Bohr, Niels

Bohr

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Introduction

One of the foremost scientists of the 20th century, Niels Henrik David Bohr was the first to apply the quantum theory, which restricts the energy of a system to certain discrete values, to the problem of atomic and molecular structure. He was a guiding spirit and major contributor to the development of quantum mechanics and atomic physics. His work on atomic theory was recognized by the Nobel Prize for Physics in 1922.

Early life.

Bohr was born in Copenhagen on Oct. 7, 1885. His father, Christian Bohr, professor of physiology at the University of Copenhagen, was known for his work on the physical and chemical aspects of respiration. His mother, Ellen Adler Bohr, came from a wealthy Jewish family prominent in Danish banking and parliamentary circles. Bohr's scientific interests and abilities were evident early, and they were encouraged and fostered in a warm, intellectual family atmosphere. Niels's younger brother, Harald, became a brilliant mathematician.

Bohr distinguished himself at the University of Copenhagen, winning a gold medal from the Royal Danish Academy of Sciences and Letters for his theoretical analysis of and precise experiments on the vibrations of water jets as a way of determining surface tension. In 1911 he received his doctorate for a thesis on the electron theory of metals that stressed the inadequacies of classical physics for treating the behaviour of matter at the atomic level. He then went to England, intending to continue this work with Sir J.J. Thomson at Cambridge. Thomson never showed much interest in Bohr's ideas on electrons in metals, however, although he had worked on this subject in earlier years. Bohr moved to Manchester in March 1912 and joined Ernest Rutherford's group studying the structure of the atom.

At Manchester Bohr worked on the theoretical implications of the nuclear model of the atom recently proposed by Rutherford and known as the Rutherford atomic model. Bohr was among the first to see the importance of the atomic number, which indicates the position of an element in the periodic table and is equal to the number of natural units of electric charge on the nuclei of its atoms. He recognized that the various physical and chemical properties of the elements depend on the electrons moving around the nuclei of their atoms and that only the atomic weight and possible radioactive behaviour are determined by the small but massive nucleus itself. Rutherford's nuclear atom was both mechanically and electromagnetically unstable, but Bohr imposed stability on it by introducing the new and not yet clarified ideas of the quantum theory being developed by Max Planck, Albert Einstein, and other physicists. Departing radically from classical physics, Bohr postulated that any atom could exist only in a discrete set of stable or stationary states, each characterized by a definite value of its energy. This description of atomic structure is known as the Bohr atomic model.

The most impressive result of Bohr's essay at a quantum theory of the atom was the way it accounted for the series of lines observed in the spectrum of light emitted by atomic hydrogen. He was able to determine the frequencies of these spectral lines to considerable accuracy from his theory, expressing them in terms of the charge and mass of the electron and Planck's constant (the quantum of action, designated by the symbol *h*). To do this, Bohr also postulated that an atom would not emit radiation while it was in one of its stable states but rather only when it made a transition between states. The frequency of the radiation so emitted would be equal to the difference in energy between those states divided by Planck's constant. This meant that the atom could neither absorb nor emit radiation continuously but only in finite steps or quantum jumps. It also meant that the various frequencies of the radiation emitted by an atom were not equal to the frequencies with which the electrons moved within the atom, a bold idea that some of Bohr's contemporaries found particularly difficult to accept. The consequences of Bohr's theory, however, were confirmed by new spectroscopic measurements and other experiments.

Bohr returned to Copenhagen from Manchester during the summer of 1912, married Margrethe Nørlund, and continued to develop his new approach to the physics of the atom. The work was completed in 1913 in Copenhagen but was first published in England. In 1916, after serving as a lecturer in Copenhagen and then in Manchester, Bohr was appointed to a professorship in his native city. The university created for Bohr a new Institute of Theoretical Physics, which opened its doors in 1921; he served as director for the rest of his life.

Through the early 1920s, Bohr concentrated his efforts on two interrelated sets of problems. He tried to develop a consistent quantum theory that would replace classical mechanics and electrodynamics at the atomic level and be adequate for treating all aspects of the atomic world. He also tried to explain the structure and properties of the atoms of all the chemical elements, particularly the regularities expressed in the periodic table and the complex patterns observed in the spectra emitted by atoms. In this period of uncertain foundations, tentative theories, and doubtful models, Bohr's work was often guided by his correspondence principle. According to this principle, every transition process between stationary states as given by the quantum postulate can be "coordinated" with a corresponding harmonic component (of a single frequency) in the motion of the electrons as described by classical mechanics. As Bohr put it in 1923, "notwithstanding the fundamental departure from the ideas of the classical theories of mechanics and electrodynamics involved in these postulates, it has been possible to trace a connection between the radiation emitted by the atom and the motion of the particles which exhibits a far-reaching analogy to that claimed by the classical ideas of the origin of radiation." Indeed, in a suitable limit the frequencies calculated by the two very different methods would agree exactly.

Bohr's institute in Copenhagen soon became an international centre for work on atomic physics and the quantum theory. Even during the early years of its existence, Bohr had a series of coworkers from many lands, including H.A. Kramers from The Netherlands, Georg Charles von Hevesy from Hungary, Oskar Klein from Sweden, Werner Heisenberg from Germany, and John Slater from the United States. Bohr himself began to travel more widely, lecturing in many European countries and in Canada and the United States.

At this time, more than any of his contemporaries, Bohr stressed the tentative and symbolic nature of the atomic models that were being used, since he was convinced that even more radical changes in physics were still to come. In 1924 he was ready to consider the possibility that the conservation laws for energy and momentum did not hold exactly on the atomic level but were valid only as statistical averages. This extreme measure for avoiding the apparently paradoxical particle-like properties of light soon proved to be untenable and also unnecessary. During the next few years, a genuine quantum mechanics was created, the new synthesis that Bohr had been expecting. The new quantum mechanics required more than just a mathematical structure of calculating; it required a physical interpretation. That physical interpretation came out of the intense discussions between Bohr and the steady stream of visitors to his world capital of atomic physics, discussions on how the new mathematical description of nature was to be linked with the procedures and the results of experimental physics.

Bohr expressed the characteristic feature of quantum physics in his principle of complementarity, which "implies the impossibility of any sharp separation between the behaviour of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear." As a result, "evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects." This interpretation of the meaning of quantum physics, which implied an altered view of the meaning of physical explanation, gradually came to be accepted by the majority of physicists. The most famous and most outspoken dissenter, however, was Einstein.

Einstein greatly admired Bohr's early work, referring to it as "the highest form of musicality in the sphere of thought," but he never accepted Bohr's claim that quantum mechanics was the "rational generalization of classical physics" demanded for the understanding of atomic phenomena. Einstein and Bohr discussed the fundamental questions of physics on a number of occasions, sometimes brought together by a close mutual friend, Paul Ehrenfest, professor of theoretical physics at the University of Leiden, Neth., but they never came to basic agreement. In his account of these discussions, however, Bohr emphasized how important Einstein's challenging objections had been to the evolution of his own ideas and what a deep and lasting impression they had made on him.

During the 1930s Bohr continued to work on the epistemological problems raised by the quantum theory and also contributed to the new field of nuclear physics. His liquid-drop model of the atomic nucleus, so called because he likened the nucleus to a liquid droplet, was a key step in the understanding of many nuclear processes. In particular, it played an essential part in 1939 in the understanding of nuclear fission (the splitting of a heavy nucleus into two parts, almost equal in mass, with the release of a tremendous amount of energy). Similarly, his compound-nucleus model of the atom proved successful in explaining other types of nuclear reactions.

Bohr's institute continued to be a focal point for theoretical physicists until the outbreak of World War II. The annual conferences on nuclear physics as well as formal and informal visits of varied duration brought virtually everyone concerned with quantum physics to Copenhagen at one time or another. Many of Bohr's collaborators in those years have written lovingly about the extraordinary spirit of the institute, where young scientists from many countries worked together and played together in a lighthearted mood that concealed both their absolutely serious concern with physics and the darkening world outside. "Even Bohr," wrote H.B.G. Casimir, one of the liveliest of the group, "who concentrated more intensely and had more staying power than any of us, looked for relaxation in crossword puzzles, in sports, and in facetious discussions."

Later life.

When Denmark was overrun and occupied by the Germans in 1940, Bohr did what he could to maintain the work of his institute and to preserve the integrity of Danish culture against Nazi influences. In 1943, under threat of immediate arrest because of his Jewish ancestry and the anti-Nazi views he made no effort to conceal, Bohr, together with his wife and some other family members, was transported to Sweden by fishing boat in the dead of night by the Danish resistance movement. A few days later the British government sent an unarmed Mosquito bomber to Sweden, and Bohr was flown to England in a dramatic flight that almost cost him his life. During the next two years, Bohr and one of his sons, Aage (who later followed his father's career as a theoretical physicist, director of the institute, and Nobel Prize winner in physics), took part in the projects for making a nuclear fission bomb. They worked in England for several months and then moved to Los Alamos, N.M., U.S., with a British research team.

Bohr's concern about the terrifying prospects for humanity posed by such atomic weapons was evident as early as 1944, when he tried to persuade British Prime Minister Winston Churchill and U.S. President Franklin D. Roosevelt of the need for international cooperation in dealing with these problems. Although this appeal did not succeed, Bohr continued to argue for rational, peaceful policies, advocating an "open world" in a public letter to the United Nations in 1950. Bohr was convinced that free exchange of people and ideas was necessary to achieve control of nuclear weapons. He led in promoting such efforts as the First International Conference on the Peaceful Uses of Atomic Energy, held in Geneva (1955), and in helping to create the European Council for Nuclear Research (CERN). Among his many honours, Bohr received the first U.S. Atoms for Peace Award in 1957.

In his last years Bohr tried to point out ways in which the idea of complementarity could throw light on many aspects of human life and thought. He had a major influence on several generations of physicists, deepening their approach to their science and to their lives. Bohr himself was always ready to learn, even from his youngest collaborators. He drew strength from his close personal ties with his coworkers and with his sons, his wife, and his brother. Profoundly international in spirit, Bohr was just as profoundly Danish, firmly rooted in his own culture. This was symbolized by his many public roles, particularly as president of the Royal Danish Academy from 1939 until the end of his life. Bohr died in Copenhagen on Nov. 18, 1962.

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