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Big Bang

Category: The Cosmological Context

The big bang theory was developed to explain the origin of the expanding universe, uniting cosmology with general relativity and elementary particle physics. About 13 to 14 billion years ago, an explosion called the big bang created energy and matter, space and time. Ever since, space has been expanding with time, carrying matter and electromagnetic radiation with it. As space has expanded, its contents have evolved.

OVERVIEW

Sir Isaac Newton's law of universal gravitation led him to suggest that a static universe with a finite distribution of stars would collapse, but that an infinite universe could be stable. The possibility of an expanding universe, however, is contained within Albert Einstein's general theory of relativity, which he published in 1915. In 1917, Einstein himself found that his general theory in its original form would not permit a static universe. Because the scientific consensus then was that the universe on the large scale is static and unchanging, Einstein added an arbitrary constant (later called the cosmological constant) to his field equations to allow static solutions. Physically, the cosmological constant represents a long-distance repulsion that would balance gravitational attraction on a cosmic scale and thus permit a static universe.

Just five years later, in 1922, the Russian mathematical physicist Alexander Alexandrovich Friedmann found two solutions to the original general relativistic field equations (without the cosmological constant) in which the universe initially expands with time. In one (called "open"), the universe continues to expand forever. In the other (called "closed"), the universe expands to some maximum size, after which it contracts.

In 1927, the Belgian priest and cosmologist Abbé Georges Lemaître independently derived the same two solutions to the field equations of general relativity that Friedmann had obtained earlier. However, Lemaître went further, speculating about the origin of the expansion. Extrapolating backward in time, he realized that everything in the universe would come together at the same time in the distant past, thus pointing to a unique beginning of the universe. He envisioned all matter and space compressed into a "primeval atom" that split into all the atoms of all the elements present in the universe. An enormous explosion initiated the expansion of space and its fragmented matter. As he described the aftermath,

> The evolution of the world could be compared to a display of fireworks just ended—some few red wisps, ashes, and smoke. Standing on a well-cooled cinder, . . . we try to recall the vanished brilliance of the origin of the worlds.

Today we know that the chemical elements could not have been created the way Lemaître proposed. However, Lemaître's basic idea was prophetic. Many years later, the explosive origin of the universe was dubbed the "big bang." Just before his death in 1966, Lemaître learned of the discovery of the cosmic microwave background, which is greatly redshifted radiation emitted just a few hundred thousand years after the big bang—the "vanished brilliance of the origin of the worlds" about which he had speculated so many years earlier.

Observational confirmation that the universe actually is expanding came in 1929, when Edwin Hubble, assisted by Milton Humason, showed there is a correlation between galaxy distances and the redshifts of their spectra; the farther away a galaxy is, the more its spectrum is redshifted. The cause of this redshift, termed cosmological, is the expansion of the universe. As the universe expands, wavelengths of electromagnetic radiation are stretched by the expansion, so visible light is shifted toward longer, redder wavelengths. (The term "redshift" has come to be applied to a shift to longer wavelengths of any part of the electromagnetic spectrum.)

Starting in 1935, Friedmann's student George Gamow began work on more rigorously developing Lemaître's hypothesis of an explosive origin. Gamow proposed that the very dense initial state would have been very hot, and the universe cooled as it expanded. In 1946, he suggested that the primordial substance, which he called "ylem," had consisted of neutrons at a temperature of about 10 billion degrees, some of which decayed during the early stages of expansion to form protons and electrons. Successive interactions of the neutrons and protons then led to the formation of all the chemical elements by nuclear fusion reactions while the early universe still was very hot and dense. Gamow worked out the details of this nucleosynthesis of all the chemical elements with his colleague Ralph A. Alpher at George Washington University. Before they published their results in 1948, Gamow persuaded Hans Albrecht Bethe, the physicist who first described nuclear fusion reactions in stars, to allow them to add his name to their paper to make the list of authors "Alpher, Bethe, Gamow," a wordplay on the first three letters of the Greek alphabet. This came to be referred to as the alpha-beta-gamma theory of the origin of the universe and its chemical elements. (Today we know that the early universe cooled too quickly

George Gamow: Physicist, Cosmologist, Geneticist

Born March 4, 1904, in Odessa, Russia, George Gamow started his scientific career as a boy, when his father gave him a telescope for his thirteenth birthday. Little did his father know that his son would one day become one of the greatest scientists of the twentieth century.

(AP/Wide World Photos)

After graduating from the University of Leningrad in 1926, Gamow went to Göttingen, a center for the study of the new quantum mechanics. At this time, natural radioactivity was the focus of research of many of the great physicists of the day, from the Curies to Lord Rutherford, and Gamow was particularly interested in its relationship to the atomic nucleus. In 1928, he made his first great contribution when he described quantum tunneling of alpha particles to explain the radioactive process of alpha decay. His investigation of the atomic nucleus would take him to Copenhagen, where he worked under Niels Bohr laying the theoretical groundwork for nuclear fusion and fission.

During the 1930's, Gamow taught at universities in Copenhagen, Leningrad, Cambridge, Paris, and the United States. In Washington, D.C., he and Edward Teller worked on the theory of beta decay. He also turned his attention to astrophysics and the origin of the elements. This work led to his 1948 proposal of the "big bang" theory of the universe, for which he is best known.

Gamow was more than a theoretical physicist, however: Known for his sense of humor and revered by his students, he was also devoted to education. His "Mr. Tompkins" series used science fiction to explain difficult science in a way that anyone—including Tompkins, whose attention span was notoriously short—could understand. In 1954, inspired by the Watson-Crick DNA model, he theorized that the order of the DNA molecules determined protein structure. The problem, as he saw it, was to determine how the four-letter "alphabet" of nucleic acid bases could be formed into "words." His "diamond code" paved the way for Marshall W. Nirenberg to crack the genetic code in 1961.

In 1956, Gamow settled in Boulder to teach at the University of Colorado. That year, he received UNESCO's Kalinga Prize for his popularization of science, and two years later he was married (a second time) to Barbara "Perky" Perkins, who initiated the George Gamow Lecture Series after his death, in 1968.