

ATOMIC PIONEERS

Book 2

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



by Ray and Roselyn Hiebert



A WORLD OF THE ATOM SERIES BOOKLET

 

The Authors

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The Cover

Left to right, top row, Michael Faraday, Joseph Henry, and Dmitri Mendeléev; middle row, Stanislao Cannizzaro, Max Planck, and Lord Rayleigh; bottom row, Marie Curie, Pieter Zeeman, and Frederick Soddy.

A WORLD OF THE ATOM SERIES BOOKLET

Foreword

This booklet is one in a series of basic educational booklets that explains many aspects of nuclear science including its history and applications. It is the second of a group of four biographical booklets that will describe the contributions to atomic science made by 100 individuals over a 2550-year time span. This volume covers the period from the middle of the 19th century to the early 20th century.

Edward J. Brunenkant, Director
Division of Technical Information

PREFACE

Book 1 of "Atomic Pioneers" traced the development of atomic science from the scientists of ancient Greece like Pythagoras and Anaxagoras to the chemists and physicists of the 19th century like John Dalton and Sir Humphry Davy.

This book is concerned with the last half of the 19th and the beginning of the 20th century when a great surge of knowledge vital to atomic science took place. In rapid succession came such significant work as Michael Faraday's discoveries about electromagnetism, the development of a systematic table of elements by Dmitri Mendeléev, and the discovery of X rays by Wilhelm Roentgen and radioactivity by Henri Becquerel and Pierre and Marie Curie.

Each succeeding discovery brought atomic science closer to the great breakthrough that marked the close of classical physics. This was Max Planck's quantum theory, which laid the foundations for modern physics. Other great work, such as Albert Einstein's theory of relativity, Ernest Rutherford's theory of the nuclear atom, and Otto Hahn's discovery of fission of the uranium atom, would propel atomic science along toward the unleashing of nuclear energy.

This book gives a brief account of the lives and work of 26 men and women who contributed to this explosion of knowledge.

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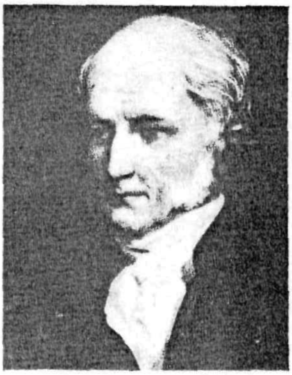


WILLIAM PROUT

William Prout, English chemist and physiologist, was born in Horton, Gloucestershire, on January 15, 1785, and died in London on April 9, 1850.

Biographical Details

William Prout was a practicing physician in London for most of his life. He was also interested in organic chemistry* and the process of nutrition.

He was the author of two anonymous papers in the *Annals of Science,* which proposed his famous hypothesis concerning atomic weights.

Scientific Achievements

Prout's interest in organic chemistry led to a discovery that stunned physicians of the

*Organic chemistry is a branch of chemistry dealing with compounds of carbon.

time. He found that the acid secreted by the stomach is hydrochloric acid, a powerful substance that in more concentrated form can burn flesh or corrode metal.

He also pioneered in nutrition studies and was the first man to divide food into groups that we still use—carbohydrates, fats, and proteins.

But his most noteworthy achievement was announced anonymously and was not in the field of organic chemistry at all. At a time when few atomic weights were known, he developed the hypothesis that all atomic weights were integral (whole number) multiples of the atomic weight of hydrogen, which is the lightest element. Thus if hydrogen were given the number 1, then oxygen would be 16 and sodium 23.

Contribution to Atomic Science

Prout's hypothesis that the hydrogen atom was the building block of the other elements was a great stimulus for others to measure atomic weights more accurately. Though his theory of integral atomic weights seemed wrong and was ignored for some time, work on isotopes a century later by Frederick Soddy and Francis Aston would prove the hypothesis to have real importance.

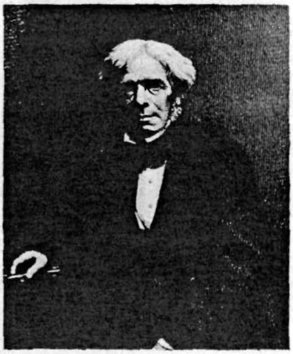
MICHAEL FARADAY

Michael Faraday, English physicist and chemist, left the world the richest heritage of scientific knowledge since Isaac Newton. His significant discoveries include the principle of electromagnetic induction, the field concept that describes the way objects interact, and the two basic laws of electrolysis. He was born in Newington, Surrey, on September 22, 1791, and died in Hampton Court near London on August 25, 1867.

Biographical Details

Faraday was one of ten children of a poverty-stricken blacksmith and had little formal education. At 14 he was apprenticed to a bookbinder who allowed the boy to read books and attend scientific lectures. During a lecture given by Sir Humphry Davy, Faraday took notes, which he sent to the scientist. Because of the excellence of these notes, he later became Davy's assistant at the Royal Institution.

From then on Faraday developed rapidly as a scientist and was awarded many honors. (In 1825 he became Director of the Royal Institution and finally professor of chemistry for life in 1833.) However, he belonged to a religious group, now extinct, which didn't approve of worldly rewards. Because of this he declined knighthood and the presidency of the Royal Society of which he was a member. His religious convictions also made him refuse to prepare poison gas for Britain's use in the Crimean War.



In addition to being a brilliant scientist, Faraday was also a gifted lecturer. He particularly enjoyed giving a special series of scientific lectures for children every year at Christmas.

Scientific Achievements

Faraday was one of the greatest experimental geniuses in the physical sciences. In 1822, impressed by the discovery that an electric current produced a magnetic field, he determined that it was possible to make magnetism produce electricity. He later showed that a movable wire carrying an electric current will rotate around a fixed magnet. Faraday had converted electricity and magnetic forces into mechanical energy, and from this experiment came the principle of the electric motor.

In 1823 he devised methods to liquefy gases. He also produced below-zero temperatures on the Fahrenheit scale in the laboratory for the first time. In 1825 he discovered benzene, a compound important for future work in representing molecular structures in organic chemistry.

His next contribution was in the field of electrochemistry. Davy had produced pure metals by passing an electric current through molten compounds of these metals. Faraday named this process *electrolysis* and called the compound or solution that could carry an electric current an *electrolyte*. He gave the name *electrodes* to the metal rods put into the solution and, at the suggestion of William Whewell, a Cambridge University philosopher, he called the positive rod an *anode* and the negative rod a *cathode*.

In 1832 he developed his laws of electrolysis, which stated that the amount of chemical change produced by an electric current is proportional to the total quantity of electricity. The amounts of different elements that can be deposited or dissolved by a specific quantity of electricity are proportional to the chemical equivalent weight of the element. This implies that the same quantity of electricity is required to liberate the equivalent weight of any element by electrolysis. This quantity is now called the faraday. (The chemical equivalent weight of an element is its atomic weight divided by a number, now called the valence, which describes the combining power of the element with other elements.)

Faraday's experiments demonstrated electromagnetic induction. He connected a coil of wire to a galvanometer* and thrust a magnet into the coil. By inserting or removing the magnet he caused the galvanometer's needle to deflect indicating that an electric current flowed through the wire. If the coil was moved over the magnet, current flowed. But no current flowed if the magnet and the coil were not moved.

Though uneducated, Faraday had a great talent for picturing scientific concepts. To make his ideas clear, he imagined magnetic lines of force as stretching out in all directions

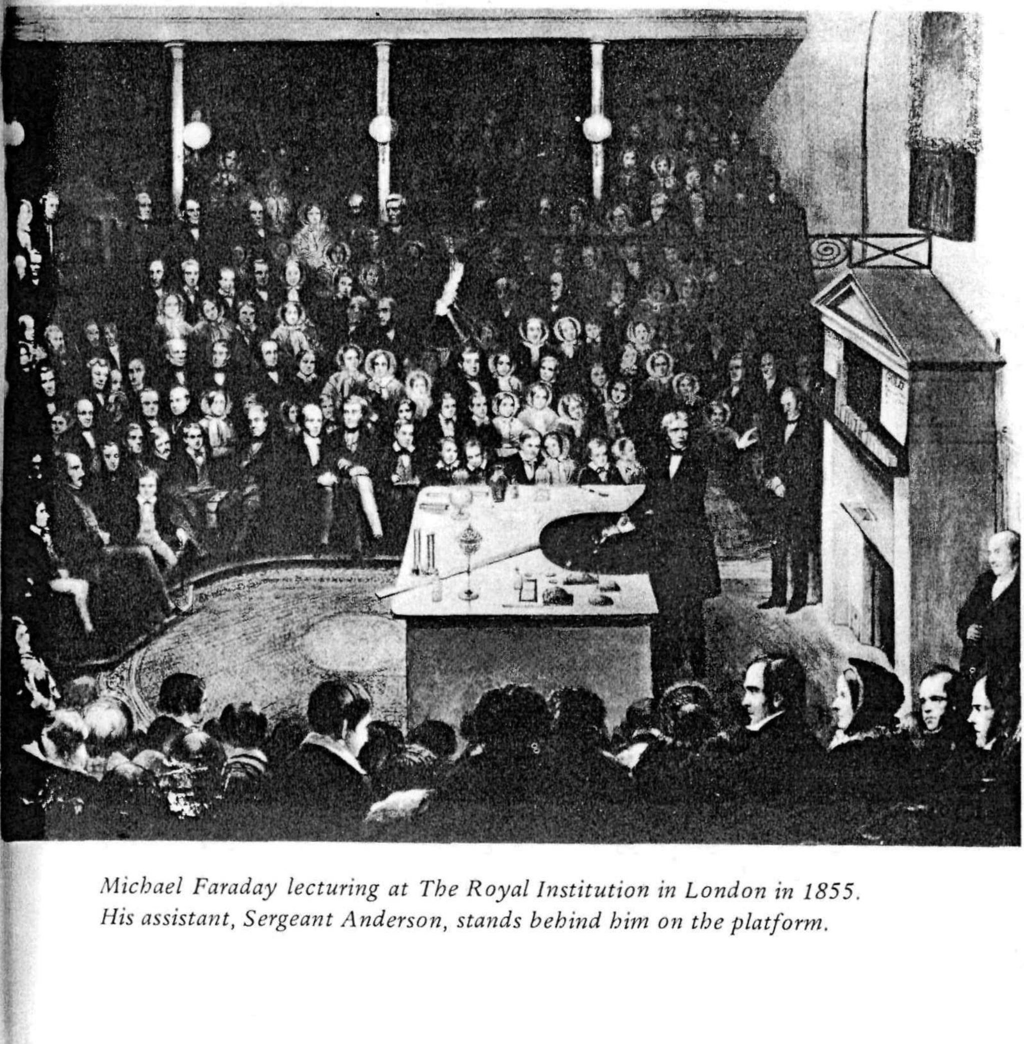
*An instrument for measuring a small electric current or for detecting its presence or direction.

from an electric current, filling all space as a kind of magnetic field.

Now that he had induced electricity by magnetism, he wanted to produce it in a continuous current rather than in short bursts. He turned a copper wheel so that its edge passed between the poles of a permanent magnet. A current was induced and flowed while the wheel turned. Using suitable electrical contacts he led the current off the wheel device and thus could put electricity to work in the world's first electric generator. The energy of water power or burning fuel in a steam engine could turn the copper wheel and be converted to electricity. For the first time in history an abundant source of electricity was possible.

Contribution to Atomic Science

Faraday opened a new era of electrical science and laid the foundations for two areas of practical electric science, electrochemistry and electromagnetic induction. He discovered as well relationships between polarization of light and magnetism.



Michael Faraday lecturing at The Royal Institution in London in 1855. His assistant, Sergeant Anderson, stands behind him on the platform.

EILHARDT MITSCHERLICH

Eilhardt Mitscherlich (mish-er-lick), German chemist, discovered the similar crystal structures of related compounds, which he called isomorphism. He was born in Neuende, Germany, on January 7, 1794, and died in Schönberg near Berlin on August 28, 1863.

Biographical Details

Mitscherlich began studying medicine at the University of Heidelberg because he was interested in Oriental languages and knew that doctors could travel with more freedom than scholars to the Far East. But after taking a course in chemistry, he decided to become a chemist.

Research on phosphates and arsenates at Berlin brought him the invitation to work with Jöns J. Berzelius in Stockholm. He returned to Berlin 3 years later as a chemistry professor.

Scientific Achievements

As he worked with phosphate and arsenate compounds in 1819, Mitscherlich discovered that compounds of a similar composition crystallized together because of their similar design. He named this phenomenon isomorphism. Performing research on sulfur, he found that it crystallized in two different forms. He named this phenomenon di- or polymorphism.

At the University of Berlin he discovered the manganic* acids and the conversion of heated calcium benzoate into benzene.

Contribution to Atomic Science

Mitscherlich's discovery that certain compounds have the same crystal form through a similar design of their structure was a valuable piece of knowledge for Berzelius, who soon put this idea to use in establishing atomic weights.

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*Manganic means related to, or derived from, manganese.

JOSEPH HENRY

Joseph Henry, American physicist, developed an improved electromagnet and was the first to insulate wires in electromagnets. He was born in Albany, New York, on December 17, 1797, and died in Washington, D. C., on May 13, 1878.

Biographical Details

Henry, like Michael Faraday, came from a poor family. His father was a day-laborer who died when his son was young, and Henry had little chance for an education. Early in life he went to live with his grandmother. When he was 13, he became a watchmaker's apprentice, and when he was 16 a chance reading of a popular science book changed his life by inspiring him to return to school. He earned his tuition at Albany Academy by teaching in country schools. Later he became a teacher of mathematics and science at the Academy, and he began to work with electromagnets there.

From 1832 to 1846 he taught at Princeton University and then was chosen first secretary of the newly formed Smithsonian Institution in Washington. He became its outstanding leader and encouraged the museum's role as a clearinghouse of scientific knowledge. He also organized a weather-reporting system that became the U. S. Weather Bureau, helped establish the National Academy of Sciences, and served as its second president.

In his honor, an electrical unit is called a henry.

Scientific Achievements

Henry's interest in electromagnetism led him to develop a more powerful electromagnet than any existing at that time by insulating the wires wrapped about the coil.

He also produced an electromagnetic relay system that was actually a telegraph. He did not patent this or any of his other inventions because he wanted his work to be available to all mankind. So Samuel F. B. Morse, who had received much advice from Henry, got credit for the invention of the telegraph in 1844.

Henry could only experiment during August, which was the school vacation month. In 1830 he discovered the principle of electromagnetic induction. Before he could continue his w o r k the following August, Michael Faraday, w o r k i n g independently, published the idea. Henry was the first, however, to state the idea of self-induction and is given credit for this achievement. He revealed that varying electric current in a coil can induce another current not only in another coil, but in itself. The actual current observed in the coil is the combination of the original current and the induced current.

Henry published a paper on the electric motor in 1831. It is his motor that appears in many kinds of appliances today in which electricity turns a wheel and produces mechanical force. His description of the electric motor would revolutionize science and speed up the technological growth of America.

He also found that currents could be produced at a distance, and this experiment was the first record of the action of waves of the type used in the radio.

Contribution to Atomic Science

Henry's contribution to atomic science was his advancement of knowledge about electromagnetism.

THOMAS GRAHAM

Thomas Graham, British chemist, conducted research into the diffusion* of gases and divided substances for the first time into the two classes of crystalloids and colloids. He was born in Glasgow, Scotland, on December 20, 1805, and died in London on September 16, 1869.

Biographical Details

Graham wanted to be a minister when he entered the University of Glasgow in 1819. But he became interested in experimental science, and 4 years after he graduated, he was appointed a professor of chemistry there.

In 1837 he moved to University College in London as a professor. He remained in that position until 1855 when he was appointed Master of the Mint, a post which he kept until he died in 1869.

Scientific Achievements

Called one of the founders of physical chemistry, Graham measured the rate at which gases passed through different kinds of plugs, fine tubes, and through small openings in platinum disks. His experiments made the rate of diffusion of gases easier to measure.

Graham proposed a law that is named after him. The rate of diffusion of a gas is inversely proportional to the square root of its density. An example of this would be that since oxygen molecules are sixteen times as

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*Diffusion means to spread or scatter.

massive as hydrogen molecules, hydrogen diffuses four times as fast as oxygen.

Graham was also interested in the fact that molecules of some liquid substances diffused more slowly than others. He used

parchment to block the diffusion of liquids and found that some would pass through the parchment more easily than others. He divided these materials into two groups. Those that passed through the parchment easily, such as common salt and sugar, he called crystalloids. Those that passed through very slowly, such as gum arabic, glue, and gelatin, he called colloids. He named this group after the Greek word *kolla,* which means glue. He then developed the process of dialysis in which he showed how to separate crystalloids from colloids by placing the matter in a container made of a porous membrane and running water around it.

Through other experiments he showed how various forms of phosphoric acid differed in hydrogen content. This led chemists to the discovery of polybasic acids. A polybasic acid is an acid containing two or more atoms of hydrogen replaceable by a metal.

Contribution to Atomic Science

Graham's most important contribution was his discovery of the rate of the diffusion of gases. This principle is used in the gaseous diffusion process for separating the isotopes of uranium. This is an important part of fuel production for nuclear reactors.

STANISLAO CANNIZZARO

Stanislao Cannizzaro (kahn-nee-zah-row) was born in Palermo, Sicily, on July 13, 1826, and died in Rome on May 10, 1910.

Biographical Details

Cannizzaro grew up in Palermo. He entered a university with the idea of making medicine his career but soon turned to chemistry. After graduating, he became a professor's assistant, but the Sicilian revolution erupted in 1848, and he joined the rebels as an artillery officer at Messina. When the insurrection failed, Cannizzaro was forced to flee to France. He stayed there until 1851, when he returned to Italy as professor of physics and chemistry.

In 1860 Giuseppe Garibaldi formed a small army to attack Naples, which was then an independent kingdom (of which Sicily was a part) with a corrupt government, Garibaldi wanted to unify the independent states of Italy. Cannizzaro believed in the cause of unification, joined the army, and helped them take the city, which became a part of the new kingdom of Italy.

Later in life he became active in Italian politics and was admitted to the Italian senate where he served as vice president. He died in Rome at the age of 83.

Scientific Achievements

Cannizzaro made two useful contributions to science. Early in his career he found a method of converting aldehydes, a type of organic compound, into a mixture of an organic acid and alcohol. This process is named the Cannizzaro reaction after him.

More important to the development of atomic science was his clarification of one of Amedeo Avogadro's hypotheses. By the 1850s the field of chemistry was in a state of confusion because there had been no agreement on how to find the atomic weights of different elements. Thus a chemical compound might be given a number of different formulas instead of a single accurate one. Avogadro's hypothesis stated 40 years earlier could have been used to determine the molecular weight of gases, but it remained unnoticed. Dalton's table of atomic weights was widely accepted, but he did not clearly distinguish between the atom and the molecule in determining atomic weights. (The molecule is the smallest particle of a compound as it normally exists. The atom is the smallest particle of an element that can enter into chemical combination.)

In 1858 Cannizzaro discovered the significance of Avogadro's ideas, and in 1860 he presented his findings to the First International Chemical Congress, which was the first such meeting in history and was called to discuss the problem of atomic weights. At this meeting Cannizzaro defended Avogadro's hypothesis. With the hypothesis one could discover the molecular weight of different gases. Knowing this weight one could then ascertain the constituents of the gases. Cannizzaro pointed out how Avogadro had clearly distinguished between the molecule and the atom.

Cannizzaro's arguments convinced many scientists, among them the Russian chemist, Dmitri Mendeléev, who would go on to arrange a table of the elements in the order of their atomic weight.

Contribution to Atomic Science

The development of atomic science benefited from the fact that Cannizzaro recognized the significance of Avogadro's long-ignored hypothesis. It was necessary to distinguish precisely between atoms and molecules in order to accurately determine atomic weights and to write chemical formulas of simple compounds.

JAMES CLERK MAXWELL

James Clerk Maxwell, a Scottish mathematician and physicist, was born in Edinburgh, Scotland, on November 13, 1831, and died in Cambridge, England, in November 1879.

Biographical Details

Maxwell graduated from Cambridge University and in 1856 he was appointed professor at Aberdeen University. In 1871 he became professor of experimental physics at Cambridge University. This was the first such professorship given. Maxwell founded the Cavendish Laboratory at Cambridge, which was in later years to be a major center for pioneering work in nuclear energy.

Scientific Contributions

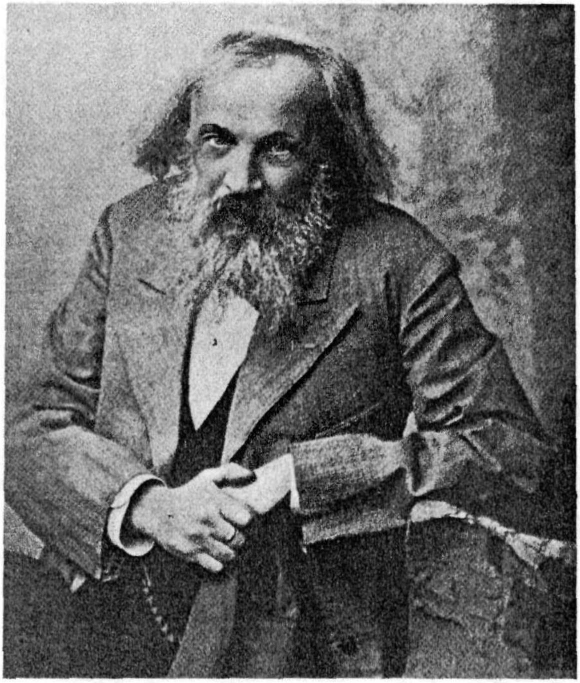
Part of Maxwell's work concerned the study of the small particles that compose gases. He was the first to apply mathematical methods to the kinetic theory of gases. The particles in gases move in every direction, and Boltzmann and Maxwell formulated an equation which stated that some of the gas molecules were slow moving and some were fast moving, but most moved at medium speeds. The average speed was increased by a temperature increase and vice versa. Ludwig Boltzmann subsequently extended and developed this mathematical treatment.

Between 1864 and 1873, Maxwell devised several equations for Michael Faraday's ideas about magnetic lines of force. These equations, called the electromagnetic theory, describe the actions of electricity and magnetism and prove that they always exist together.

From his electromagnetic research Maxwell concluded that an electric charge's vibration (oscillation) created an electromagnetic field. He also believed that light came from a vibrating electric charge and, together with other radiations, formed a large group of electromagnetic radiations. The acceptance of this theory came in 1888 when Heinrich Hertz produced radio waves for the first time by an electrical discharge.

Contribution to Atomic Science

Because of Maxwell's electromagnetic theory of light, later scientists were able to comprehend the absorption and emission of radiation by the atom.



DMITRI I. MENDELÉEV

Dmitri Ivanovich Mendeléev (men-day-łay-ef), Russian chemist, was the first man to successfully devise a periodic Table of the Elements in the order of their atomic weight. He was born in Tobolsk, Siberia, on February 7, 1834, and died in St. Petersburg, on February 2, 1907.

Biographical Details

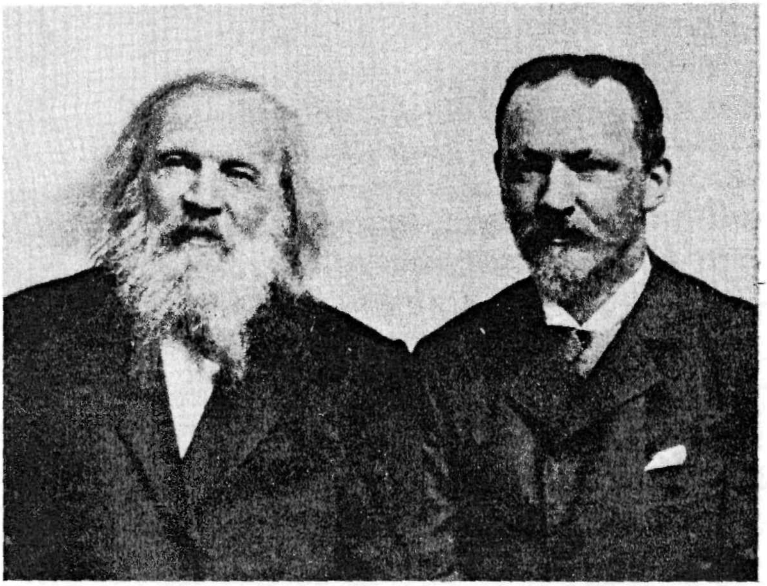
Dmitri Mendeléev was the youngest in a family of fourteen or seventeen children. (Records of the time were vague.) His father was a high school principal in Tobolsk, Siberia.

Mendeléev's father became blind when Dmitri was just a child, and his mother started a glass factory to support her large family. Mendeléev graduated from high school the same year his father died of tuberculosis and his mother's factory was destroyed in a fire. Many years later Mendeléev wrote of his mother. "When dying, she said, 'Refrain from illusions, insist on work, and not on words. Patiently search divine and scientific truth'."

She left Siberia with her youngest son and entered him in St. Petersburg University. He graduated at the top of his class and continued his studies in France and Germany. He became a professor of chemistry at the University of St. Petersburg in 1866 and gained a reputation as one of the best teachers in Europe. His chemistry textbook, *The Principles of Chemistry,* has been called the best Russian chemistry text ever written.

After Mendeléev heard Cannizzaro speak on atomic weights, he decided to systematically classify the elements. His Periodic Table of the Elements arranged by weight was published in 1869. It was translated immediately into German, and European chemists soon became familiar with it. They did not immediately accept his theory, but he was not discouraged. He continued to improve his table, and in January 1871, he published an article in which he left gaps in the table to represent elements not yet discovered and predicted their properties. (Previous periodic tables by other scientists had *not* left gaps for unknown elements.)

Within a decade his work was widely accepted and Mendeléev was hailed as a



Dmitri Mendeléev and Bohuslav Brauner in Prague in 1900. Brauner was a professor of chemistry at the Bohemian University in Prague.

world-famous chemist. Shortly before his death he lost the coveted Nobel Prize in chemistry by one vote. Almost 50 years later in 1955 his contribution to chemistry was recognized when the newly discovered element, number 101, was named mendelevium in his honor.

Scientific Achievements

Scientists had long tried to find a connection between the atomic weights of the elements and their physical and chemical properties. But it was Mendeléev who successfully systematized the properties of the 63 elements then known by arranging them in the proper order of their atomic weight.

He found that he could arrange them in rows so that elements with similar valences could be placed one under another, and these elements would resemble each other in their physical and chemical properties. An atom of an element such as lithium, which has a valence of 1, would combine with only a single atom. The atoms of an element with a valence of two would combine with two different atoms.

Arranging them in this way, he found periodic increases and decreases of valence as well as periodic similarities of physical and chemical properties. That is why he called his work a Periodic Table.

As he improved upon this table, Mendeléev placed several elements out of order of their atomic weight so that they would fit into his scheme. His decision was proved correct many years later.

Contribution to Atomic Science

His greatest achievement was the decision to leave blank spaces or gaps in the Periodic Table to represent elements not yet discovered, in order to fit existing elements into proper columns. He predicted the properties that three of these missing elements should have. Within 15 years these three elements having the properties he predicted were actually discovered.

Mendeléev brought order to the confusion of the elements. His Periodic Table helped chemists to discover missing elements like gallium, germanium, and scandium.

ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti = 50	Zr = 90	? = 180.
			V = 51	Nb = 94	Ta = 182.
			Cr = 52	Mo = 96	W = 186.
			Mn = 55	Rh = 104,4	Pt = 197,4
			Fe = 56	Ru = 104,4	Ir = 198.
			Ni = Co = 59	Pl = 106,6	Os = 199.
H = 1			Cu = 63,4	Ag = 108	Hg = 200.
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204.
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

Д. Менделѣевъ

On the right is Mendeléev's Periodic Table. Above is an early (1869) version of the table. The heading is "Tentative system of the elements". The subheading is "Based on atomic weights and chemical similarities".

The Atomic Weights of the Elements

Distribution of the Elements in Periods

Groups	Higher Salt-forming Oxides	Typical or 1st small Period	Large Periods: 1st	2nd	3rd	4th	5th
I.	R_2O	Li = 7	K 39	Rb 85	Cs 133	—	—
II.	RO	Be = 9	Ca 40	S 87	Ba 137	—	—
III.	R_2O_3	B = 11	Sc 44	Y 89	La 138	Yb 173	—
IV.	RO_2	C = 12	Ti 48	Zr 90	Ce 140	—	Th 232
V.	R_2O_5	N = 14	V 51	Nb 94	—	Ta 182	—
VI.	RO_3	O = 16	Cr 52	Mo 96	—	W 184	Ur 240
VII.	R_2O_7	F = 19	Mn 55	—	—	—	—
			Fe 56	Ru 103	—	Os 191	—
VIII.			Co 58·5	Rh 104	—	Ir 193	—
			Ni 59	Pd 106	—	Pt 196	—
I.	R_2O	H = 1. Na = 23	Cu 63	Ag 108	—	Au 198	—
II.	RO	Mg = 24	Zn 65	Cd 112	—	Hg 200	—
III.	R_2O_3	Al = 27	Ga 70	In 113	—	Tl 204	—
IV.	RO_2	Si = 28	Ge 72	Sn 118	—	Pb 206	—
V.	R_2O_5	P = 31	As 75	Sb 120	—	Bi 208	—
VI.	RO_3	S = 32	Se 79	Te 125	—	—	—
VII.	R_2O_7	Cl = 35·5	Br 80	I 127	—	—	—
		2nd small Period	1st	2nd	3rd	4th	5th
			Large Periods				

JOSEPH NORMAN LOCKYER

Joseph Norman Lockyer, English astronomer, was the first man to study sunspots. His study of the sun concentrated on spectroscopic astronomy and led to the discovery of a new element, helium. Born in Rugby, Warwickshire, on May 17, 1836, he died in Sidmouth, Devonshire, on August 14, 1920.

Biographical Details

After Lockyer attended school on the Continent, he became a clerk in the War Office of the British Government. But he spent all his leisure time studying astronomy, and eventually he became secretary to the Duke of Devonshire's royal commission on science.

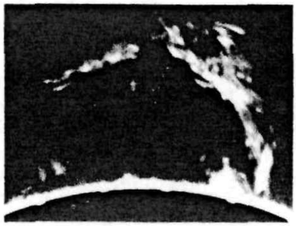
This led to the directorship of the solar physics laboratory of the Royal College of Science, and from there he conducted eight government expeditions to observe total solar eclipses. Before these expeditions began, he had announced a method of daylight observation of solar prominences, which are huge spouts of flaming gas that flare up from the sun's outer layer. Almost simultaneously, the French scientist, Pierre J. C. Janssen, announced the same discovery, and the two scientists appear on opposite sides of a French medal struck in 1872 to commemorate their independent findings. Lockyer also discovered with Janssen the existence of the previously unknown element helium in the sun.

Lockyer started the journal *Nature* in 1869 and remained its editor for 50 years until he died in 1920.

Scientific Achievements

Lockyer's great work was the study of solar spectra, or the distribution of energy emitted by the sun. As he observed the flaming gases hurled from the sun's outer layers, he discovered that they could be observed by daylight without an eclipse by leading light away from the sun's edge through a prism.

Using a spectroscope, he studied a peculiar solar line sighted during an eclipse. The line did not fit into the position of the lines of known elements, and Lockyer thought that the line belonged to an unknown element, which might not exist on earth. He called the new element helium after the Greek word *helios,* which means sun. Many scientists did not agree with Lockyer's discovery but 40 years later in 1895, helium *was* found on earth. Lockyer was knighted in 1897.



Gases leap up from the sun's outer layer.

Contribution to Atomic Science

Lockyer observed that some lines in the spectra of an element expanded under high temperatures. He believed that this meant that the atoms were breaking up into elementary pieces. Although he was not quite correct—it was the loss of electrons caused by high temperatures that caused the broadening of the lines—he was nevertheless an early pioneer of the concept of the atom's divisibility.

1870

1885

1900

1912

LORD RAYLEIGH, 3rd BARON (JOHN WILLIAM STRUTT)

Lord Rayleigh, English physicist, who discovered the first rare atmospheric gas, argon, was born in Terling, Essex, on November 12, 1842, and died in Witham, Essex, on June 30, 1919.

Biographical Details

John William Strutt, or Lord Rayleigh as he is commonly known, was the son of the 2nd Baron Rayleigh and so inherited his title as 3rd Baron. He attended Cambridge University, and in 1879 he became professor of experimental physics there and director of its Cavendish Laboratory until 1884.

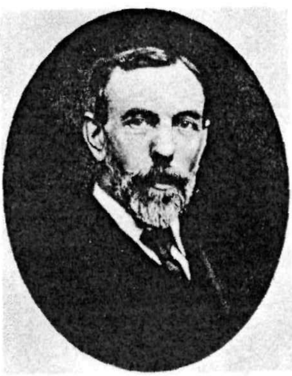
From 1887 to 1905 he was professor of natural philosophy at the Royal Institution. In 1873 he was elected to the Royal Society and was its president from 1905-1908. In 1902 he was an original recipient of the Order of Merit.

Scientific Achievements

Rayleigh combined a knowledge of mathematical analysis with a lifetime of work in physics and chemistry. He experimented with wave motion of all kinds, and confirmed the Irish physicist John Tyndall's view that the sky's blue color results from the scattering of sunlight by air molecules and to some extent by particles in the atmosphere. (The belief current at the time was that oxygen in the atmosphere caused its blueness.) He also studied sound waves, water waves, and earthquake waves. He was responsible for the precise measuring of the ohm for use as an international electrical unit.

Rayleigh wanted to determine more accurately the densities of gases to show that atomic weights were not multiples of hydrogen as Prout had theorized long before. This theory had been discounted by others many times, but Rayleigh wanted to try it himself. He determined the ratio of oxygen and hydrogen to be precisely 15.882:1.

As he worked on oxygen, he found that its density was always exactly the same. However, when he studied the nitrogen he obtained from air, it showed a slightly higher density than the nitrogen he obtained from chemical compounds.



Sir William Ramsay

He worked on this problem with the Scottish chemist, Sir William Ramsay. The men finally found a new gas in the atmosphere, the first rare inert gas (somewhat denser than nitrogen), which they named argon. Rayleigh won the 1904 Nobel Prize in physics and Ramsay the Nobel Prize in chemistry for this discovery.

Contribution to Atomic Science

Rayleigh's discovery of the rare gas argon added another element to Mendeléev's Periodic Table. During the 4 years following the discovery of argon, four other inert gases—helium, krypton, neon, and xenon—were discovered by other scientists. These inert gases would be of great theoretical importance to future work on atomic weights and isotopes.

WILHELM KONRAD ROENTGEN

Wilhelm Konrad Roentgen (rent-gan), German physicist, who discovered X rays, was born in Lennep, Prussia, on March 27, 1845, and died in Munich, Bavaria, on February 10, 1923.

Biographical Details

Wilhelm Roentgen received his early education in Holland, earned a degree in mechanical engineering and then a degree in physics in 1869.

During the next 25 years he was professor of physics at several German universities. At Würzburg he made the discovery of X rays for which he is famous. A unit of X-ray dosage is called a roentgen in his honor.

Scientific Achievements

Roentgen's discovery of X rays occurred in the fall of 1895. As he was experimenting with the conduction of electricity through gases in exhausted vacuum tubes, he became interested in the luminescence that cathode rays caused in certain chemicals. To see better, he darkened the room and enclosed the cathode-ray tube in black paper.

Later on he wrote this about his discovery: "I was working with a Crookes' tube covered by a shield of black cardboard. A piece of barium platino-cyanide paper lay on the bench and I noticed a peculiar line across the paper. . . . In a few minutes there was no doubt about it, rays were coming from the tube. . . . It was something new, something unrecorded."

On November 5, 1895, he turned on the current and his eyes were attracted by a flash of light that did not come from the tube. Some distance away a sheet of paper coated with barium platinocyanide was glowing, and it continued to remain luminescent even though the cathode-ray tube was covered with black paper.

When he turned off the current in the tube, the paper darkened, but as soon as the tube was turned on again, the coated paper glowed. Roentgen decided that an invisible radiation from the cathode tube penetrated many substances opaque to ordinary light. He found by experimentation that the radiation could pass through thick paper, flesh, and even thin metal but was stopped by other materials, such as metal or bone. He called the unknown radiation X rays, since x frequently stands for an unknown quantity in mathematics.

What he had actually found and named X rays are rays generated mainly as a result of the slowing down of fast electrons by the nuclei of the heavy atoms.

He immediately began to experiment on his fascinating discovery, hoping to publish his findings before someone else did. For 7 weeks Roentgen worked day and night to gather as much data as he could. Finally, on December 28, 1895, he published his paper on X rays.

He gave the first public showing of the mysterious rays in January 1896, taking an X-ray photograph of the hand of a 79-year-old colleague (left). News of the phenomenon flooded Europe and America and his dis-

covery became useful to medical science immediately.

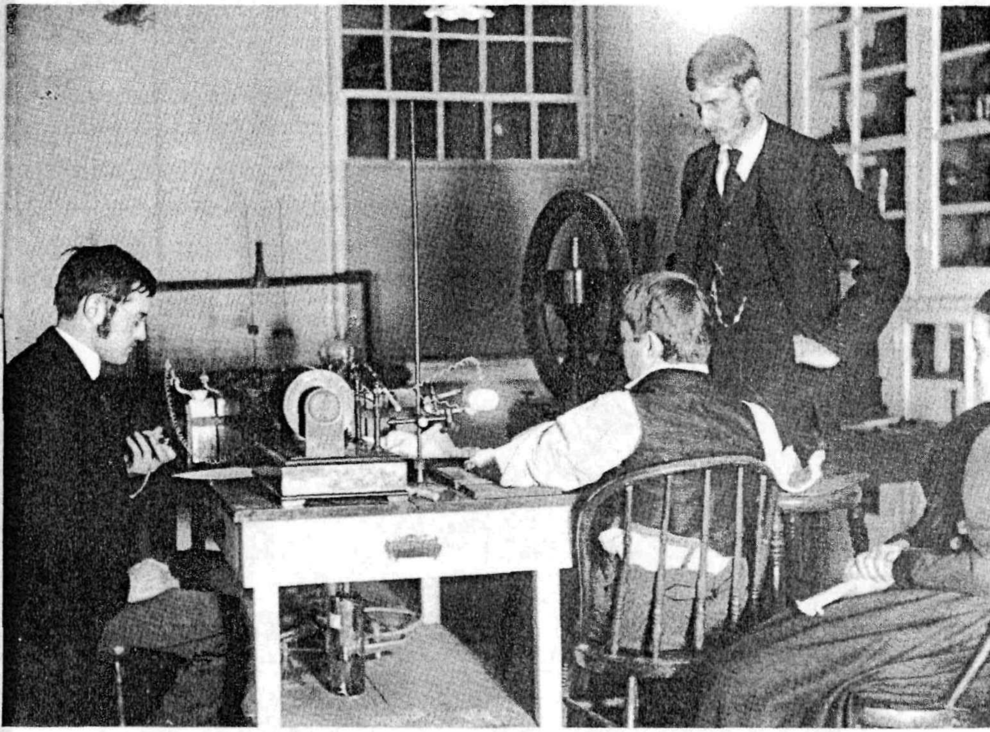
X rays passing through body tissues on their way to a photographic plate would show bones, tooth decay, and metal objects like bullets. Just 4 days after their announcement in the United States, X rays were used to find a bullet in a wounded leg.

The tremendous value of Roentgen's discovery was realized within his lifetime, and he was awarded the first Nobel Prize in physics. He refused to patent his discovery or to receive financial rewards from it. This proved a noble gesture, for he lived through World War I, which was followed by inflation and great financial hardship in Germany, and died a poor man in 1923.

Contribution to Atomic Science

The discovery of X rays, or Roentgen rays as they were called for a long time, not only aided medical science, but led to new insights into the structure of the atom.

Within a few months Becquerel discovered radioactivity and many other discoveries followed rapidly. Roentgen's work so revolutionized the study of physics that 1895, the year of his discovery, is sometimes called the beginning of the Second Scientific Revolution, the First Scientific Revolution having begun with Galileo.



No new apparatus was needed to produce the rays discovered by Roentgen, and so X-ray experiments were quickly repeated around the world. Above, on February 3, 1896, Professor Edwin B. Frost (left) and his brother Dr. Gilman Frost (standing) of Dartmouth College X-ray the fractured arm of a young patient. Professor Frost is timing the exposure. The crude equipment consists of a battery, a cathode-ray tube (illuminated), and an induction coil and film (under boy's arm).

In February 1896 Professor Michael I. Pupin of Columbia University X-rayed the hand of a New York attorney in order to aid in the surgical removal of more than 40 gunshot pellets (black spots in the X ray) embedded in the hand as a result of a hunting accident. Note Pupin's signature in lower righthand corner. Professor Pupin had set up his own X-ray apparatus after getting information on the new discovery directly from a German physicist.

ANTOINE HENRI BECQUEREL

Antoine Henri Becquerel (beck-cur-rel), French physicist, shared the 1903 Nobel Prize in physics with Pierre and Marie Curie for his discovery of radioactivity. He was born in Paris on December 15, 1852, and died at Croisic in Brittany on August 25, 1908.

Biographical Details

Henri Becquerel was descended from a family of noted physicists. He studied at the École Polytechnique and was appointed professor there in 1895.

He was elected president of the French Academy of Sciences in 1908.

Scientific Achievements

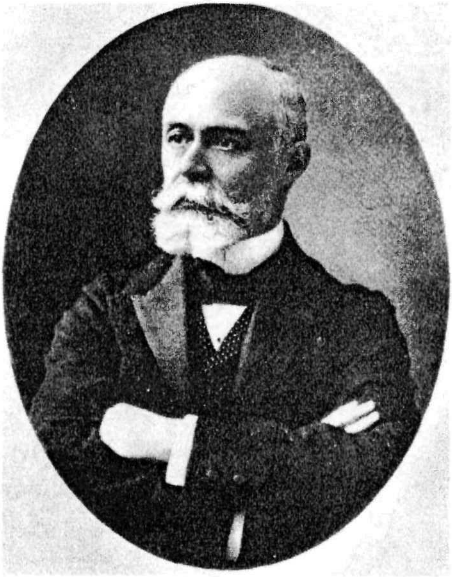
Becquerel was intrigued with Roentgen's discovery of X rays. In February 1896, he attempted to discover whether penetrating rays like X rays were emitted from a fluorescent material such as a pure specimen of a uranium salt, potassium uranyl sulfate. He wrapped a photographic plate in black paper, placed a thin crystal of the uranium salt on the paper and exposed it to sunlight. When the photographic plate was developed it had darkened; this revealed that the uranium salt emitted radiations which could penetrate paper. He showed that these rays could also penetrate thin sheets of aluminum and copper and still cause darkening of the photographic plate.

Since the sun was not shining and he believed that sunlight was essential to the success of the project, he put the experiment away for several days. But when the sun had still not shone for several days, he took the photographic plate containing the uranium crystals out and developed it, not expecting anything but just a faint trace of the original fluorescence.

To his surprise he found that the plate showed an even greater darkening. He concluded that the radiations given off by the uranium salt did not depend on sunlight and were not involved with fluorescence.

He found that the rays penetrated matter, ionized air, and were given off by the uranium salt in an unending stream. What he had discovered were called Becquerel rays until 1898 when the emission of these rays was named radioactivity by Marie Curie.

In the next 2 years Becquerel observed that radiations from radioactive substances could be deflected by a magnetic field so that part of the rays consisted of negatively charged particles. He decided that this negatively charged part was composed of speeding electrons identical to the cathode rays discovered by J. J. Thomson. (See page 46.)



Contribution to Atomic Science

In addition to the discovery of radioactivity, in 1901 Becquerel showed that the radioactivity was a property of the element uranium and did not depend on the actual nature of the substance in which the uranium was present.

HENDRIK A. LORENTZ

Hendrik Antoon Lorentz, Dutch physicist, was born in Arnhem, Holland, on July 18, 1853, and died in Haarlem on February 4, 1928.

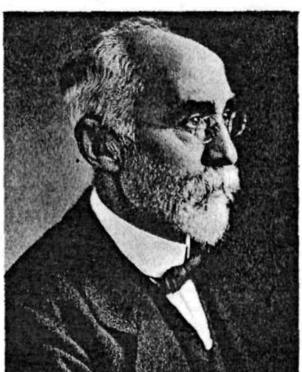
Biographical Details

Lorentz studied at Leiden University. He was appointed professor of mathematical physics and retained the post for 45 years until he died.

Toward the end of his life he helped in the Dutch project of enclosing the Zuider Zee to make more fertile land for Holland out of the shallow sea basin.

Scientific Achievements

Lorentz' greatest work was on the theory of light. By 1890 scientists had come to believe that electric current was composed of charged particles. Lorentz believed that atoms of matter might likewise contain charged particles. He advanced the idea that it was these charged particles within the atom that oscillated to produce visible light.



His pupil Pieter Zeeman showed that by placing a light in a strong magnetic field the nature of the oscillations was affected and therefore the wavelengths of the light emitted were also affected. Lorentz provided the theoretical explanation of Zeeman's experimental discovery and the two men shared the 1902 Nobel Prize in physics for work on the effects of magnetism on light.

Lorentz also defined a theory dealing with the contraction of length with motion. His electron theory showed that moving bodies would appear to be shortened in the direction of motion and their mass would increase. His mathematical equations showing how mass varied with velocity stated that the smaller the volume, the greater the mass. As the volume of an electron was reduced as it sped along, its mass would increase as the speed increased. At 161,000 miles a second, the mass of an electron is twice its value at rest, and at 186,282 miles a second, which is the speed of light, the mass must be infinite since the volume would become zero.

Contribution to Atomic Science

Lorentz' research with charged particles and his experiments on the effects of magnetism on light added to the rapidly expanding body of knowledge at the beginning of the 20th century. Equations for the Lorentz contraction describe how mass varies with velocity. When Einstein's Special Theory of Relativity was advanced in 1905, Lorentz' equations were shown to be valid not only for charged particles, but for all charged and uncharged objects.

J. J. THOMSON

Joseph John Thomson, British physicist and discoverer of the electron, was born at Cheetham Hall near Manchester on December 18, 1856, and he died in Cambridge on August 30, 1940.

Biographical Details

Thomson entered college at the age of 14. When he was only 27 years old, he succeeded Lord Rayleigh as professor of physics at Cambridge University. He became head of the Cavendish Laboratory and guided it into leadership in the field of subatomic physics for over 30 years. In 1908 he was knighted.

He was a gifted leader, and seven of his research assistants were themselves awarded Nobel Prizes, as well as his son and pupil, Sir George Paget Thomson, who won the Nobel Prize in physics in 1937.

Thomson died just before World War II and was buried near Isaac Newton in Westminster Abbey.

Sir George Thomson in 1937.

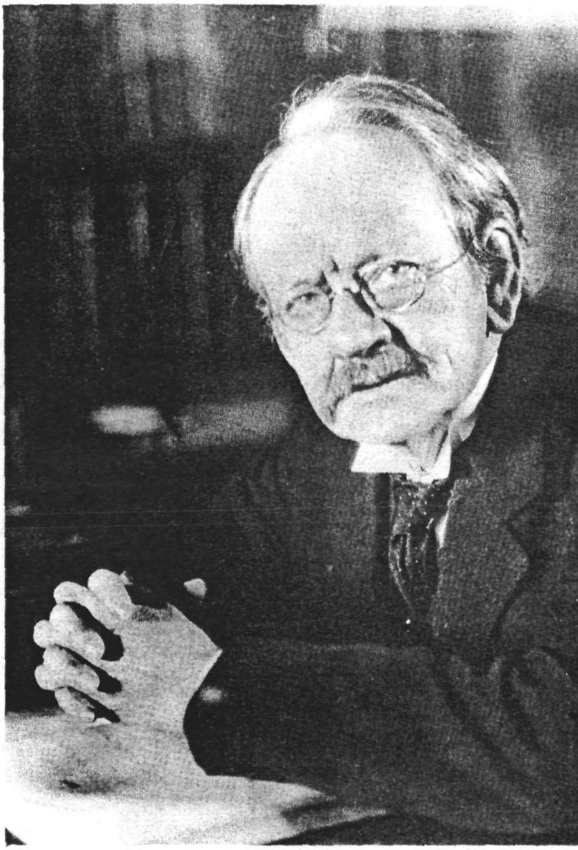
Scientific Achievements

In 1895 Thomson began to investigate the mysterious rays that occurred when electricity was passed through a vacuum in a glass tube. Because they seemed to come from the cathode, the negative electrical pole in the tube, they were called cathode rays. No one had succeeded in deflecting them by an electric field. Other scientists believed that cathode rays were like light waves, but Thomson believed that they were tiny particles of matter.

He built a special cathode-ray tube in which the rays became visible as dots on a fluorescent screen inside the tube. He measured the deflections in magnetic and electrical fields and showed that they were negatively charged particles; thereafter cathode rays were accepted as tiny particles just as Thomson believed them to be.

The Cavendish Laboratory at the University of Cambridge.

Then he measured the ratio of the charge of the cathode-ray particles to their mass. He concluded that if the charge was equal to the minimum charge on ions using Faraday's laws of electrochemistry, then the mass of the particles was only a small fraction of that of hydrogen atoms, and the cathode-ray particles



were smaller than atoms. Thomson had opened the door to research on subatomic particles.

He had proved the existence of electron particles in cathode rays. For this discovery of the electron he was awarded the 1906 Nobel Prize in physics.

He believed the electron was a universal component of matter and suggested a theory as to the internal structure of the atom.

Thomson engaged in another important discovery with his work on "channel rays", which are streams of positively charged ions that he called positive rays. He deflected these rays by magnetic and electric fields and found that ions of neon gas fell on two different spots of a photographic plate, as though they were a mixture of two types that differed in charge or mass or both. This was his first indication that ordinary elements might also exist as isotopes, which are atomic varieties of a single element differing only in their mass.

Contribution to Atomic Science

Thomson's work on cathode rays proved the existence of the electron and led to the study of subatomic particles. Furthermore, when he discovered how to identify isotopes of the chemical element neon 20 and neon 22, he showed scientists that nonradioactive isotopes existed.

MAX PLANCK

Max Karl Ernst Ludwig Planck, German physicist, introduced an idea that led to the quantum theory, which became the foundation of 20th century physics. He was born in Kiel, Germany, on April 23, 1858, and died in Göttingen on October 3, 1947.

Biographical Details

Planck lived in Munich as a child. He studied at the Universities of Munich and Berlin and became a physics professor at Berlin. He remained there until he retired in 1926.

Planck won many honors and served as president of the Kaiser Wilhelm Society for Scientific Research, which was later called the Max Planck Society in his honor.

Planck suffered greatly in his private life as a result of the Nazi rise to power because he refused to cooperate with Adolph Hitler. His first son had been killed in World War I, and his second son was accused of conspiring to assassinate Hitler and was executed by the Nazis. During an air raid attack on Berlin in World War II he lost his home and valuable library.

After the war he spent his last years in Göttingen.

Scientific Achievements

Early in his career the head of the physics department at the University of Munich told him, "Physics is a branch of knowledge that is just about complete. The important discoveries, all of them have been made. It is hardly worth entering physics anymore." This was the prevailing mood of the times, but Planck would, in years to come, bring to physics a startlingly new perspective that would open up vast areas of research.

As a young professor Planck studied black-body radiation. A black body is one that is a perfect absorber and emitter of radiation.

Other physicists were doing research on the distribution of energy in the spectrum of black-body radiation, and several had worked out equations describing how the radiation of the black body was distributed. But some equations worked only at low frequencies and others only at high frequencies.

Then in December 1900, Planck worked out an equation that described the distribution of radiation accurately over the range of low to high frequencies. He had developed a theory, which depended on a model of matter that seemed very strange at the time. The model required the emission of electromagnetic radiation in small chunks or particles. These particles were later called quantums. The energy associated with each quantum is measured by multiplying the frequency of the radiation, ν, by a universal constant, h. Thus, energy, or E, equals $h\nu$. The constant, h, is known as Planck's constant. It is now recognized as one of the fundamental constants of the universe.

Planck's theory that radiant energy is absorbed or emitted as quanta was so revolutionary that many scientists were slow to realize its significance. Even Planck did not like the results of the theory!

But Albert Einstein and Niels Bohr applied the quantum theory to problems of photoelectric emission and to the structure of the atom, and with its use they could explain a good deal that 19th century physics could not. The importance of Planck's quantum theory was solidly established, and he won a Nobel Prize in 1918 for his work.

Contribution to Atomic Science

The introduction of the quantum theory in 1900 marks the turning point between classical and modern physics. Planck's concept of quanta has influenced virtually every aspect of modern physical science and made it possible for Bohr's theory of atomic spectra to develop in 1913 as well as for new forms of mathematical analysis, called quantum mechanics, to emerge.

SVANTE A. ARRHENIUS

Svante August Arrhenius (are-ray-nee-us), Swedish chemist and physicist, is considered a founder of modern chemistry. He was born in Wijk near Uppsala, Sweden, on February 19, 1859, and died in Stockholm on October 2, 1927.

Biographical Details

Arrhenius was a child prodigy. He taught himself to read when he was 3 years old and showed extraordinary ability at mathematics. At the age of 17 he entered the University of Uppsala and studied the process whereby electricity passed through solutions. He received his doctor's degree for a thesis on galvanic conduction through electrolytes. Though the thesis was considered barely acceptable and was awarded the lowest grade without actually being turned down, it was its very development that won Arrhenius a Nobel Prize.

Arrhenius became professor and rector of Stockholm University, and in 1905 was appointed director of the Nobel Institute for Physical Chemistry. He remained there until just before he died.

Scientific Achievements

For his doctoral thesis Arrhenius developed the idea that some substances such as salt (sodium chloride) conducted electricity while in solution and were electrolytes while others such as sugar (sucrose) did not and were nonelectrolytes. (The difference between electrolytes and nonelectrolytes was already well known.) He suggested that electrolytes such as sodium chloride broke up into particles, a sodium ion and a chloride ion, as soon as the electrolyte was placed in solution. The positive sodium ion and the negative chloride ion carried electric charges, and this explained how the solution could transmit an electric current.

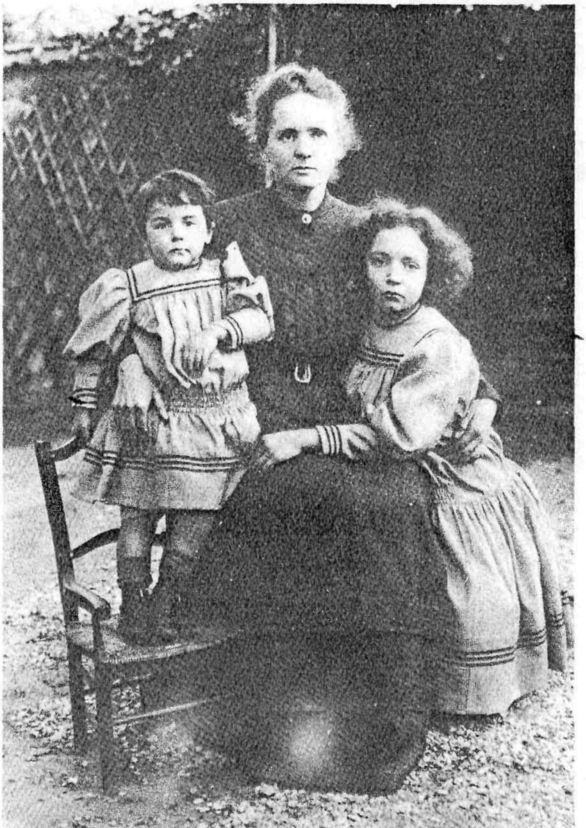
It was well known that there must be electrically charged atoms (or groups of atoms) in solution. The word "ion" was in fact used by Faraday in the 1830s and by others later. It was commonly accepted that solutions of electrolytes contain ions that serve to transmit an electric current. There was no good theory, however, as to how they originated.

Contribution to Atomic Science

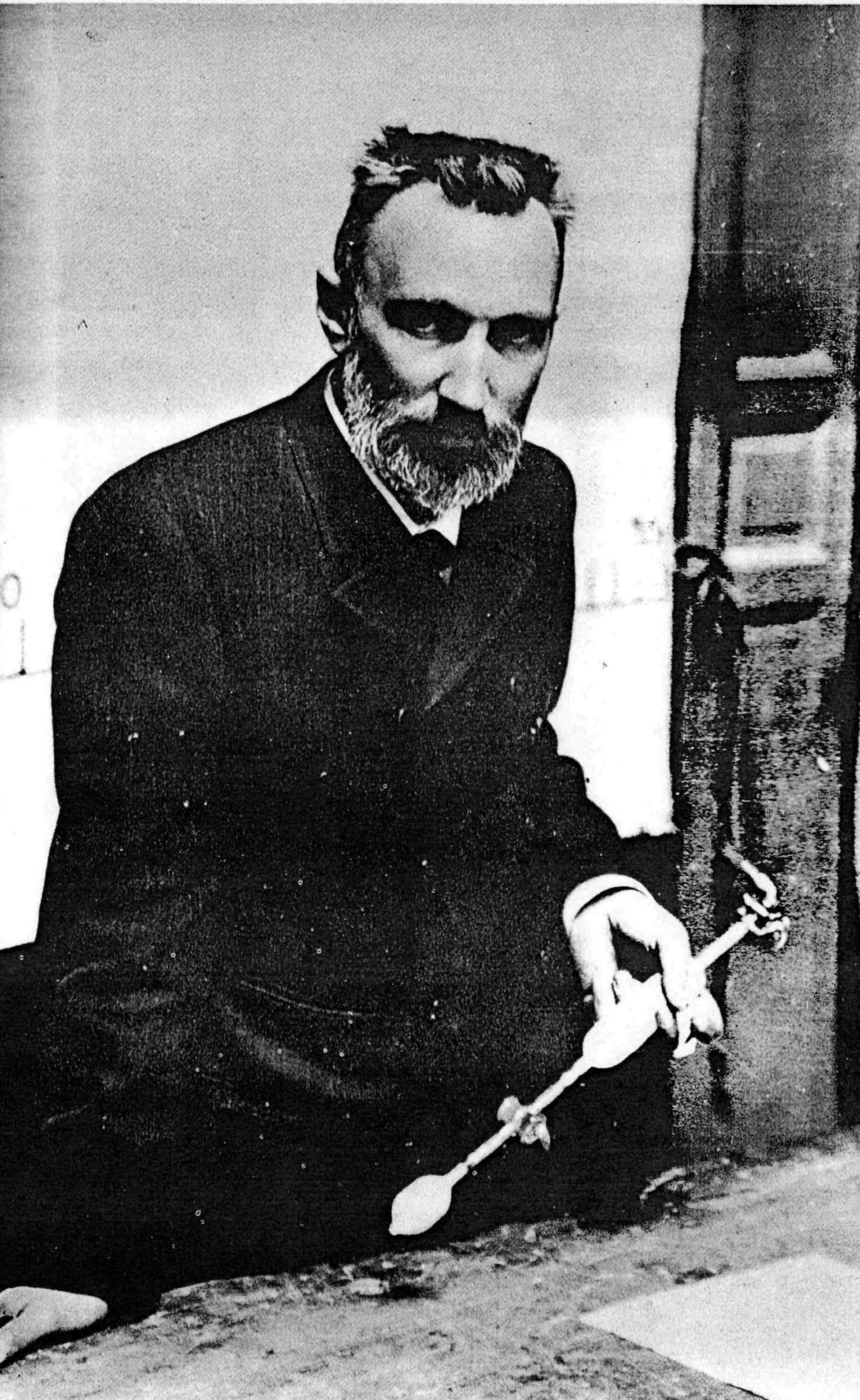
Arrhenius' great contribution was to suggest that the electrolyte substance, e.g., a salt, split up spontaneously into ions when the salt was dissolved in water. This was later found by X-ray diffraction to be consistent with the structure of salt crystals. It was also in harmony with theories of molecular structure developed later.

PIERRE CURIE

Pierre Curie, French chemist, did research on the magnetic properties of metals. With his wife, Marie, and Henri Becquerel, he is credited with the discovery of radioactivity, for which they were awarded the 1903 Nobel Prize in physics. He was born in Paris on May 15, 1859, and died there on April 19, 1906.



Marie Curie and her two daughters, Eve (left) and Irene, in 1908. On the opposite page is Pierre Curie during a class lecture in 1906, the year of his death.



Biographical Details

Curie studied at the Sorbonne University and became a professor at the school of physics and chemistry. In 1895 he married Marie Sklodowska, and they began their joint scientific research. Their mutual love of science once led Pierre Curie to say, "I have got a wife made expressly for me to share all my preoccupations."

In 1906, two years after he was appointed a professor of physics at the Sorbonne he was killed by a horse-drawn carriage on a street in Paris. He was 47 years old.

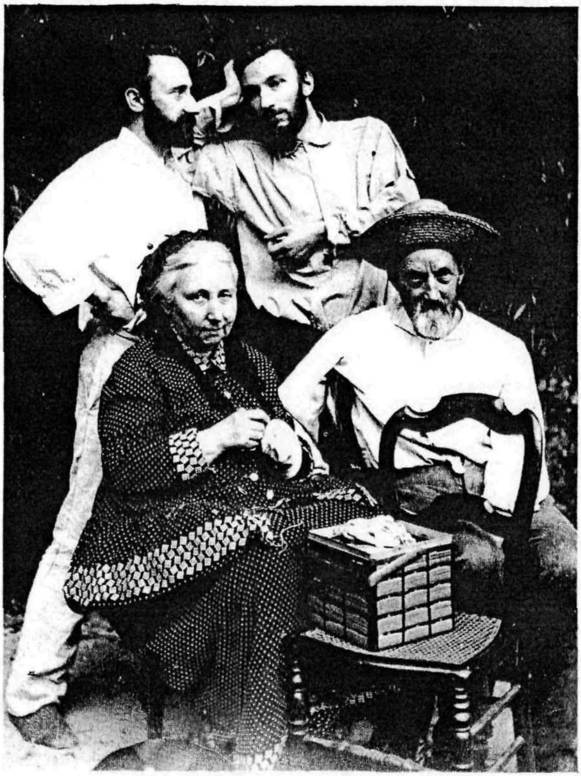
Scientific Achievements

For his doctor's degree, Curie did work on the magnetic properties of metals. He demonstrated that there is a certain critical temperature (now called the Curie point) above which magnetic properties disappear or are greatly reduced.

In 1880 he noticed how electric potential varied directly with the pressure applied to crystals. He named the phenomenon *piezoelectricity*, for the Greek word meaning to press, and crystals with these properties now make up an important part of present-day electronic devices such as microphones.

Contribution to Atomic Science

Curie's discovery of radium and polonium with his wife led the way toward advances in atomic science. He said of the discovery, "Radium is not to enrich anyone. It is an element; it is for all people." His measurement of the heat given off by radium as 140 calories per gram per hour gave the initial realization to atomic scientists of the vast potentials of energy hidden within the atom.



Pierre Curie (standing, right), his brother Jacques (left), and his mother and father.

Marie Curie's mother.

Marie Curie's father and three of his daughters in 1890. Left to right, Marie, Bronya, and Hela.

MARIE CURIE

Marie Sklodowska Curie, Polish–French chemist, is the only person to win two Nobel Prizes in science. She was born in Warsaw, Poland, on November 7, 1867, and died in Haute Savoie, France on July 4, 1934.

Biographical Details

Marie Curie's father was a Polish physics teacher and her mother was the principal of a girls' school. When her parents died, she followed her older brother and sister to Paris. She enrolled at the Sorbonne, living an impoverished existence but graduating at the top of her class.

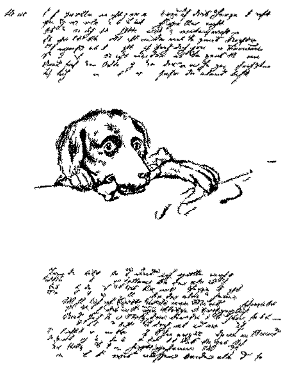
In 1894 she met the French chemist, Pierre Curie. They married a year later on July 26, 1895. The two became fascinated with the discoveries of X rays by Roentgen and of uranium radiation by Becquerel. Pierre abandoned his own research, and for the final 7 years of his life he served as his wife's collaborator. Together they studied radioactivity in uranium and isolated two new elements, naming them radium and polonium, for which they jointly received the 1903 Nobel Prize in physics with Becquerel.

Writing about the discovery of radium with her husband, Marie Curie said, "One of our joys was to go into our workroom at night; we then perceived on all sides the feebly luminous silhouettes of the bottles or capsules containing our products. It was really a lovely sight and always new to us. The glowing tubes looked like faint fairy lights."

Above, Marie and Bronya in 1885. Below, Marie with her brother and sisters about 1873. Left to right, Zosia, Hela, Marie, Joseph, and Bronya.

The Curies lived modestly, using all their earnings to pay for shipping tons of waste ore, rich in uranium, from abandoned mines in Bohemia. This ore was delivered to the physics school where they conducted their research.

They had two daughters. One was Irène, a scientist who with her husband Frédéric Joliot would win the 1935 Nobel Prize in chemistry.



A page written in 1885 from Marie Curie's private notebook The text is a German poem by Heinrich Heine

When her husband was killed in a street accident in 1906, Marie succeeded him as professor of physics at the Sorbonne, the first woman ever to teach there. She overcame many professional obstacles, but she could not overcome all prejudices against women working as scientists. Though she was nominated to the French Academy, she lost by one vote because she was a woman.

However, in 1911 she was awarded another Nobel Prize in chemistry for research that she and Pierre had done in the discovery of radium and polonium, which she named for her native Poland.

In World War I she interrupted her work to drive an ambulance on the battlefields of France. After the war, she spent her years supervising the Paris Institute for Radium, which she founded.

Marie Curie summarized her life in a few simple words, "I was born in Warsaw of a family of teachers. I married Pierre Curie and had two children. I have done my work in France."

In honor of Marie and Pierre Curie, the quantity of any radioactive substance that emits particles at the same rate as does 1 gram

Marie Curie and President Warren G. Harding during her tour of the United States in 1921. A gram of radium—then worth about $100,000—was presented to her and her daughter Irene by the President. The money had been contributed by the American people in a campaign directed by Mrs. William Brown Meloney, a New York newspaper editor. Funds left over provided Madame Curie with a life income.

of radium (37 billions per second) is called a curie.

Scientific Achievements

After the discovery of X rays, the Curies undertook a systematic study of the radioactive properties of pitchblende, or uranium.

Applying Pierre's discovery of piezoelectricity to the measurement of radioactivity in uranium, they found that some uranium ore must contain elements much more radioactive than uranium.

In July 1898, they isolated a tiny amount of a new intensely radioactive element, which they named polonium. In December 1898, they discovered another intensely radioactive substance, radium, in such small quantities that it could only be detected as a trace impurity. Now they wanted to produce radium in visible quantities, and for 4 years they purified tons and tons of ore into small samples of pure radium. By 1902 they had prepared a tenth of a gram of radium from all the tons of uranium shipped to their laboratory.

Contribution to Atomic Science

The discovery of radium and polonium by Marie and Pierre Curie and their research on radioactivity laid the foundation for new discoveries in nuclear physics and chemistry. Scientists would follow close on their trail to discover other radioactive elements.

PIETER ZEEMAN

Pieter Zeeman (zay-mahn), Dutch physicist, was born in Zonnemaire, The Netherlands, on May 25, 1865, and died in Amsterdam on October 9, 1943.

Biographical Details

Zeeman studied at the University of Leiden. In 1900 he was appointed professor of physics at the University of Amsterdam, and served as head of Amsterdam's Physical Institute until his retirement in 1935.

Scientific Achievements

Zeeman is best known for research with his teacher, Hendrik A. Lorentz. The phenomenon of the Zeeman effect, named after him, consisted of splitting a spectral line into components of slightly different frequency when the light source was placed in a magnetic field. For this contribution Zeeman shared the 1902 Nobel Prize in physics with Lorentz.

Contribution to Atomic Science

The Zeeman effect had considerable impact on the study of the structure of the atom. Zeeman's work also helped improve measurement of the strength of the magnetic field on the surface of the sun and other stars.

THEODORE W. RICHARDS

Theodore William Richards, American chemist, who determined the atomic weights of many elements with great accuracy, was born in Germantown, Pennsylvania, on January 31, 1868, and died in Cambridge, Massachusetts, on April 2, 1928.

Biographical Details

Richards came from a family of painters and poets, but he chose science as his career. He became professor of chemistry at Harvard and during his 30 years there he and his students made accurate measurements of the atomic weights of many elements. For these investigations he won a Nobel Prize in 1914.

Scientific Achievements

Richards measured atomic weight values of over sixty elements with the greatest accuracy possible through chemical means. Scientists who worked with him called Richards the foremost experimental chemist of his time because he had certain important scientific qualities—"He had an infinite capacity for taking pains, an uncompromising attitude toward the possibility of hidden errors . . . [and] an extraordinary persistence in the patient repetition of exacting and laborious experiments."

In 1913 he began, at the suggestion of K. Fajaus, new work to determine the precise atomic weight of lead from different sources, and he found minute variations in its weight. This work confirmed the existence of isotopes of stable elements and also the theory that lead was the end product of the radioactive series.

Contribution to Atomic Science

Richards' chemical methods of measuring atomic weights brought the end of the classical era of atomic weight measurements. His work contributed much to the discovery of isotopes and to the body of knowledge concerning the atomic weight of lead. After their discovery, measurement of the mass of elements would turn to electromagnetic methods.

C. T. R. WILSON

Charles Thomson Rees Wilson, a Scottish physicist, was born in Glencorse, Midlothian, on February 14, 1869, and died near Edinburgh on November 15, 1959.

Biographical Details

Wilson was the son of a sheep farmer near Edinburgh, Scotland. His father died when he was four, and his mother took her family to Manchester. He entered Owens College at 15 and graduated at 18. He received a degree from Cambridge at 22, and in 1895 he went to work at the Cavendish Laboratory where J. J. Thomson was the director.

In 1900, at the age of 31, he became a member of the Royal Society. He remained at Cambridge until 1934 when he retired and returned to Scotland.

Scientific Contributions

In 1894 Wilson observed the effect of the sun on the clouds at the top of Ben Nevis, the highest hill in Scotland. In the Cavendish Laboratory he began studying cloud formations. Under laboratory conditions he expanded moist air in a container, and produced a cloud of water drops which formed around dust particles. In experiments with dust-free air, Wilson concluded that water drops formed around ions, which are atoms or molecules that have lost or gained one or more electrons and are thus electrically charged.

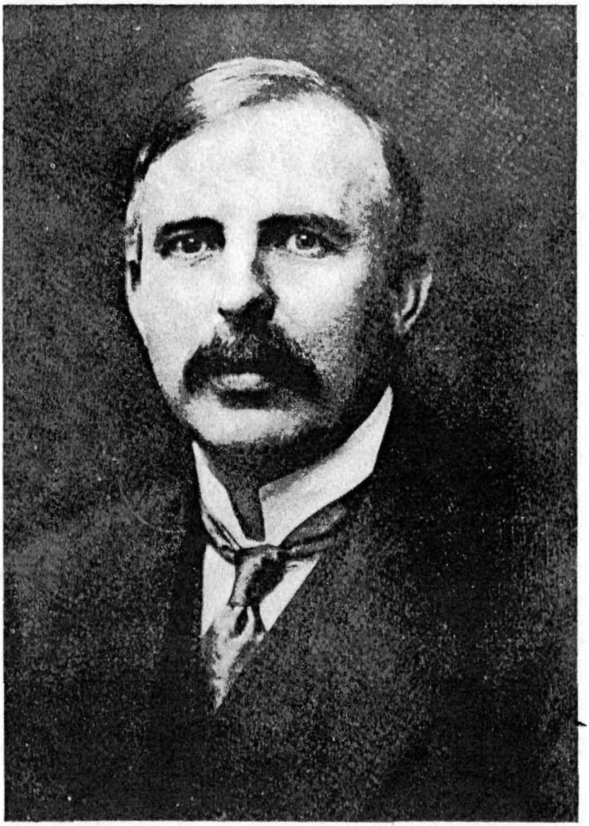
In 1896 the discovery of X rays was announced, and Wilson bombarded his container with X rays. This radiation caused more intense cloud formation in the dust-free air and proved conclusively that ions could serve as condensation nuclei. The radiation had knocked electrons in its path out of atoms and, in so doing, condensation had then occurred around the electrons.

In 1911 Wilson noticed that radiation produced water droplet tracks that were visible during expansion of the cloud chamber. These were the tracks of individual charged particles.

He was awarded the 1927 Nobel Prize in physics for his cloud chamber.

Contribution to Atomic Science

Wilson's contribution was the invention of the cloud chamber, which acted as a "window" to the world of charged particles and atomic interactions. The cloud chamber particle tracks could also be photographed and thus recorded for future research.



ERNEST RUTHERFORD

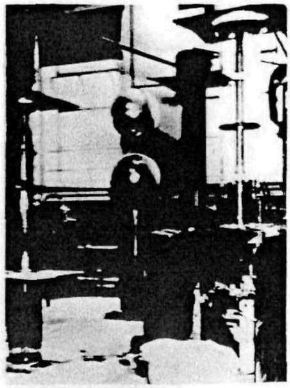
Ernest Rutherford, a British physicist whose contributions to science of the theory of the nuclear atom brought him the title of "father of nuclear science", formulated the theory of radioactive disintegration of elements, identified alpha and beta particles, and devised the theory of the nuclear structure of the atom. He was born on a farm near Nelson, New Zealand, on August 30, 1871, and died in London on October 19, 1937.

Biographical Details

Rutherford was the son of a wheelwright and farmer. As a child he helped his father dig potatoes on the farm. He was a promising student and won a scholarship to Canterbury University in New Zealand and to Cambridge University in England.

Working at McGill University in Montreal, he continued work he had begun in the field of radioactivity. Then he returned to Manchester University and Cambridge where he remained until his death.

He won many honors for his scientific achievements. He was knighted in 1914, and in 1931 was named 1st Baron Rutherford of Nelson.



Rutherford's laboratory at Cambridge University in the 1930s.

Scientific Achievements

Rutherford's great contributions to science began at McGill University with work in the field of radioactivity. There he reported on the discovery that rays given off by radioactive substances are of several different kinds. He called the positively charged ones alpha rays and the negatively charged ones beta rays. The names are still used, but today the rays are known to be speeding particles and are called alpha and beta particles. When Paul Villard discovered in 1900 that some rays were not affected by a magnetic field, Rutherford proved that these consisted of electromagnetic waves, which he called gamma rays.

Rutherford in the 1930s.

Rutherford and Soddy collaborated in research on radioactive disintegration. They believed that, starting with uranium, each radioactive element decays, or breaks down, into a different element, and this element breaks down into another, etc. The last element formed is lead.

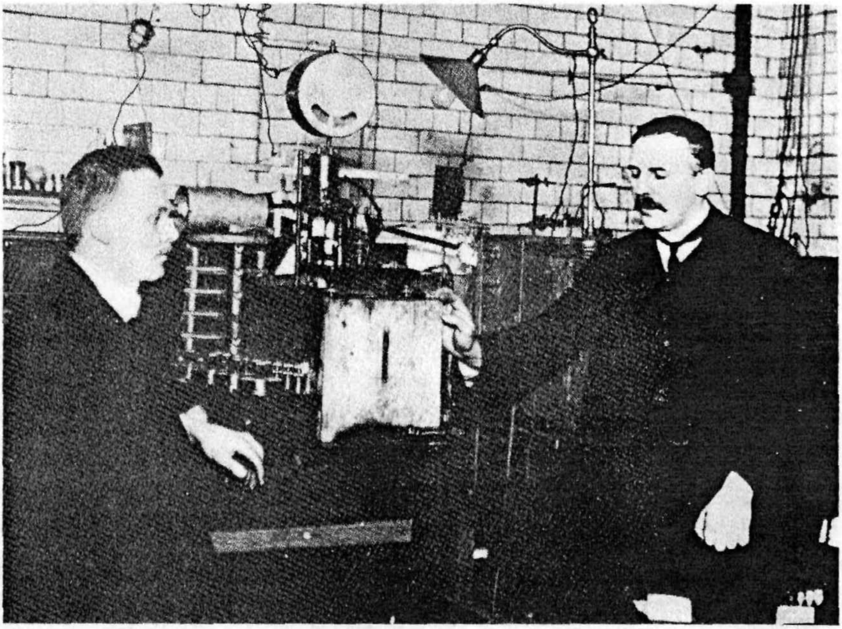
Rutherford began to study how alpha particles are scattered by thin sheets of metal. Two years later when he fired alpha particles at a thin sheet of gold foil, most of the particles passed through unaffected. But some of them scattered at large angles, which meant that somewhere in the atom there was a massive positively charged region that deflected the positively charged alpha particle. Rutherford described this as "almost as incredible as if you fired a fifteen-inch shell at a piece of tissue paper and it came back and hit you".

Rutherford lecturing in New Zealand in 1926.

Rutherford went to Manchester University in 1909 and established a center for the study of radioactivity. He proved that the alpha particle was a helium atom with its electrons removed. (Later he said that the simplest positive rays must be those obtained from hydrogen and that these must be a fundamental positively charged particle, which he called a proton.)

From this research Rutherford evolved the nuclear theory, the greatest of all his contributions to physics. He suggested that the atom contains a very tiny nucleus at its center, which is positively charged and contains all the protons of the atom and therefore almost all its mass. Very light negatively charged electrons, posing little barrier to alpha particles passing through the atom, make up the outer regions.

In 1908 he won a Nobel Prize for "his investigations of the chemistry of radioactive substances". In a letter to his mother he said that the prize was very acceptable, "both as regards honour and cash".



Hans Geiger (left) and Rutherford at Manchester University about 1910.

The nuclear theory was not Rutherford's sole contribution to science. With Hans Geiger he used a scintillation counter to measure radioactivity. They counted the flashes (scintillations), each of which signified a colliding particle, on a zinc sulfide screen and determined that a gram of radium emitted 37 billion alpha particles a second. This is the basis for the unit called the curie. See page 63.

Scintillation counting was very tedious. Rutherford usually had his assistants perform this task because the one time that he attempted it, he "damned vigorously and retired after two minutes".

In 1917 he continued his research into radioactivity. In 1919 he succeeded in disintegrating nitrogen nuclei by alpha particle bombardment, producing charged hydrogen atoms and oxygen at the same time. With this act he accomplished the first artificial transmutation* of one element into another. This was the first man-made "nuclear reaction", and by 1924 Rutherford accomplished the feat of knocking the protons out of the nuclei of most of the lighter elements.

Rutherford was a marvelous teacher and infected his students with his own enthusiasm for scientific research. (Among his many illustrious students were Ernest Marsden, Hans Geiger, Ernest Walton, James Chadwick, Francis Aston, John Cockcroft, Henry Moseley, Otto Hahn, Frederick Soddy, etc.) His students said of him, "He had none of the meaner faults and was just as willing to attend to the youngest student and if possible learn from him as . . . to listen to any recognized scientific authority. He made us feel as if we were living very near the center of the scientific universe."

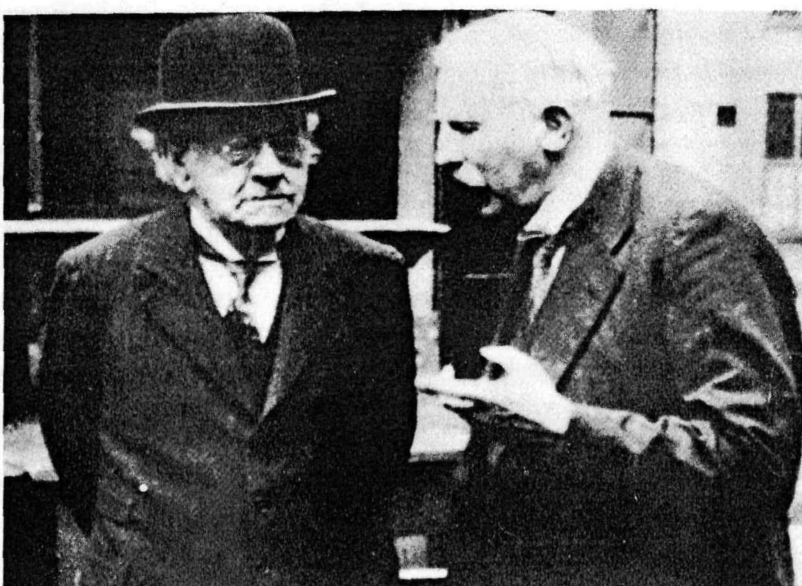
He had a short temper, which he sometimes displayed when experiments were not going to his satisfaction. When things ran along smoothly, he would walk through the

*To transmute means to change or alter.

laboratory singing "Onward Christian Soldiers".

Contribution to Atomic Science

Lord Rutherford contributed the theory of the basic structure of the atom itself. He was, in addition, the first scientist in history to produce man-made atomic disintegration, when he bombarded nitrogen atoms with alpha particles and produced protons. Fellow scientist Niels Bohr said when Rutherford died that, like Galileo, he "left science in quite a different state from that in which he found it". A physicist once said to Rutherford, "You are a lucky man. . . . always on the crest of the wave!" "Well," Rutherford remarked, "I made the wave, didn't I?"



Sir J. J. Thomson and Lord Ernest Rutherford.

FRANCIS W. ASTON

Francis William Aston, British physicist and chemist, invented the mass spectrograph, which made possible the separation of heavier and lighter atoms and proved that almost all elements are composed of mixtures of various isotopes. He was born in Harborne, England, on September 1, 1877, and died in Cambridge on November 20, 1945.

Biographical Details

A bright student who finished high school at the top of his class, Aston attended Malvern College and the University of Birmingham. His training was in chemistry, and in 1909 he became an assistant to J. J. Thomson at Cambridge University.

World War I interrupted the work that the two were conducting on neon gas and for 4 years Aston served in the British armed forces. Then he returned to Thomson's laboratory and redesigned Thomson's positive ray deflection apparatus into his own mass spectrograph. For his mass spectrograph and the knowledge he gained from it, he won the 1922 Nobel Prize in chemistry.

Scientific Achievements

In the mass spectrograph the electric and magnetic fields were arranged so that all particles having the same mass were brought to a focus that produced a fine line on photographic film. Each line indicated the presence of atoms or molecules of a particular mass. With this apparatus Aston confirmed that two forms of neon existed with atomic masses of 20 and 22. From the comparative darkness of the lines he decided that the ions of the mass 20 were ten times as numerous as those of 22. If put together all the ions would have an average mass of 20.2, which was the actual atomic weight of neon.

Working on chlorine, Aston came to similar conclusions about its atomic weight. He formulated his whole number rule: Atomic weights of the isotopes of elements are very close to integers (whole numbers) if the mass of hydrogen is taken as one. The fractional atomic weights are due to the presence of two or more isotopes, or mixtures of different atoms of different integral weights in one element. See page for a discussion of isotopes.

Aston continued to measure the exact masses of isotopes, and with a refined mass spectrograph was able to show that the atomic mass of individual isotopes on the atomic weight scale was a little different from integers, sometimes just a little higher or lower, but these slight differences turned out to represent the energy that went into binding the component parts of the nuclei together.

Contribution to Atomic Science

Aston discovered 212 out of 287 naturally occurring isotopes. His work in measuring more precisely the exact masses of the isotopes was indispensable to progress in mid-20th century atomic research. Aston developed the mass spectrograph, which J. J. Thomson "invented", into a refined instrument capable of making accurate measurements of atomic masses.

FREDERICK SODDY

Frederick Soddy, British chemist, was the first to believe that certain elements could exist in different forms or isotopes, differing only in their atomic weights. Soddy was born in Eastbourne, Sussex, on September 2, 1877, and died in Brighton on September 22, 1956.

Biographical Details

Soddy attended Oxford University and spent some time in London with William Ramsay where he became interested in radioactivity. He then moved to Montreal, Canada, to work at McGill University with Ernest Rutherford on radioactive disintegration.

He returned to England and became a professor at Aberdeen University and at Oxford University. He won the Nobel Prize in chemistry in 1921 for his discovery of isotopes.

Scientific Achievements

At McGill University Soddy helped Rutherford to explain radioactive disintegration. Soddy enjoyed working with the enthusiastic Rutherford. Shortly after arriving at McGill, Soddy said, "Rutherford . . . got me. I abandoned all to follow him and for more than two years scientific life became hectic to a degree rare in the lifetime of an individual." They theorized that each radioactive element beginning with uranium or thorium breaks down to form another element as it emits an alpha or beta particle. This process is repeated as the new element breaks down, until lead is formed.

In the process of studying these radioactive transformations Soddy detected forty to fifty elements with different radioactive properties, but there were not enough spaces on Mendeléev's Periodic Table of the Elements for them. Soddy said that different radioactive elements could be fitted into the same space on the table. He named these elements isotopes (from the Greek words *isos* and *topos*, which mean same place). The position in which the individual isotope could be placed depended upon the emission of an alpha or beta particle, when an alpha particle is emitted, it causes the atomic number* of the new element to decrease by two. When a beta particle is emitted, the atomic number increases by one.

Soddy's work made it clear that isotopes were really atoms of a single chemical element having differing masses. They differed in radioactive characteristics because of differences in the composition of the nucleus; radioactive characteristics depend on the nature of the nucleus. But isotopes of one element had the same chemical properties because they had the same number of electrons in the outer regions of the atom.

In 1914 he also proved that the final stable element into which radioactive intermediates were converted was lead.

Contribution to Atomic Science

Before 1913 it was generally believed that chemical properties of the elements were determined by their atomic weights. Soddy's discovery of isotopes made clear the fact that certain elements could exist in two or more forms and with different atomic weights and yet be indistinguishable and inseparable chemically. From this significant discovery of isotopes, many mysterious aspects of chemical elements could finally be solved.

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*Atomic number is the number of protons in the nucleus of an atom, and also its positive charge. Each chemical element has its characteristic atomic number.

LISE MEITNER

Lise Meitner (mite-nur), Austrian physicist, was born in Vienna, Austria, on November 7, 1878, and died there on October 28, 1969.

Lise Meitner in 1916.

Biographical Details

Lise Meitner was the third in a family of eight children of a Viennese lawyer. She studied physics at the University of Vienna and moved to Berlin to study under Max Planck. Soon she joined Otto Hahn in his research on radioactivity and this collaboration lasted for 30 years.

She became a member of the Kaiser Wilhelm Institute for Chemistry in 1913 and became head of its physics section and co-director with Otto Hahn. In 1926 she became a professor of physics at the University of Berlin.

Lise Meitner at her final lecture on nuclear physics at Catholic University, Washington, D. C., on May 23, 1946.

During the early 1930s when Hitler began to persecute Jews, Lise Meitner, who was Jewish, was safe in Germany because she was an Austrian citizen. However, she was forced into exile in 1938 after the Nazi takeover of Austria and moved to Stockholm, Sweden.

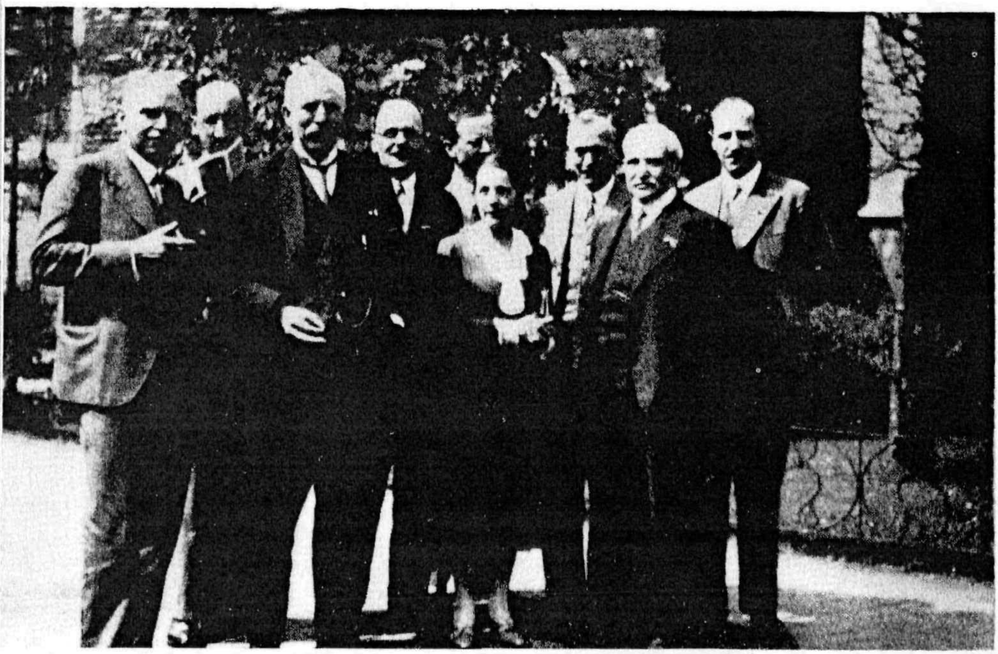
In Stockholm she became a member of the Nobel Institute staff and in 1949 became a Swedish citizen. She was elected to the Swedish Academy of Science, a rare honor for a woman.

Scientific Contributions

Lise Meitner's research on radioactivity with Otto Hahn led to the joint discovery of the new element protactinium in 1918.

In 1938 before she was forced to flee Berlin, she had been deeply interested in research on uranium bombardment by neutrons. Confusing theories had been proposed as the result of experiments. Finally in 1938 Hahn, her former collaborator, and Fritz Strassmann studied uranium bombardment by neutrons. They theorized that the resulting radioactive barium might be formed by a division of the uranium atom into two almost equal parts. Hahn hesitated to interpret this revolutionary theory, but Meitner, exiled in Stockholm, and her nephew, Otto Frisch, did give a theoretical interpretation to Hahn's observations.

Left to right, back row: George von Hevesy, Hans Geiger, James Chadwick, Karl Przibram, and Frederick Paneth; front row: Otto Hahn, Lord Rutherford, Lise Meitner, and Stefan Meyer.



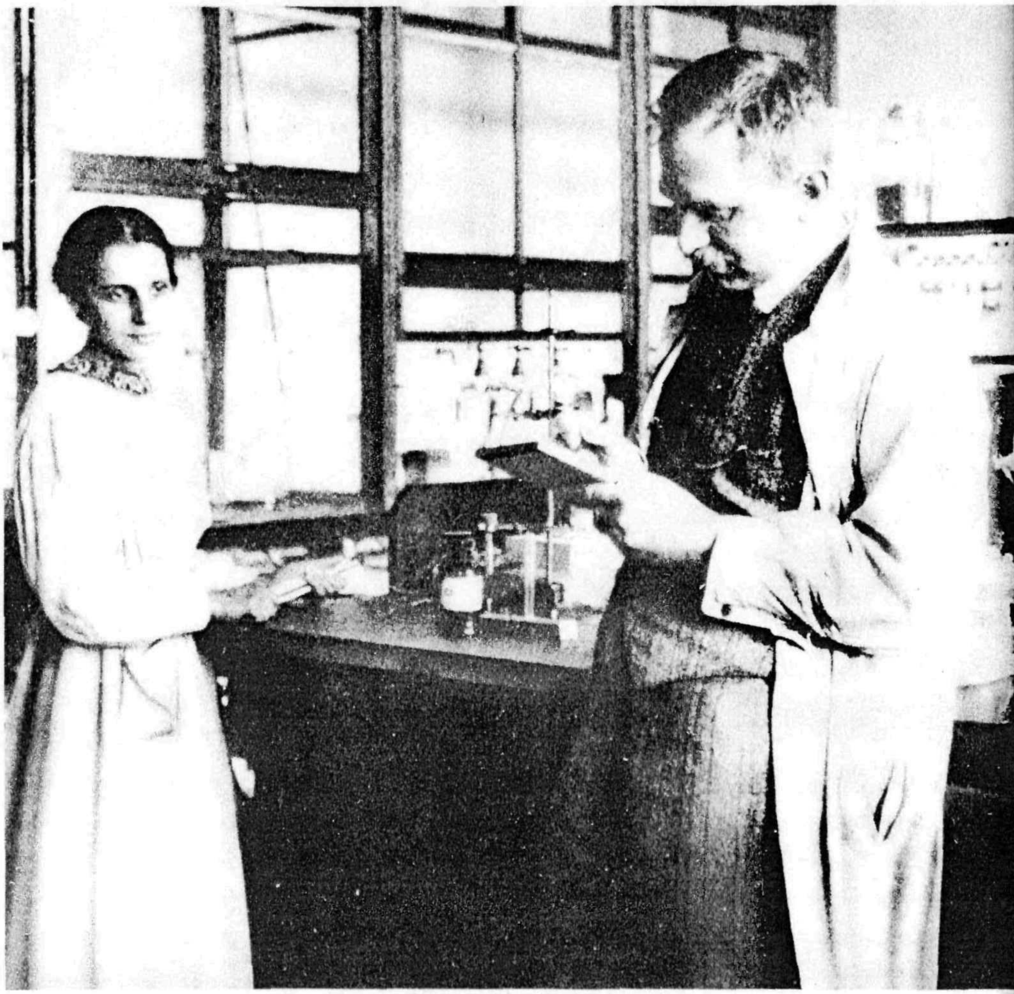
In January 1939, she and Frisch published a correct interpretation of this phenomenon of the interaction between neutrons and uranium. The announcement was made in a letter, entitled "A New Type of Nuclear Reaction", to the journal *Nature*. The term fission was suggested to Frisch by W. A. Arnold, and he and Meitner used it to describe the division of a heavy atomic nucleus into two approximately equal parts and predicted that the fragments of fission would be unstable, undergoing a chain of disintegrations and would be accompanied by the liberation of a large amount of energy.

Otto Frisch

Within a few months reports of the process of nuclear fission were brought to Washington, D. C., by Niels Bohr. This knowledge ultimately led to the sustained fission chain reaction in a nuclear reactor in Chicago in 1942.

Contribution to Atomic Science

Lise Meitner's publication of Hahn's milestone fission experiment did much to accelerate nuclear research.



Lise Meitner and Otto Hahn in their laboratory in the 1930s.

OTTO HAHN

Otto Hahn, German chemist, discovered with Fritz Strassmann the fission of the uranium nucleus, thereby laying the foundation for all later work on atomic energy. He was born in Frankfurt-am-Main, Germany, on March 8, 1879, and died in Göttingen, West Germany, on July 28, 1968.

Biographical Details

Hahn was educated in Munich. He began to study radioactive materials with William Ramsay at the University of London and continued at McGill University in Montreal under Ernest Rutherford.

He returned to Germany in 1912 to work at the Kaiser Wilhelm Institute. He became its director and much of his work on the atom was done there. In 1918 with his longtime collaborator, Lise Meitner, he discovered the new element protactinium. In 1938 with Fritz Strassmann he discovered the fission of the uranium nucleus.

Hahn continued his experiments in Germany during the war.

Scientific Achievements

Hahn's greatest contribution to science came after Fermi's bombardment of uranium with neutrons in the mid-1930s. In 1938 Hahn and Strassmann bombarded uranium with a stream of neutrons. They concluded that one of the products of neutron-bombarded uranium was radioactive barium.

Hahn decided that the radioactive barium being produced might have been formed only by the breaking in half of the uranium atom, since the uranium atom was much heavier than the barium atom. This process of division of an atom into two nearly equal parts was later called fission. It was such a revolutionary concept that Hahn hesitated to interpret the theory.

For this work on uranium fission Hahn won the 1944 Nobel Prize in chemistry.

Contribution to Atomic Science

Otto Hahn's concept of fission of the uranium nucleus was the basic idea needed to invent all methods of successfully tapping atomic energy. It provided American atomic research with the clues necessary to begin the rapid wartime development of the atomic bomb as well as the peaceful uses of atomic energy.

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

Discoverer of X Rays Wilhelm Conrad Roentgen, Arnulf K. Esterer, Julian Messner, New York, 1968, 191 pp., $3.50. Grades 7-10.

Discovery of the Elements (seventh edition), Mary E. Weeks, Chemical Education Publishing Company, Easton, Pennsylvania, 1968, 910 pp., $12.50. Grades 9-12.

Elements of the Universe, Glenn T. Seaborg and Evans G. Valens, E. P. Dutton and Company, Inc., New York, 1958, 253 pp., $5.95 (hardback); $2.15 (paperback). Grades 6-9.

Ernest Rutherford Architect of the Atom, Peter Kelman and A. Harris Stone, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1969, 72 pp., $3.95. Grades 5-7.

Faraday, Maxwell, and Kelvin, D. K. C. MacDonald, Doubleday and Company, Inc., New York, 1964, 143 pp., $1.25.

Giant of the Atom Ernest Rutherford, Robin McKown, Julian Messner, New York, 1962, 191 pp., $3.50. Grades 7-12.

Madame Curie: A Biography, Eve Curie, translated by Vincent Sheean, Doubleday and Company, Inc., New York, 1937, 385 pp., $5.95 (hardback); $0.95 (paperback). Grades 9-12.

Men Who Mastered the Atom, Robert Silverberg, G. P. Putnam's Sons, New York, 1965, 193 pp., $3.30. Grades 7-9.

On the Various Forces of Nature, Michael Faraday, Crowell Collier and Macmillan, Inc., New York, 1961, 155 pp., $2.75. A reprint of the famous Christmas Lectures given at the Royal Institution in 1859. These lectures deal with fundamental physical concepts: gravitation, cohesion, chemical affinity, heat, magnetism, electricity, and the correlation of physical forces.

The Questioners: Physics and the Quantum Theory, Barbara Lovett Cline, Crowell Collier and Macmillan, Inc., New York, 1965, 274 pp., $5.00 (hardback); *Men Who Made a New Physics: Physicists and the Quantum Theory* (paperback title), New American Library, Inc., New York, $0.75. Grades 9-12.

The Restless Atom, Alfred Romer, Doubleday and Company, Inc., New York, 1960, 198 pp., $1.25. Grades 9-12.

Secret of the Mysterious Rays: The Discovery of Nuclear Energy, Vivian Grey, Basic Books, Inc., Publishers, New York, 1966, 120 pp., $3.95. Grades 4-8.

The Story of Radioactivity, Colin A. Mawson, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1969, 64 pp., $3.95. Grades 3-6.

Wilhelm Roentgen and the Discovery of X Rays, Bern Dibner, Franklin Watts, Inc , New York, 1968, 149 pp., $2 95. Grades 5-8.

Working with Atoms, Otto R Frisch, Basic Books, Inc , Publishers, New York, 1965, 96 pp , $4 95 Grades 9-12

X Rays and Gamma Rays, Daniel S. Halacy, Jr , Holiday House, Inc , New York, 1969, 159 pp., $4 50 Grades 10-12.

Advanced Books

Asimov's Biographical Encyclopedia of Science and Technology The Living Stories of More than 1000 Great Scientists from the Age of Greece to the Space Age, Isaac Asimov, Doubleday and Company, Inc., New York, 1964, 662 pp., $8 95.

The Atomists (1805–1933), Basil Schonland, Oxford University Press, Inc., New York, 1968, 198 pp., $5.60.

The Autobiography of Science (revised edition), Forest Ray Moulton and Justus J Schifferes (Eds), Doubleday and Company, Inc , New York, 1960, 748 pp , $6 95

The Flash of Genius, Alfred B Garrett, Van Nostrand Reinhold Company, New York, 1963, 249 pp., $6.50.

A History of Science (fourth edition), Sir William Cecil Dampier, Cambridge University Press, New York, 1949, 527 pp., $7 50 (hardback), $3.45 (paperback).

J. J. Thomson: Discoverer of the Electron, George Thompson, Doubleday and Company, Inc., New York, 1966, 240 pp., $1.45.

Michael Faraday, L. Pearce Williams, Basic Books, Inc., Publishers, New York, 1965, 531 pp., $12.50.

Otto Hahn A Scientific Autobiography, Otto Hahn, Willy Ley (editor and translator), Charles Scribner's Sons, New York, 1966, 320 pp., $7.95.

Otto Hahn. My Life, Otto Hahn, translated by Ernest Kaiser and Eithne Wilkins, Herder and Herder, Inc., New York, 1970, 240 pp., $6.50.

Physics and Beyond Encounters and Conversations, Werner Heisenberg, translated by Arthur J. Pomerans, Harper & Row, Publishers, New York, 1970, 247 pp., $7.95.

Sourcebook on Atomic Energy (third edition), Samuel Glasstone, Van Nostrand Reinhold Company, New York, 1967, 883 pp., $9.25.

Universe, Earth and Atom· The Story of Physics, Dr. Alan E. Nourse, Harper and Row, Publishers, New York, 1969, 640 pp., $8.95.

The World of the Atom, 2 volumes, Henry A. Boorse and Lloyd Motz (Eds.), Basic Books, Inc., Publishers, New York, 1966, 1873 pp., $35.00.

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The Atomic Nucleus, Robert Hofstadter, *Scientific American,* 195: 55 (July 1956).

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The Discovery of Fission, Otto Hahn, *Scientific American,* 198: 76 (February 1958).

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Joseph Henry, Mitchell Wilson, *Scientific American,* 191: 72 (July 1954).

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The Septuagenarian Electron, Sir George Thomson, *Physics Today*, 20: 55 (May 1967).

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