Physics

The 1920s were the most important decade in 20th century physics as scientists translated their experiments on atoms into quantum theory. Meanwhile, there was intense debate over Einstein's theories of space and time, and rocket science began on a farm in Massachusetts.

Physics underwent a massive upheaval in the first two decades of the 20th century. The German physicist Albert Einstein (1879-1955) shattered familiar notions of space and time with his special and general theories of relativity. Meanwhile, the new science of atomic physics, spearheaded by New Zealand-born British physicist Ernest Rutherford (1871-1937), was providing a wealth of information about the fundamental make-up of matter. The 1920s became the most important decade of 20th century physics as theoreticians translated these experimental results into the theory of quantum physics. While this mathematical work was mostly carried out in Europe, American physicists were responsible for several crucial tests of these ideas. These investigations began a tradition of American experimentation that placed the United States at the forefront of atomic and nuclear research.

Near the end of the 19th century, scientists were starting to believe that physics was almost complete. The American physicist Albert Abraham Michelson (1852-1931) summarized the mood in a typically overoptimistic statement of the time: "Our future discoveries must be looked for in the sixth decimal place." But this situation was about to radically change. In 1896 the French physicist Antoine Henri Becquerel (1852-1908) discovered radioactivity when he accidentally found that invisible radiation from uranium blackened photographic plates. Then in 1897 the British physicist Joseph John Thomson (1856-1940) discovered the electron in rays from a cathode tube—a glass cylinder through which electricity is passed—finding the first subatomic particle, with a mass nearly 2000 times smaller than any atom. A decade later, in 1911, Rutherford showed that atoms contain a small, dense nucleus surrounded by orbiting electrons.

But all was not well with the theory of atoms. Electromagnetism predicts that an electron orbiting a nucleus should radiate energy and fall into the center of the atom. Yet atoms appeared stable and their electrons had precise energies. Furthermore, both the German physicist Max Planck (1858-1947) and Einstein had explained certain anomalies in the behavior of light by radiation that comes in discrete packets of energy. Such radiation quanta, however, had no explanation in known physics. The solution to these problems would revolutionize our view of the physical world.

At the same time as many physicists were preparing for quantum theory, other scientists were looking in completely different directions. In 1916 Einstein proposed his theory that gravity is a distortion of space and time, overturning several centuries of physics. Three years later the American engineer Robert Hutchings Goddard (1882-1945) published his book *A Method of Reaching Extreme Altitudes,* in which he conceives of a rocket reaching the moon. Also in 1919 the American astronomer Edwin Powell Hubble (1889-

1953) begun work at Mount Wilson observatory near Pasadena, California, where he will discover that the universe is expanding and fundamentally change our view of the cosmos.

The Quantum Revolution

The 1920s discovery of quantum physics—the theory behind atomic and nuclear phenomena—is the most important event in 20th century science. It radically changed how scientists view the world and enabled the development of new technologies such as nuclear power, the atom bomb, lasers, superconductors, and solid-state electronics for computer chips. The main causes of this quantum revolution were a combination of insightful theoretical work in Europe backed by crucial experiments in the United States. European universities contained a new generation of young, mathematically gifted academics brought up on the revolutionary theories of Einstein. Meanwhile, American laboratories and university departments had plentiful private funds geared towards industrial and experimental research.

In 1913 the Danish physicist Niels Bohr (1885-1962) laid the groundwork for quantum physics. Seeking to show how Rutherford's picture of electrons orbiting a nucleus was consistent with Planck and Einstein's light quanta, Bohr proposed the first quantum theory of the atom. In his atomic model electrons rotate around the nucleus in distinct energy levels, releasing or absorbing packets of radiation energy when they jump between levels. This theory worked well for hydrogen—which has just a nucleus and one electron—giving the correct answers for its radiation energies. But it failed for atoms that are more complex, like helium. Moreover, Bohr's model seemed to capture some part of nature, yet was incomplete and simplistic. Further progress in quantum physics had to wait several years as Europe entered World War I (1914-1918).

The next major event in quantum theory came in 1922 when American physicist Arthur Holly Compton (1892-1962) discovered how light scatters off electrons in atoms. While working at Washington University, St. Louis, he found that high-energy X-rays appeared to act like particles, rather than waves, when they hit electrons. This effect agreed with the idea that quantum packets of radiation energy were in fact particles, which Compton named 'photons.' Physicists were now becoming familiar with one of the main ideas in quantum theory: that light could sometimes behave like a wave (when traveling, for example) and at other times act like a particle. Somehow, quantum physics combined these two, apparently contradictory, notions.

A French theoretician, Louis Victor de Broglie (1892-1987), provided the next piece in the puzzle. In 1924 he proposed that since light, an electromagnetic wave, could be particle-like, then particles such as electrons should sometimes behave like waves. This wave-particle duality provided the necessary key for the Austrian physicist Erwin Schrödinger (1887-1961) to postulate his 1925 wave equation for matter in quantum physics. Schrödinger solved his wave equation for electrons orbiting the hydrogen atom and found answers similar to Bohr's atomic model; furthermore, the extension of his results to the helium atom also agreed with experiment.

Direct experimental validation of de Broglie's ideas was provided in 1927 by American researchers Clinton Davisson (1881-1958) and Lester Germer (1896-1971). Working at the Bell Telephone Laboratories, Davisson and Germer showed that a crystal diffracted electrons in a similar way to light and other electromagnetic waves. Therefore electrons could sometimes behave like waves and at other times act like particles, just like light. Quantum physics was now on a firm footing.

In the following years no fundamental flaws have been found in the basic principles of quantum physics. Scientists have discovered phenomena inside the atom and described the basic constituents of its nucleus, but all new physics has remained within the original framework from the 1920s. Meanwhile, quantum physics has completely changed our view of the world. The wave-particle duality of all basic matter—electrons, atomic nuclei, and subatomic particles—means they are distributed throughout space, disappearing from one place and reappearing at another as they change energy and interact.

Cosmic rays

At the start of the 20th century scientists were beginning to comprehend that the earth is being bombarded by high-energy radiation from outer space, called cosmic rays. Austrian-American physicist Victor Franz Hess (1883-1964) discovered this radiation between 1911 and 1912. By placing detectors in balloons, he showed that radiation became stronger at higher altitudes and thus was likely to come from outside the earth's atmosphere.

Throughout the 1920s American physicist Robert Andrews Millikan (1868-1753) pursued the main research into cosmic radiation. At the time he was the most famous scientist in the United States and had achieved a Nobel Prize in physics for an ingenious measurement of the charge of an electron. Millikan's experiments confirmed Hess's original discovery, which many scientists doubted at that time, and greatly developed the technology of cosmic radiation measurement. He also thought of the name 'cosmic rays.'

Most of Millikan's work on cosmic rays was done at the Norman Bridge Laboratory of Physics at the California Institute of Technology (Caltech) in Pasadena, California, where he was appointed director in 1921. Under his leadership the laboratory became one the foremost research centers in the world.

Particle accelerators

Towards the end of the 1920s the American physicist Ernest Orlando Lawrence (1901-1958) was thinking about the future of atomic and nuclear physics. While working at the University of California in Berkeley in 1929 he conceived the cyclotron—a circular device where charged particles such as electrons and atomic nuclei are accelerated to extremely high velocities and then collided. The cyclotron works by having two D-shaped electromagnets that guide the charged particles in semi-circular paths; between the Ds is a slight gap over which a strong electric field accelerates the particles. Thus the particles circle around the cyclotron, gaining higher and higher speeds.

Such particle accelerators became the main instruments for 20th century nuclear and particle physics research. Most major discoveries, such as the various subatomic particles and the creation of new atomic elements, used devices based on Lawrence’s original cyclotron. Moreover, the instrument used to electromagnetically separate uranium-235 for the atomic bomb was also of similar design.

Lawrence's first cyclotron, which was built by his student American physicist Milton Stanley Livingston (1905-1986), was a few meters across and applied about thirteen thousand volts of electricity. Modern particle accelerators such as the Tevatron at the Fermi National Accelerator Laboratory (Fermilab) in Illinois are several miles in diameter and use about one trillion volts. The Lawrence Berkeley Radiation Laboratory in California, which Lawrence founded, is named after him.

Einstein's theory of relativity

At the start of the 1920s the world was still reeling from Albert Einstein's discoveries. In his 1916 theory of general relativity Einstein suggested that gravity—the force that makes objects fall and planets orbit the sun—is actually caused by mass distorting space and time. Thus a satellite actually travels in a straight line, but appears to have a circular orbit because space is bent. In 1919 the British astronomer Sir Arthur Stanley Eddington (1882-1944) confirmed Einstein's theory by photographing a solar eclipse, finding that the positions of stars were distorted near the sun in exactly the way predicted by general relativity.

Einstein embarked on a lecture tour of the United States in 1921, visiting many of the major universities such as Princeton and New York University. He spoke to packed auditoriums and lecture halls, and his actions were reported widely in the American press. From the 1920s onward Einstein spent a large amount of his life in the United States working on his unified theory of gravity and electromagnetism—efforts that were to prove in vain, with this problem still unsolved today.

Working at Mount Wilson observatory, California, the astronomer Edwin Powell Hubble made several important discoveries about the cosmos that had a direct effect on general relativity. Between 1922 and 1924 he showed that the universe contains galaxies other than our own vast star system the Milky Way. Then in 1927 he discovered that these galaxies are moving away from our galaxy—in other words the universe is expanding. Einstein had previously assumed the universe was static and altered his original equations to model this effect. However, his changes looked artificial and spoilt the elegance of the theory. An expanding universe meant these changes were no longer necessary, which Einstein later called his "greatest blunder."

The birth of rocket science

Widely acknowledged as the father of modern rocket science, the American inventor Robert Hutchings Goddard single-handedly developed the theory and practice of rocket propulsion. Motivated by the future possibility of space travel to other planets, it was Goddard's ambition to send a rocket to the moon. Although his work achieved scant notice in the United States during his lifetime, Goddard did more than any other scientist to bring rocket flight to reality.

After receiving modest financial support from the Smithsonian Institution, Goddard put his theory of rocket propulsion into practice. Over the years 1920 to 1926 he designed, tested, and built the first rocket to use liquid fuel, using a mix of petrol and liquid oxygen. Then on March 16, 1926, Goddard successfully sent his liquid-propelled rocket on its first flight at his Aunt's farm in Auburn, Massachusetts. Three years later Goddard shot the first scientific payload—a barometer, thermometer, and camera—in a rocket flight.

In 1929 after receiving unwanted media attention from a noisy test flight, Goddard attracted more financial support through a petition by the famous American aviator Charles Augustus Lindbergh (1902-1974) to the Guggenheim Foundation Fund for the Promotion of Aeronautics. This funding meant he could employ assistants to help create rockets that could reach higher altitudes. Goddard's research later proved instrumental to missile technology and space flight. NASA's Goddard Space Flight center in Greenbelt, Maryland, is named in his honor.

American Nobel Prizes in Physics (1901-1939)

Beginning in 1901, the Nobel Prize is the highest public accolade that any scientist can receive. It was founded by the Swedish inventor Alfred Bernhard Nobel (1833-1896) in response to the wartime horrors of his invention dynamite. In the first few decades of the 20th century many American physicists won Nobel Prizes for their outstanding scientific discoveries.

1907: Albert Abraham Michelson for "his optical precession instruments and metrological investigations carried out with their aid." In 1887 Michelson and American chemist Edward Morley (1838-1923) experimentally disproved the ether—a medium that everything was thought to move through—motivating Einstein's work on relativity.

1923: Robert Andrews Millikan for "his [1909] work on the elementary charge of electricity and on the photoelectric effect."

1927: Arthur Holly Compton for "his discovery of the effect named after him." In 1922 Compton showed that light acts like particle when scattering off electrons in metals.

1936: Carl David Anderson (1905-1991) for "his [1932] discovery of the positron." The positron is the antiparticle of an electron, with the same mass but opposite electric charge.

1937: Clinton Joseph Davisson for his "experimental [1927] discovery of the diffraction of electrons by crystals." Davisson's discovery provided the first evidence that electrons could sometimes be wave-like.

1939: Ernest Orlando Lawrence for "the invention and development of the cyclotron and for results obtained with it, especially with regard to artificial radioactive elements." Lawrence designed and built the first particle accelerator.

Clinton Joseph Davisson

The American physicist Clinton Joseph Davisson was born in 1881 at Bloomington, Illinois, where he went to public school and gained a scholarship to study physics and mathematics at the University of Chicago. After being recommended by Robert Millikan he worked as a researcher at several institutions. Finally, in 1918 he settled at the Bell Telephone Laboratories, where he spent most of his career and did his best work.

In 1927 Davisson and his assistant Lester Germer found that a metallic crystal diffracts electrons similarly to light waves. Thus electrons could sometimes be wave-like, one of the main principles of quantum physics. Davisson received the 1937 Nobel Prize in physics for this important discovery. Continuing his research into the wave-like properties of electrons, Davisson later helped to develop the electron microscope. By using electrons instead of light, these microscopes can magnify up to one million times and have revolutionized biology and materials science.

A 1920s view of matter

At the start of the 20th century scientists had a reasonable understanding of matter. They believed that all common substances are made from atoms chemically combined into various compounds and molecules. Chemists had found about 90 types of atom, composing pure elements such as hydrogen, oxygen, and gold. Furthermore, the chemical and physical properties of these elements displayed patterns—for example, the second, tenth, and eighteenth heaviest atoms (helium, neon, and argon) were inert gases, whereas the third, eleventh, and nineteenth (lithium, sodium, and potassium) were highly reactive metals. Scientists summarized this behavior in a chart called the *periodic table*.

By the 1920s the understanding of the atom had increased enormously. Rutherford showed that each atom had a tiny nucleus containing most of the atomic mass, around which revolved electrons. This nucleus had a positive electric charge to which the negatively charged electrons were attracted, while the atom was neutral. Bohr supposed the electron orbits had precise energies that grouped into shells, of which the first shell had two orbits, and the next two had eight orbits. Linking this pattern to the periodic table, scientists explained each atom's chemistry by the number of electrons filling these shells—inert helium, neon, and argon have full shells, for example, while reactive lithium, sodium, and potassium have a shell with one free electron.

See also:
Astronomy
Compton, Arthur H.
Hubble, Edwin P.
Lawrence, Ernest O.

Millikan, Robert A.