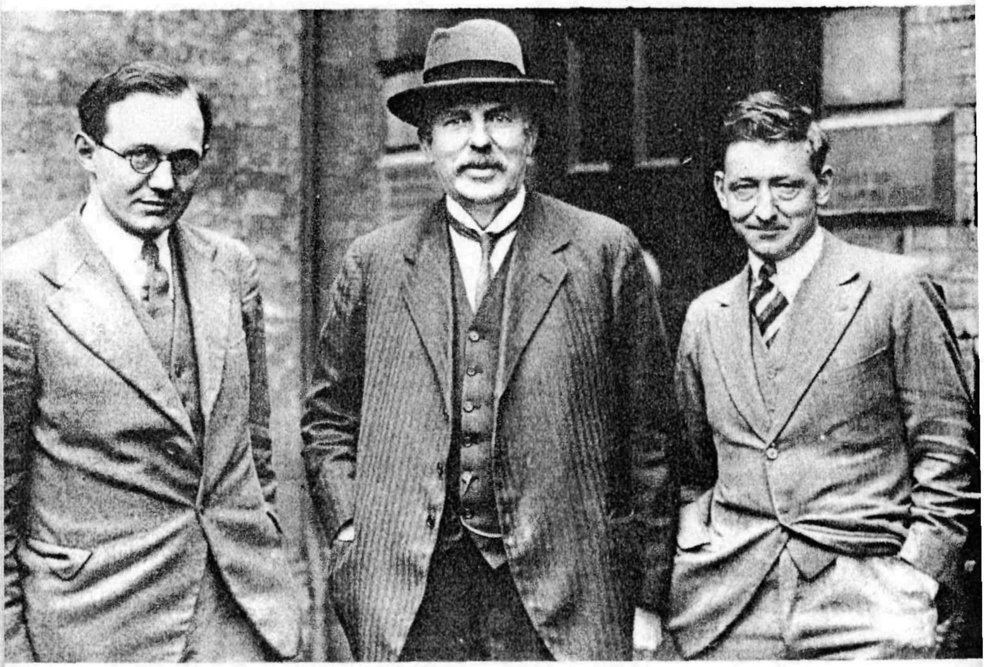
Contribution to Atomic Science

Urey's discovery of the isotope deuterium led directly to the post-war development of the hydrogen bomb.



JOHN D. COCKCROFT

John Douglas Cockcroft, British physicist, shared the 1951 Nobel Prize in physics with E. T. S. Walton for transmutation of atomic nuclei with artificially accelerated atomic particles. He was born in Todmorden, Yorkshire, on May 27, 1897, and died on September 18, 1967.



Inventors of one of the first accelerators, Ernest T. S. Walton, left, and John D. Cockcroft, right, with Lord Rutherford, at Cambridge University in the early 1930s.

Biographical Details

Cockcroft went to Manchester University and graduated with a degree in engineering. He served with the Royal Field Artillery in World War I and then attended Cambridge University where he received a Ph.D. degree.

During World War II, he directed the Air Defence Research and Development Establishment. He became head of the Canadian Atomic Energy Project in 1944 and 2 years later became director of the Atomic Energy Research Establishment at Harwell, England. In 1954 he was research member of the United Kingdom Atomic Energy Authority.

In 1959 be became master of Churchill College at Cambridge University. Later he was chosen as chancellor of the Australian National University at Canberra.

He was knighted in 1948 and received the Atoms-for-Peace award in 1961.

Scientific Achievement

When Cockcroft went to work for Rutherford in the Cavendish Laboratory, he devised an instrument that would accelerate protons to great speeds. He bombarded the lithium atom with a beam of these protons. The lithium nucleus absorbed the proton to form an unstable nucleus that broke up into two helium nuclei. He and his assistant Ernest Walton had thus formed helium by using artificially accelerated particles.

Contribution to Atomic Science

Cockcroft's pioneering work on an artificially produced nuclear reaction aided greatly in the development of atomic knowledge.

PATRICK M. S. BLACKETT

Patrick Maynard Stuart Blackett, English physicist, was awarded the 1948 Nobel Prize in physics for his method of photographing the positron. He was born in London on November 18, 1897.

Biographical Details

Intending to make a career in the British Navy, Blackett entered naval school at the age of 13. But after serving at sea in World War I, he resigned from the Navy and attended Cambridge University. There he studied under Rutherford and worked on cloud chamber improvements in the 1920s and 1930s.

In the mid-thirties he became a professor of physics at the University of Manchester and established an internationally known school of cosmic-ray research. Through his interest, the Jodrell Bank Observatory for radioastronomy was built.

During World War II he helped develop radar and the atomic bomb.

Scientific Achievement

Blackett developed and improved the Wilson cloud chamber into an automatic device for studying nuclear disintegration. Bombarding nitrogen in the cloud chamber with alpha particles, he took over 20,000 photographs of the tracks of the particles. Just a few of the pictures showed the collision of an alpha particle with a nitrogen particle, which indicated the correctness of Rutherford's belief of transmutation during the process.

Blackett used the cloud chamber and Geiger counters to show that gamma rays sometimes disappear when passing through lead, producing a positron and an electron. This showed for the first time the conversion of energy into matter and confirmed Einstein's equation of $E = mc^2$.

Contribution to Atomic Science

Blackett's improvement of the cloud chamber as an effective instrument to study nuclear disintegration provided significant knowledge to the field of cosmic-ray and nuclear research.

ISIDOR I. RABI

Isidor Isaac Rabi (rah'bee), Austrian-American chemist, received the 1944 Nobel Prize in physics for the resonance method of measuring nuclear magnetic properties. He was born in Rymanow, Austria, on July 29, 1898.

Biographical Details

Rabi was brought to the United States as a baby. He received a degree in chemistry from Cornell University and studied for 2 years with various European physicists. In 1929 he was appointed professor at Columbia University and he remained there until just before World War II.

In 1940 he was chosen as associate director of the Radiation Laboratory at Massachusetts Institute of Technology where he helped develop microwave radar. In 1945 he returned to Columbia and helped the physics department grow into a pioneering group in the field of high-energy physics. In 1964 he became that university's first University Professor, which is a professorship without departmental connections.

In 1955 he assisted in the organization of the United Nations conference on peaceful uses of atomic energy. He served as chairman of the advisory committee to the Atomic Energy Commission from 1952 to 1956 and served on the United Nations Science Committee.

Scientific Achievements

As the field of nuclear physics became more complex, there was a demand for more precise accuracy. The knowledge of nuclear forces and models required accurate measurement, especially of the magnetic moment of the nucleus.

In previous methods a magnetic field was kept in a small space between the poles of magnets. The atomic beam was therefore in the field for only a brief time. Rabi improved on this by arranging long wires, which produced electric currents, and which ran along the beam's direction. Thus the beam was in contact with the field for a longer period. Rabi also used other magnetic fields that could be changed in many ways. This addition eventually produced the development of the molecular-beam resonance method, which measured the sizes and signs of the moments very accurately.

Contribution to Atomic Science

The molecular-beam resonance technique for measuring nuclear magnetic moments was a considerable impetus to the development of more accurate nuclear models and to theoretical physics in general.

LEO SZILARD

Leo Szilard (zee'lahrd), Hungarian-American physicist, along with Enrico Fermi, originated the method of arranging graphite and uranium to make possible the first self-sustaining nuclear reactor in 1942. He was born in Budapest, Hungary, on February 11, 1898, and died in La Jolla, California, on May 30, 1964.

Biographical Details

Szilard studied at the University of Berlin and was a professor there during the 1920s. In 1937 after the Nazis took control of Germany, Szilard fled to England and then to America.

There he worked with Enrico Fermi on the Manhattan Project. He became a U. S. citizen in 1943.

He left the field of nuclear physics after the war and became a professor of bio-physics at the University of Chicago in 1946.

He was given the Atoms-for-Peace award in 1959.

Scientific Achievements

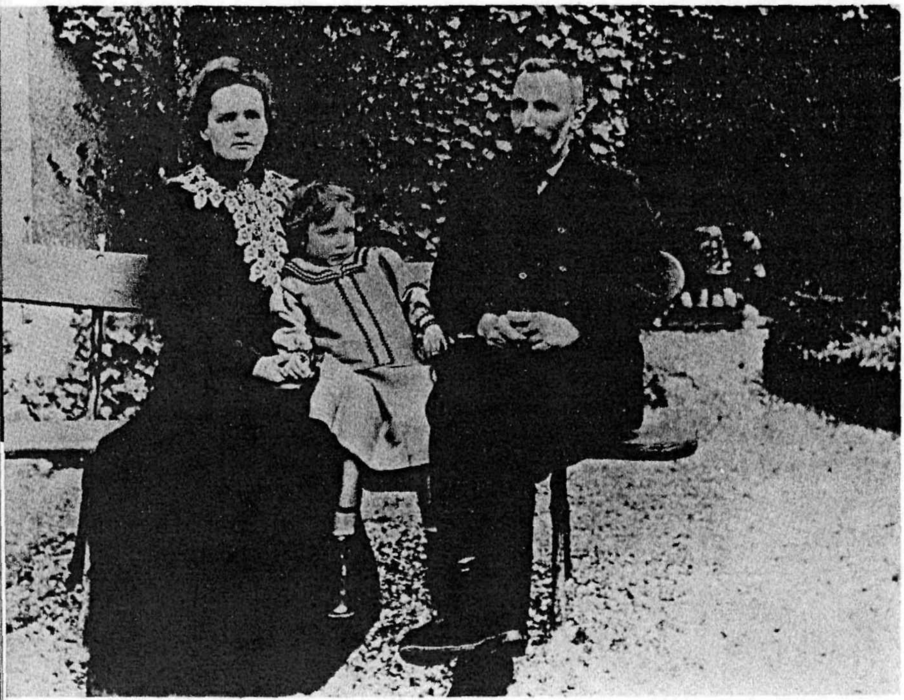
In England in 1934, Szilard conceived the idea of a nuclear chain reaction in which one neutron is captured and two are released, and a quantity of energy is liberated. He applied for a patent, and the idea was classified and assigned to the British Government. His nuclear chain reaction, though correct in its general idea, proved to be impossible because it was based on the use of beryllium, the neutrons of which do not possess the high energy required for the chain to be maintained.

After the theory of nuclear fission was revealed, Szilard realized how vital it was to develop an atom bomb before Germany could manufacture one. He and Eugene Wigner, a fellow scientist, persuaded Einstein to sign a letter to President Franklin D. Roosevelt which caused the President to initiate the development of the bomb.

He worked with Fermi to develop a self-sustaining nuclear reactor using graphite to slow neutrons down so they could be more readily captured.

Contribution to Atomic Science

Szilard contributed the idea of the first nuclear chain reaction to atomic science. He went on to actually produce the chain reaction for the first time in a nuclear reactor in 1942.

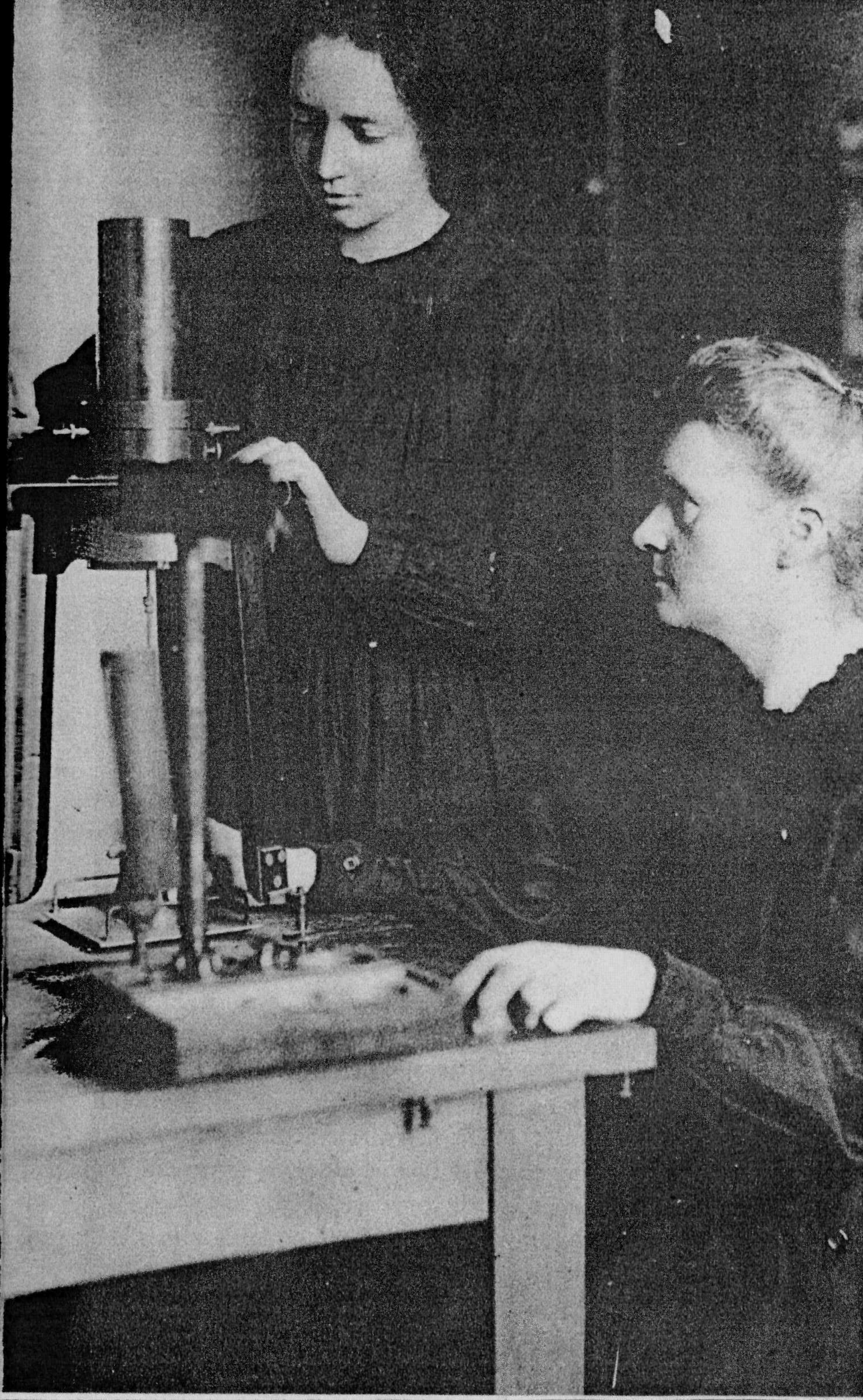


Irène Curie with her parents, Pierre and Marie Curie, in 1904.

JEAN FRÉDÉRIC JOLIOT-CURIE AND IRÈNE JOLIOT-CURIE

The husband-and-wife team of Frédéric and Irène Joliot-Curie won the Nobel Prize in chemistry in 1935 for the discovery of new radioactive elements prepared artificially. Jean Frédéric Joliot (zhoh-lyoh) was born in Paris on March 19, 1900, and died there on August 14, 1958. His wife, Irène Curie, was born in Paris on September 12, 1897, and died there on March 17, 1956.

Irène and her mother in a laboratory in 1925.



Biographical Details

Joliot-Curie obtained an engineering degree in 1923, and in 1925 he took the job of special assistant to Marie Curie. There he met Irène, the elder daughter of the Curies, who

Frédéric Joliot-Curie

worked as her mother's assistant. The two young scientists were married in 1926, and Joliot added his wife's name to his at that time. He did this in order to perpetuate the famous Curie name since Pierre and Marie had no son.

The Joliot-Curies worked as a scientific team. He had been appointed to the staff of the Radium Institute in 1925, and he later became a professor there. In the 1920s the two conducted research on radioactivity at the institute.

During World War II, the Joliot-Curies remained in France and helped organize French Resistance* movements. In 1946, Frédéric was appointed French high commissioner for atomic energy. In 1950 he resigned from this post.

Scientific Achievements

The Joliot-Curies almost won in two narrow races of scientific discovery. The first was when Chadwick discovered the neutron in 1932 and the next was when Anderson announced the discovery of the positron in 1933. Each time the Joliot-Curies were close behind.

But they won their next race when they contributed the knowledge of how to produce radioactivity in elements that did not normally possess radioactive properties.

In 1934 they bombarded boron, aluminum, and magnesium with alpha particles and found that after the bombardment was stopped, radiation continued. In bombarding aluminum, they produced phosphorus in a form that created an isotope which did not occur in nature and was radioactive. This

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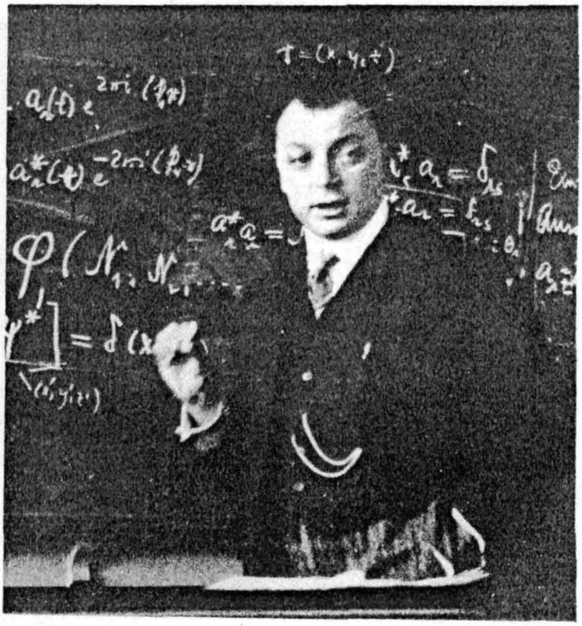
*This was an underground organization whose aim was to oust the German invaders. The Resistance methods included sabotage and other secret operations to wear down occupation forces.

isotope of phosphorus kept on breaking down and emitting radiation.

The Joliot-Curies had discovered how to produce radioactivity in elements not exhibiting radioactivity in their natural state by producing an isotope of the element artificially.

Contribution to Atomic Science

The discovery of how to produce radioactive isotopes by artificial means was a great contribution to atomic studies. Since the first one was produced by the Joliot-Curies, many other isotopes have proved valuable to medical research and industry.



Wolfgang Pauli lecturing in Copenhagen in April 1929.

WOLFGANG PAULI

Wolfgang Pauli, Austrian-American physicist, contributed to atomic studies his exclusion principle which stated that no two electrons in an atom can occupy exactly the same energy state. For this concept he was awarded the Nobel Prize in physics in 1945. He was born in Vienna, Austria, on April 25, 1900, and died in Zurich, Switzerland, on December 15, 1958.

Biographical Details

At the tender age of 19, he was asked by his physics professor at the University of Munich to write the relativity theory article for an encyclopaedia. After Einstein read this article he wrote: "Whoever studies this mature, and grandly conceived work, can hardly believe that the author is a twenty-one-year-old man. One hardly knows what to admire and wonder at most, the psychological understanding of the development of the ideas, the sureness of the mathematical deductions, the deep physical insight, the capacity for a systematic, clear exposition, the knowledge of the literature, the completeness of the treatment, the sureness of the critical appraisal."

Pauli obtained his doctor's degree at the University of Munich in 1921. He studied with Born and Bohr and then became a professor at the University of Hamburg in 1923. In 1928 he became a professor at the Federal Institute of Technology in Zurich, and under his direction it became a great center of research.

From 1935 to 1954 Pauli was a visiting professor at the Institute for Advanced Study at Princeton, New Jersey. He became an American citizen in 1946.

Scientific Achievements

Before Pauli's time, it had been difficult to show how the electrons were arranged about the nucleus in atoms with more than two electrons. The energy levels of electrons had been computed earlier and were denoted as three quantum numbers. Pauli assigned a fourth quantum number and he showed a way of assigning positions to the electrons of each atom in Mendeléev's Periodic Table so that only two electrons could move along in the same energy state if their spins were in opposite directions.

In accounting for the disappearance of energy in ordinary radioactive decay accompanied by the emission of beta particles, Pauli suggested the existence of the neutrino in 1931. This subatomic particle was detected many years later.

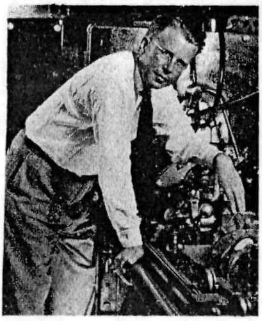
Contribution to Atomic Science

Pauli's idea that no two electrons can occupy the same energy state in an atom made it possible to completely explain the position of elements of Mendeléev's Table. The exclusion principle forms a substantial part of the foundation for quantum mechanics and contemporary physics.

His hypothesis, later proved correct, of the existence of a tiny but vastly important particle, the neutrino, gave increased knowledge of the atom in the 1930s.

Pauli and the physicist Paul Ehrenfest share a joke on the ferry to Copenhagen in 1929.

ERNEST O. LAWRENCE



Lawrence stands in fro of the ion source of t 184-inch cyclotron 1948.

Ernest Orlando Lawrence, American physicist, won the 1939 Nobel Prize in physics for the invention of the cyclotron and some experiments on radioactive elements made with it. He was born in Canton, South Dakota, on August 8, 1901, and died in Palo Alto, California, on August 27, 1958.

Biographical Details

Lawrence came from a family of Norwegian descent and grew up in a small South Dakota town where his father was superintendent of schools. He studied at St. Olaf's College in Minnesota, at the state university, and received a Ph.D. degree from Yale University in 1925.

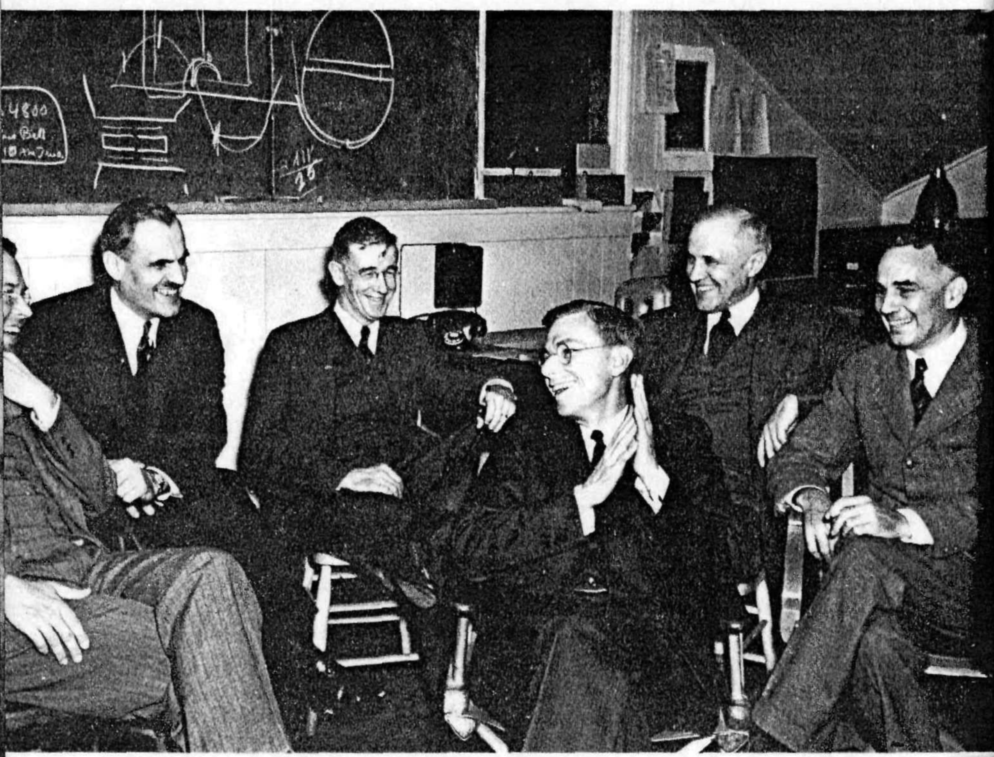
In 1928 he joined the faculty at the University of California at Berkeley. In 1930 he invented the cyclotron, and in 1936 he became director of the Radiation Laboratory.

During World War II he worked on the Manhattan Project and advised the government on atomic energy during the postwar years.

Scientific Achievements

In 1931 accelerators for bombarding atomic nuclei had been developed by Cockcroft and Robert Van de Graaff. In 1930 Lawrence developed his own idea for the cyclotron, which would have charged particles

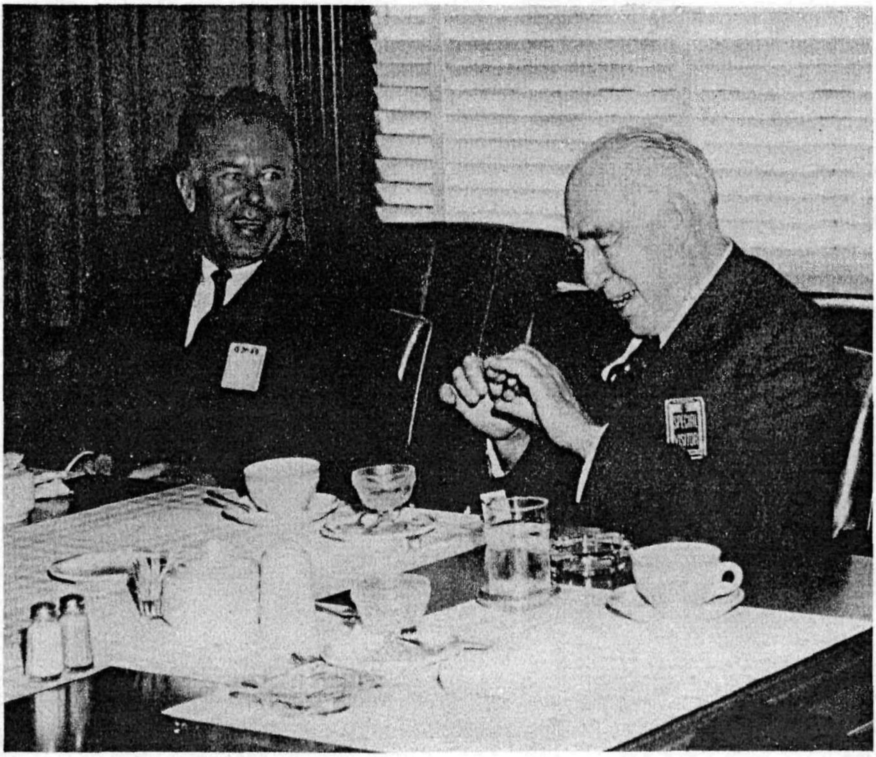
Ernest O. Lawrence holds a model of the cyclotron in 1930, a year after its conception.



Discussing the proposed giant cyclotron at Berkeley, California, in April 1940, are, left to right, Ernest O. Lawrence, Arthur H. Compton, Vannevar Bush, James B. Conant, Karl T. Compton, and Alfred Loomis.

move in a spiral path and give the passing ions an electrical "kick" to speed them up each time they passed a certain cross line. They would thus whirl faster and faster, reaching very high speeds and high voltage and, when finally shot at a target, would act like atomic bullets. He built a small demonstration cyclotron in 1931 and other more powerful ones were developed from this model.

After the Japanese attack on Pearl Harbor, he worked with other top scientists to separate the isotope uranium-235 from

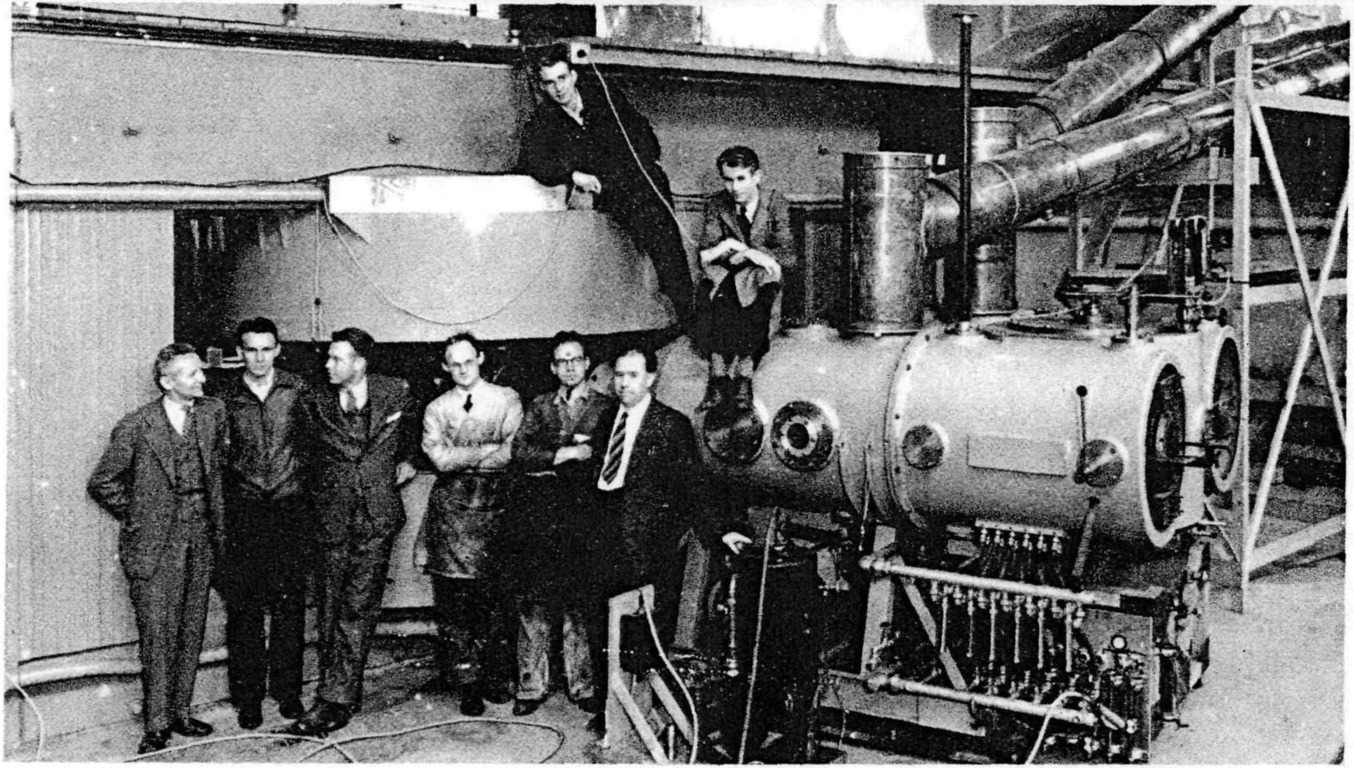


Lawrence with Niels Bohr.

uranium-238 to achieve an atomic bomb explosion. After the war, he and his associates developed increasingly more powerful accelerators for the purpose of nuclear bombardment.

Contribution to Atomic Science

The cyclotron has been used to determine nuclear energy states, binding energy of nuclei, creation of new particles, etc. Essentially it is used to determine the nature of the nucleus and to generate subnuclear particles and to study these particles as the building blocks of matter.



The 60-inch cyclotron at the Lawrence Radiation Laboratory soon after its completion in 1939. Key figures in the development of the machine are: standing, left to right, Donald Cooksey, Dale Corson, Ernest O. Lawrence, Robert Thornton, John Backus, and Winfield W. Salisbury. Top, right, are Luis W. Alvarez and Edwin M. McMillan. Alvarez leans against part of the magnet and half sits on the housing for the coils; McMillan sits on one of the tanks holding the dees inside the accelerating chamber. The copper cylinders slanting down from right carry power for the accelerating system.

The control panel of the 60-inch cyclotron shortly after it began operating in 1939. In the foreground is Ernest Lawrence, the cyclotron's inventor. With him is his brother Dr. John Lawrence.

ENRICO FERMI

Enrico Fermi (fehr-mee), Italian-American physicist, received the 1938 Nobel Prize in physics for identifying new elements and discovering nuclear reactions by his method of nuclear irradiation and bombardment. He was born in Rome, Italy, on September 29, 1901, and died in Chicago, Illinois, on November 28, 1954.

Biographical Details

As a young school boy in Rome, Fermi was already interested in mathematics and experimental physics. He graduated from the University of Pisa with a doctorate in 1922 and went to the University of Göttingen to study with Max Born.

In 1924 he became a faculty member at the University of Florence and from 1927 to 1938 was professor of physics at the University of Rome.

Because he was not in sympathy with the Fascists and because of the increasing persecution of Jews under this regime (Mrs. Fermi is Jewish), the Fermis left Italy in 1938. In 1939 he became professor at Columbia University. He then worked upon nuclear chain reactions at the University of Chicago and after the controlled chain reaction was achieved on December 2, 1942, he moved to Los Alamos, New Mexico, to help develop an atomic bomb.

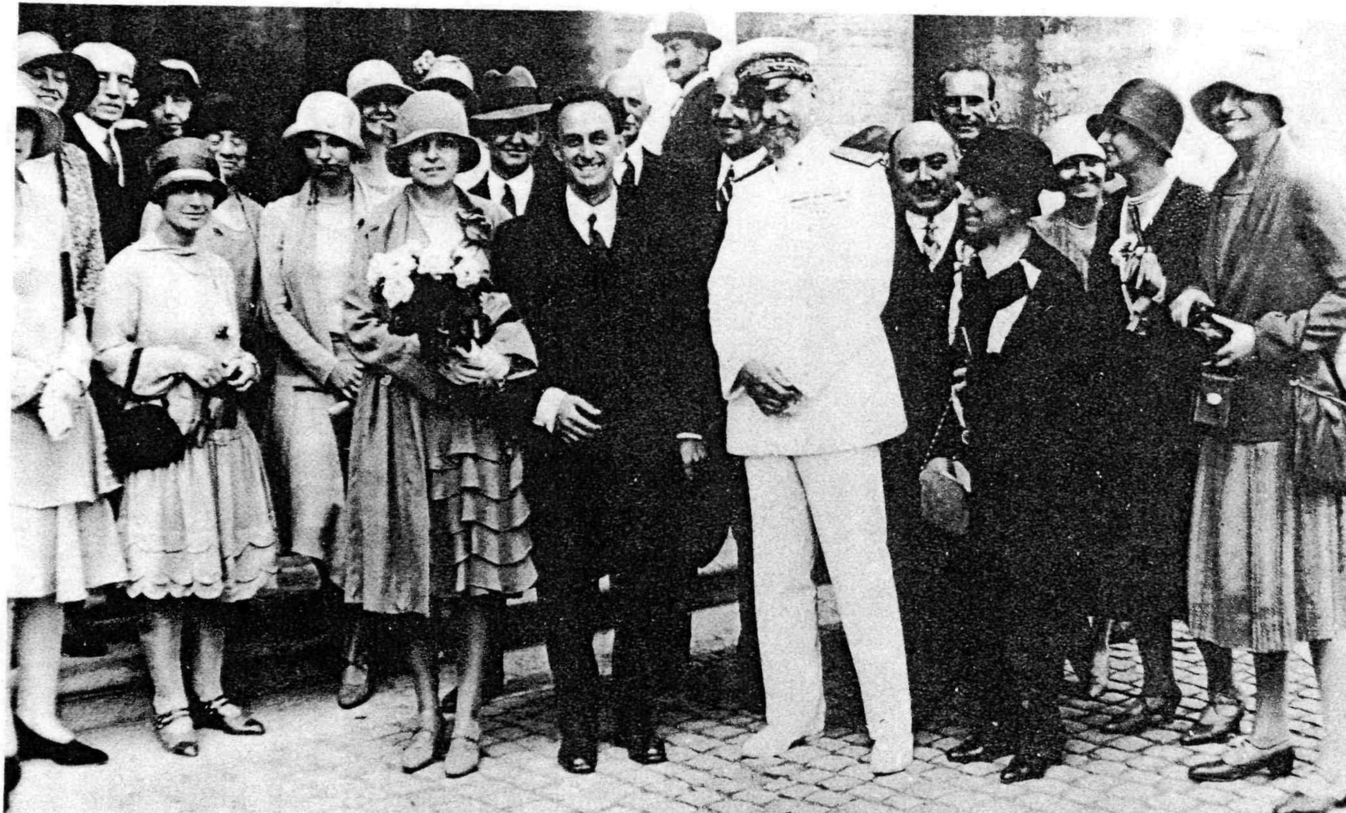
After the war he returned to Chicago to the newly created Institute for Nuclear Studies, which was later named after him. The

Enrico Fermi (4 years old) stands between his brother Giulo and his sister Maria.

element with atomic number 100 was named fermium in his honor shortly after his death in 1954.

Scientific Achievements

In the 1930s Fermi used thermal neutrons to bombard the nucleus. The thermal neutrons were formed by passing them through water or paraffin. Some of the neutrons' energy was removed and so they moved at a slower speed. They were thus absorbed more readily by the nucleus. He used these neutrons to bombard uranium while trying to create a transuranium element, i.e., an element above uranium in the periodic table.



Laura and Enrico Fermi at their wedding in 1928. The Naval officer is Mrs. Fermi's father and her mother is second from right.

Niels Bohr and Fermi discuss physics as they walk along the Appian Way outside Rome in 1931.

Unwittingly he had been experimenting with uranium fission, but it was not until 1938, when Meitner announced the fission process, that this was known.

After coming to America in 1938, he and Leo Szilard speculated on the possibility of creating a chain reaction with uranium fission. In this reaction a neutron would split an atom releasing energy and more neutrons, which would in turn split more atoms and release more energy and more neutrons, etc. An enormous amount of energy could thus be produced.

When the Manhattan Engineer District was formed during World War II, Fermi led the group that built the first nuclear reactor. The work took place at the University of Chicago. A large pile of uranium metal,

Walter H. Zinn

Herbert L. Anderson

uranium oxide, and graphite blocks was stacked up according to careful specifications. The following excerpt describing this work is taken from the AEC educational booklet *The First Reactor.*

About 8:30 on the morning of Wednesday, December 2nd, the group began to assemble in the squash court beneath the Stagg Field Stadium at the University of Chicago.

At the north end of the squash court was a balcony about ten feet above the floor of the court. Fermi, Walter Zinn, Herbert L. Anderson, and Arthur Compton were grouped around instruments at the east end of the balcony. The remainder of the observers crowded the little balcony. R. G. Nobles, one of the young scientists who worked on the pile, put it this way: "The control cabinet was surrounded by the 'big wheels'; the 'little wheels' had to stand back."

On the floor of the squash court, just beneath the balcony, stood George Weil, whose duty it was to handle the final control rod. In the pile were three sets of control rods. One set was automatic and could be controlled from the balcony. Another was an emergency safety rod. Attached to one end of this rod was a rope running through the pile and weighted heavily on the opposite end. The rod was withdrawn from the pile and tied by another rope to the balcony. Hilberry was ready to cut this rope with an axe should something unexpected happen, or in case the automatic safety rods failed. The third rod, operated by Weil, was the one which actually held the reaction in check until withdrawn the proper distance.

Since this demonstration was new and different from anything ever done before, complete reliance was not placed on mechanically operated control rods. Therefore, a "liquid-control squad," composed of Harold Lichtenberger, W. Nyer, and A. C. Graves, stood on a platform above the pile. They were prepared to flood the pile with cadmium-salt solution in case of mechanical failure of the control rods.

George Weil

Each group rehearsed its part of the experiment.

At 9:45 Fermi ordered the electrically operated control rods withdrawn. The man at the controls threw the switch to withdraw them. A small motor whined. All eyes watched the lights which indicated the rods' position.

But quickly, the balcony group turned to watch the counters, whose clicking stepped up after the rods were out. The indicators of these counters resembled the face of a clock, with "hands" to indicate neutron count. Nearby was a recorder, whose quivering pen traced the neutron activity within the pile.

Shortly after ten o'clock, Fermi ordered the emergency rod, called "Zip," pulled out and tied.

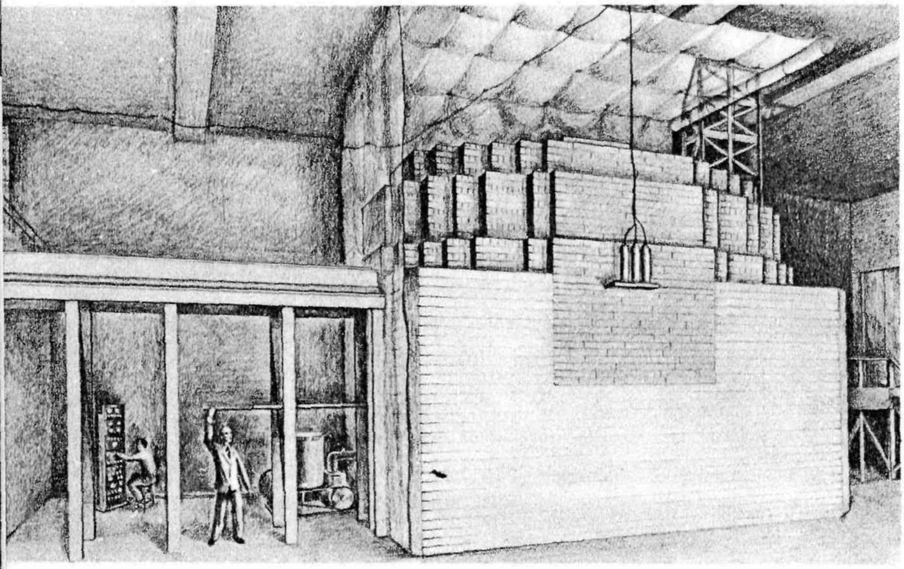
"Zip out," said Fermi. Zinn withdrew "Zip" by hand and tied it to the balcony rail. Weil stood ready by the "vernier" control rod which was marked to show the number of feet and inches which remained within the pile.

Norman Hilberry

At 10:37 Fermi, without taking his eyes off the instruments, said quietly:

"Pull it to 13 feet, George." The counters clicked faster. The graph pen moved up. All the instruments were studied, and computations were made.

"This is not it," said Fermi. "The trace will go to this point and level off." He



indicated a spot on the graph. In a few minutes the pen came to the indicated point and did not go above that point. Seven minutes later Fermi ordered the rod out another foot.

Again the counters stepped up their clicking, the graph pen edged upwards. But the clicking was irregular. Soon it leveled off, as did the thin line of the pen. The pile was not self-sustaining—yet.

At eleven o'clock, the rod came out another six inches; the result was the same: an increase in rate, followed by the leveling off.

Fifteen minutes later, the rod was further withdrawn and at 11:25 was moved again. Each time the counters speeded up, the pen climbed a few points. Fermi predicted correctly every movement of the indicators. He knew the time was near. He wanted to check everything again. The automatic control rod was reinserted without waiting for its automatic feature to operate. The graph line took a drop, the counters slowed abruptly.

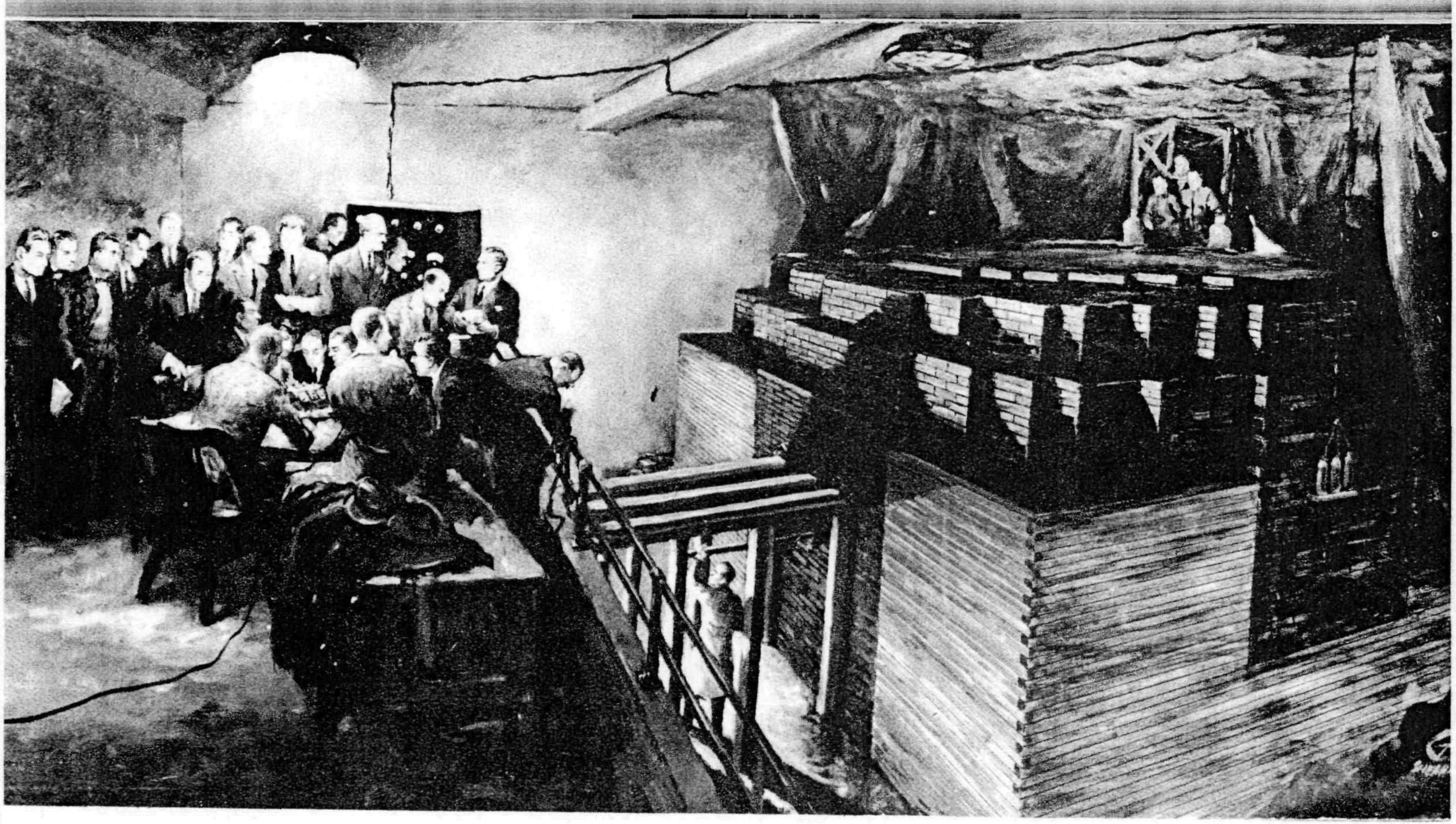
At 11:35, the automatic safety rod was withdrawn and set. The control rod was adjusted and "Zip" was withdrawn. Up went the counters, clicking, clicking, faster and faster. It was the clickety-click of a fast train over the rails. The graph pen started to climb. Tensely, the little group watched, and waited, entranced by the climbing needle.

Whrrrump! As if by a thunder clap, the spell was broken. Every man froze—then breathed a sigh of relief when he realized the automatic rod had slammed home. The safety point at which the rod operated automatically had been set too low.

"I'm hungry," said Fermi, "Let's go to lunch."

Perhaps, like a great coach, Fermi knew when his men needed a "break."

It was a strange "between halves" respite. They got no pep talk. They talked about everything else but the "game." The redoubtable Fermi, who never says much, had even less to say. But he appeared supremely confident. His "team" was back on the squash court at 2:00 p.m. Twenty minutes later, the automatic rod was reset and Weil stood ready at the control rod.



This painting depicts the scene of December 2, 1942, when the first nuclear reactor achieved a self-sustaining chain reaction. The original painting, executed in 1957 by Gary Sheahan, Chicago Tribune *Staff artist, after 4 months of research, is now owned by the Chicago Historical Society.*

"All right, George," called Fermi, and Weil moved the rod to a predetermined point. The spectators resumed their watching and waiting, watching the counters spin, watching the graph, waiting for the settling down and computing the rate of rise of reaction from the indicators.

At 2:50 the control rod came out another foot. The counters nearly jammed, the pen headed off the graph paper. But this was not it. Counting ratios and the graph scale had to be changed.

"Move it six inches," said Fermi at 3:20. Again the change—but again the leveling off. Five minutes later, Fermi called: "Pull it out another foot."

Weil withdrew the rod.

"This is going to do it," Fermi said to Compton, standing at his side. "Now it will become self-sustaining. The trace will climb and continue to climb, it will not level off."

Fermi computed the rate of rise of the neutron counts over a minute period. He silently, grim-faced, ran through some calculations on his slide rule.

In about a minute he again computed the rate of rise. If the rate was constant and remained so, he would know the reaction was self-sustaining. His fingers operated the slide rule with lightning speed. Characteristically, he turned the rule over and jotted down some figures on its ivory back.

Three minutes later he again computed the rate of rise in neutron count. The group on the balcony had by now crowded in to get an eye on the instruments, those behind craning their necks to be sure they would

Leona Woods

know the very instant history was made. In the background could be heard William Overbeck calling out the neutron count over an annunciator system. Leona Marshall (the only girl present), Anderson, and William Sturm were recording the readings from the instruments. By this time the click of the counters was too fast for the human ear. The clickety-click was now a steady brrrrr. Fermi, unmoved, unruffled, continued his computations.

"I couldn't see the instruments," said Weil. "I had to watch Fermi every second, waiting for orders. His face was motionless. His eyes darted from one dial to another. His expression was so calm it was hard. But suddenly, his whole face broke into a broad smile."

Fermi closed his slide rule—

"The reaction is self-sustaining," he announced quietly, happily. "The curve is exponential."

The group tensely watched for twenty-eight minutes while the world's first nuclear chain reactor operated.

The upward movement of the pen was leaving a straight line. There was no change to indicate a leveling off. This was it.

"O.K., 'Zip' in," called Fermi to Zinn who controlled that rod. The time was 3:53 p.m. Abruptly, the counters slowed down, the pen slid down across the paper. It was all over.

Man had initiated a self-sustaining nuclear reaction—and then stopped it. He had released the energy of the atom's nucleus and controlled that energy.

Right after Fermi ordered the reaction stopped, the Hungarian-born theoretical physicist Eugene Wigner presented him with a bottle of Chianti wine. All through the experiment Wigner had kept this wine hidden behind his back.

Fermi uncorked the wine bottle and sent out for paper cups so all could drink. He poured a little wine in all the cups, and silently, solemnly, without toasts, the scientists raised the cups to their lips—the Canadian Zinn, the Hungarians Szilard and Wigner, the Italian Fermi, the Americans Compton, Anderson, Hilberry, and a score of others. They drank to success—and to the hope that they were the first to succeed.

The chianti bottle that Eugene Wigner brought to the gathering on December 2. Many of the scientists autographed the basket. Fermi's signature is just below the label.

A small crew was left to straighten up, lock controls, and check all apparatus. As the group filed from the West Stands, one of the guards asked Zinn:

"What's going on, Doctor, something happen in there?"

The guard did not hear the message which Arthur Compton was giving James B. Conant at Harvard, by long-distance telephone. Their code was not prearranged.

"The Italian navigator has landed in the New World," said Compton.

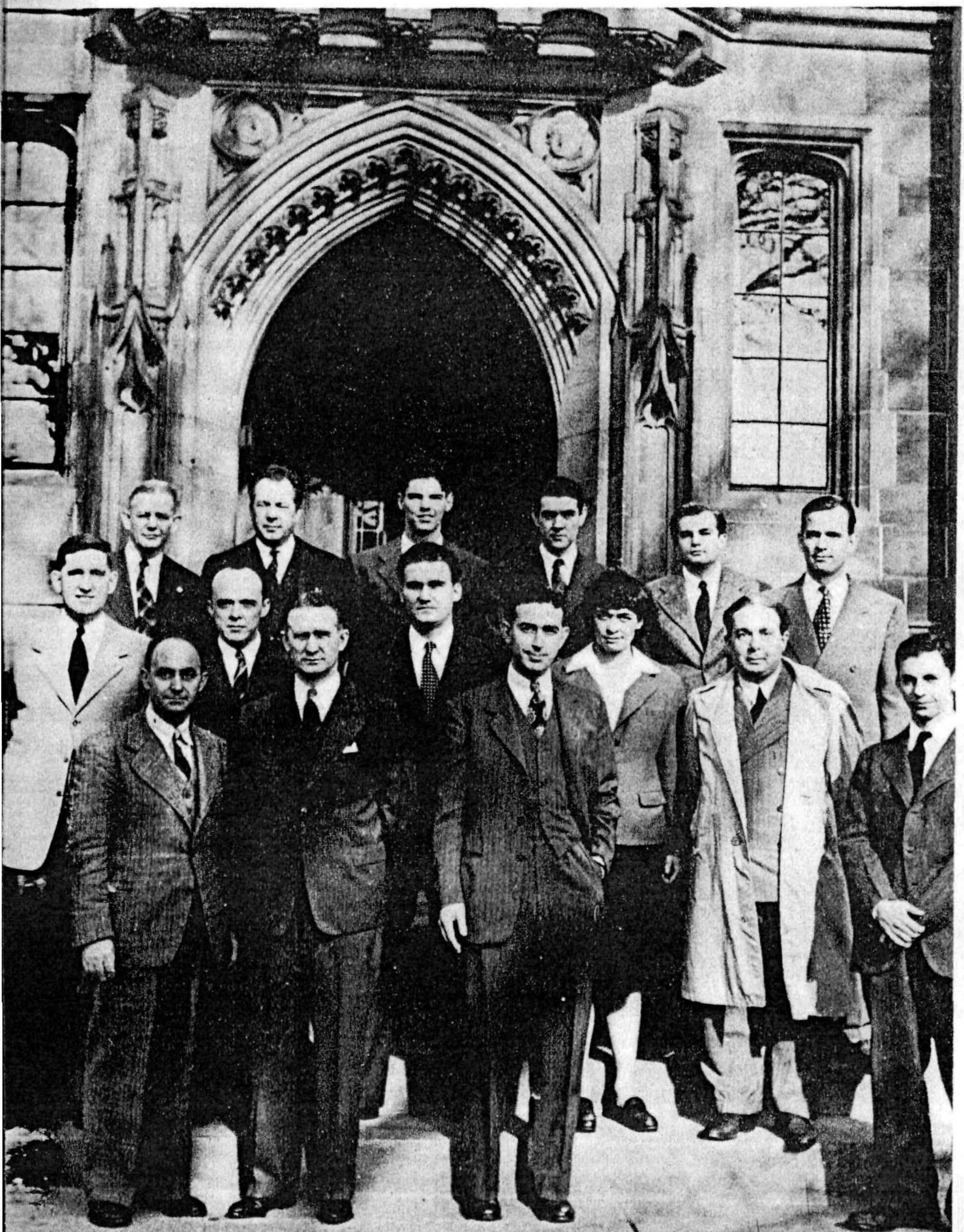
"How were the natives?" asked Conant.

"Very friendly."

Contribution to Atomic Science

Fermi's achievement in setting off the first self-sustaining nuclear chain reaction from his design of an atomic pile led to a new Age of the Atom. The controlled release of nuclear energy was now a reality.

Scientists at the University of Chicago on December 2, 1946, the fourth anniversary of their success. Back row, left to right, Norman Hilberry, Samuel Allison, Thomas Brill, Robert G. Nobles, Warren Nyer, and Marvin Wilkening. Middle row, Harold Agnew, William Sturm, Harold Lichtenberger, Leona W. Marshall, and Leo Szilard. Front row, Enrico Fermi, Walter H. Zinn, Albert Wattenberg, and Herbert L. Anderson.



ROBERT J. VAN DE GRAAFF

Robert Jemison Van de Graaff, American physicist, invented an electrostatic accelerator to provide high electrostatic potentials to accelerate electrons or ions to high energies. He was born in Tuscaloosa, Alabama, on December 20, 1901, and died on January 16, 1967, at Boston, Massachusetts.

Biographical Details

Van de Graaff attended school in Alabama and graduated from the University of Alabama in 1922. He studied at the Sorbonne in Paris and was then given a Rhodes Scholarship to study at Oxford University. After he received his Ph.D. degree there in 1928, he worked at Princeton Uni-

Van de Graaff explains his electrostatic generator to Karl Compton, president of the Massachusetts Institute of Technology, after demonstrating it at the 1931 American Institute of Physics inaugural dinner.

versity and then at the Massachusetts Institute of Technology. While there he invented the high-voltage generator named for him.

Scientific Achievements

In 1931 at M.I.T. Van de Graaff completed the electrostatic generator. An accelerator builds a high electrical charge and it speeds up charged particles to be used for atom smashing. The generator is used to produce beams of particles with precise (constant and uniform) energies.

Contribution to Atomic Science

Van de Graaff's accelerator is an extremely important tool to nuclear physics research, since it provides a continuous beam of projectiles for probing atomic nuclei.

READING LIST

More information on the scientists in this booklet can be found in encyclopedias, in individual biographies listed in *Books in Print,* which you can use in most libraries, and in the following books.

Elementary Books

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