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Henryk Anzulewicz

ALEMBERT, JEAN LE ROND D'

SEE **d'Alembert, Jean**.

ALFVÉN, HANNES OLOF GOSTA

(*b.* Norrkorping, Sweden, 30 May 1908; *d.* Stockholm, Sweden, 2 April 1995), *physics, plasma state of matter, magnetohydrodynamics, plasma cosmogony, plasma cosmology.*

Alfvén, winner of the 1970 Nobel Prize in Physics, is acknowledged as one of the greatest creative and intuitive intellects of the twentieth century. Alfvén made contributions to physics that are being applied in the early twenty-first century in the development of particle beam accelerators, controlled thermonuclear fusion, hypersonic flight, rocket propulsion, and the braking of reentering space vehicles. Applications of his research in space science include explanations of the Van Allen radiation belt, the reduction of Earth's magnetic field during magnetic storms, the magnetosphere (a protective plasma envelope surrounding Earth), the formation of comet tails, the formation of the solar system, the dynamics of plasmas in the Earth's galaxy, and the fundamental nature of the universe itself.

Alfvén played a central role in the development of several modern fields of physics, including plasma physics, the physics of charged particle beams, and interplanetary and magnetospheric physics. He is also regarded as the founder of the branch of plasma physics known as magnetohydrodynamics. The number of concepts bearing his name indicates the significance of his contributions to science: Alfvén waves, Alfvén number, Alfvén layer, Alfvén velocity, and so on. He also made important contributions in which his role as originator was not widely known for many years. In 1963, for example, he was the first to assert the large-scale filamentary structure of the universe.

Early Life and Education. Alfvén came from a family of high achievers. His father, Johannes Alfvén, was a physician, as was his mother, Anna-Clara Romanus Alfvén (a pioneer in her own right, being one of the first female physicians in Sweden), and his uncle, Hugo Alfvén, was a famous composer. Two childhood experiences had a significant influence on his intellectual development and scientific career. One was the gift of a popular book on astronomy by Camille Flammarion, which kindled his lifetime fascination with astronomy and astrophysics. The other was the school's radio club, in which he was an active member, building radio receivers and learning firsthand how radio waves behave within Earth's varying ionospheric plasma. These interests led to his study at the University of Uppsala, where he specialized in mathematics and experimental and theoretical physics, and where he received his doctor's degree in 1934. His thesis was titled "Investigations of the Ultra-short Electromagnetic Waves."

Royal Institute of Technology. In 1934 Alfvén became a member of the Nobel Institute for Physics in Stockholm, and in 1940, at age thirty-two, he became professor of electromagnetic theory and electrical measurements at the Royal Institute of Technology in Stockholm. There in 1945 he was elected to a newly created chair of electronics, which became chair of plasma physics in 1963. At this time Alfvén's research dealt with the properties of high-voltage phenomena.

Sweden utilized long-distance, high-voltage direct current (DC) electrical power lines in order to increase its power capacity and minimize transmission losses from its hydroelectric generators in the north to the industrial south. One attribute of the DC system is the reduced cost of construction. However, a shortcoming of high-voltage DC lines occurs at the substation, where corona discharges cause the porcelain insulators to break down. By chance, such a substation was clearly visible from the window of Alfvén's laboratory. Alfvén set his energies to the task of resolving this problem and, in the process proposed what was to become a much studied phenomenon of plasma physics: "double layers," regions of strong electric fields parallel to the local magnetic field in the rarefied plasma of space. Earlier, the Nobel chemist Irving Langmuir had discovered the tendency for plasmas to set barriers, or "cells," within itself which Langmuir called cathode or double sheaths. It was the application of this new particle-accelerating mechanism and the tendency for plasma to form sheaths, cells, and current filaments that led Alfvén into the world that came to be called space and cosmic plasmas, the environmental space surrounding planetary probes and Earth orbiting satellites.

Alfvén's approach to physics was based on insight and intuition. He was quick to understand how nature works and was able to place new observations into a framework larger than that required for merely explaining the observations themselves. For example, in the early 1930s it was commonly thought that the cosmic rays filling the universe were gamma rays. However, when it was discovered in 1937 that they were charged particles, Alfvén offered the unique suggestion that the galaxy contained a large-scale magnetic field and that the cosmic rays moved in spiral orbits within the galaxy because of the forces brought to bear by the magnetic field. He stated that if plasma was spread throughout the galaxy, the latter could be completely permeated by a magnetic field. This plasma could carry the electrical currents that would then generate the galactic magnetic field.

Such a hypothesis, based on a great leap of creative intuition but without grounding in apparent rational thought or inference, left Alfvén's proposal open to much criticism because, at the time, interstellar space was thought to be a vacuum incapable of supporting the electrical currents and particle beams he was proposing. But Alfvén had got the scientific community thinking about an idea that would be very much in vogue in the 1980s and 1990s.

Alfvén Waves. Alfvén's discovery of hydromagnetic waves in 1942 is another instance of an original idea having a far-reaching impact on multidisciplinary science. On strictly physical grounds, Alfvén concluded that an electromagnetic wave could spread through a highly conducting medium, such as the ionized gas of the sun, or in plasmas anywhere. Generally, it was thought that electromagnetic waves could penetrate only a very short distance into a conductor and that, as the resistance of a conductor became smaller and smaller, the depth of penetration by an electromagnetic wave would go to zero. Thus, with an ideal electrical conductor, there could be no penetration of electromagnetic radiation. But Alfvén was proposing a form of electromagnetic wave that could propagate in a perfect conductor with no attenuation or reflection.

His work was not acknowledged as both correct and important until 1948, when he gave lectures on hydrodynamic waves while on his first trip to the United States. Alex Dessler, professor at the University of Arizona and former editor of the esteemed journal, *Geophysical Research Letters,* provided an oversimplified statement of what happened: "During Alfvén's visit he gave a lecture at the University of Chicago, which was attended by [Enrico] Fermi," Dessler reported. As Alfvén described his work, the Arizona professor continued, Fermi nodded his head and said, "Of course." The next day the entire world of physics said, "Oh, of course" (Alfvén 1988b, p. 250).

Contributions to Science. Alfvén's contributions were primarily in electrical engineering, space plasma science, physics, and astrophysics. In 1937 he postulated a galactic magnetic field, a postulate that forms the basis for one of today's fastest-growing areas of research in astrophysics—cosmic magnetism. With his colleague, Nicolai Herlofson, Alfvén in 1950 became the first to identify nonthermal radiation from astronomical synchrotron radiation, which is produced by fast-moving electrons in the presence of magnetic fields. The realization that the synchrotron mechanism of radiation is important in celestial objects has been one of the most fruitful developments in astrophysics because almost all the radiation recorded by radio telescopes derives from this mechanism.

His prediction of the existence of the phenomenon called critical ionization velocity—which is crucial to understanding how accelerating matter to extreme velocities leads to its changes of state, as well as being the primary mechanism for the formation of planets—was verified to exist in interstellar space only in 1997, two years after his death.

Conflicts with Prevailing Views. Alfvén became active in interplanetary and magnetospheric physics at a time when his viewpoint in this field was a minority opinion. Alfvén's opinions were consistent with those of the founder of magnetospheric physics, the great Norwegian scientist Kristian Birkeland, who went on to found the Norwegian industrial energy megagiant, *Norsk Hydro.* By the end of the nineteenth century, Birkeland had presented a strong case—backed by theory, laboratory experiments, polar expeditions, and a chain of magnetic-field observatories throughout the world—that electric currents flowing down along Earth's magnetic fields into the atmosphere were the cause of aurora and polar magnetic disturbances.

However, in the decades after Birkeland's death in 1917, Sydney Chapman, the highly regarded British geophysicist, became the recognized leader in interplanetary and magnetospheric physics. Chapman proposed, in opposition to Birkeland's ideas, that currents flowed only in the ionosphere, with no downflowing currents. Chapman's theory was so mathematically elegant that it won wide acceptance. Based on Chapman's ideas, algebraic expressions of the ionospheric current system could, with absolute mathematical rigor, be derived by any student of the subject. Birkeland's work might have disappeared completely except for Alfvén, who became involved long after Chapman's ideas had gained predominance. Alfvén insisted that Birkeland's current system made more sense because downflowing currents that followed Earth's magnetic field lines were necessary for driving most of the ionospheric currents. The dispute was finally settled in 1974, four years after Chapman's death, when Earth satellites measured downflowing currents for the first time.

This account illustrates problems that were typical of the those Alfvén faced in his scientific career. Interplanetary space was generally regarded to be a good vacuum, disturbed only by occasional comets. This opinion was broadly accepted because space appeared to be that way, having been viewed only with telescopes at optical wavelengths. The electrical currents offered by Alfvén, however, created a telltale signature only in the radio portions of the electromagnetic spectrum, so they had not yet been observed at the time he stated his view that such currents existed in space. Therefore, Alfvén's proposition met with great skepticism.

In 1939 Alfvén proposed an extraordinary hypothesis of magnetic storms and auroras that has broadly influenced contemporary theories of plasma dynamics in Earth's magnetosphere. He used the idea of electric charges spiraling in magnetic fields to compute the movement of electrons and ions. This approach came to be universally adopted by plasma physicists and was used until the boring task was consigned to computers in the mid-1970s. Yet in 1939, when Alfvén offered his paper on the subject to the leading American geophysical journal, *Terrestrial Magnetism and Atmospheric Electricity,* the paper was turned down because it did not correspond with the theoretical calculations of Chapman and his colleagues. As a result, Alfvén had to publish this seminal paper, "A Theory of Magnetic Storms and of the Aurorae" (1939) in a Swedish-language journal not readily accessible to the worldwide scientific community, *Kungliga Svenska Vetenskapsakademiens Handlingar, Tredje Serien.* Several of Alfvén's other key articles faced similar difficulties.

It is common in science that one or two major discoveries locate their author in the rank of leading authorities, with enormous influence and continuous funding usually ensuing. This, however, did not happen to Alfvén. At no time during his scientific career before winning the Nobel Prize did those scientists who were using his work generally recognize Alfvén as a leading innovator.

Dessler has written of his recognition that Alfvén's contributions were going unnoticed:

> When I entered the field of space physics in 1956, I recall that I fell in with the crowd believing, for example, that electric fields could not exist in the highly conducting plasma of space. It was three years later that I was shamed by S. Chandrasekhar into investigating Alfvén's work objectively. My degree of shock and surprise in finding Alfvén right and his critics wrong can hardly be described. I learned that a cosmic ray acceleration mechanism basically identical to the famous mechanism suggested by Fermi in 1949 had [previously] been put forth by Alfvén. (Dessler, 1970, p. 605)

Alfvén and Nuclear Energy. In 1967 Alfvén issued a scathing denunciation of Sweden's nuclear research program, objecting to what he thought was the insufficient provision of funds for projects on peaceful uses of thermonuclear energy, and he left his homeland saying, "My work is no longer desired in this country" (Weinraub, 1970, p. 2708).

Part of his antinuclear rational derived from the granite found in Scandinavia, which—because of its strength and hardness—was proposed for the storage of nuclear waste. Alfvén had an interest in geophysics, primarily for reasons related to problems of planetary evolution. Taking visitors through the Swedish countryside on their way to a morning breakfast of *pannkakor* (Swedish pancakes), he frequently stopped along the way to point out the cracks in the granite rocks and remark on their inadequacy as a nuclear waste depository.

After Alfvén announced his intention to leave Sweden, he was immediately offered professorships in both the Soviet Union and the United States. Following two months in the Soviet Union, he moved to the United States, where he tested the professorial waters in the departments of electrical engineering at the University of Southern California in Los Angeles and then the University of California at San Diego in La Jolla. Reconciled with the Swedish government in the end, Alfvén for the rest of his life alternated between California and Sweden, from October to March in La Jolla and April to September in Stockholm.

Alfvén and Astrophysics. Because his ideas frequently were at odds with generally accepted or standard theories, Alfvén always had difficulty with the peer review system, especially as practiced by Anglo-American astrophysical journals. "I have no trouble publishing in Soviet astrophysical journals," Alfvén once disclosed, "but my work is unacceptable to the American astrophysical journals" (Peratt, 1988, p. 197).

Alfvén never gained the nearly automatic acceptance generally given senior scientists in scientific journals. "The peer review system is satisfactory during quiescent times, but not during revolutionary or catastrophic times in a discipline such as astrophysics, when the establishment seeks to preserve the status quo," he remarked (Peratt, 1988, p. 197).

One reason that Alfvén's work in astrophysics was ignored may be that he regarded himself, first and foremost, as an electrical power engineer; in fact, he rather enjoyed the accusation of encroachment into astrophysics leveled by other cosmologists and theoreticians. Alfvén claimed that plasma physics had traditionally been neglected in astrophysics:

> Students using astrophysical textbooks remain essentially ignorant of even the existence of plasma concepts, despite the fact that some of them have been known for half a century. The

> conclusion is that astrophysics is too important to be left in the hands of astrophysicists who have gotten their main knowledge from these textbooks. Earthbound and space telescope data must be treated by scientists who are familiar with laboratory and magnetospheric physics and circuit theory, and of course with modern plasma theory. (Alfvén, 1986b, p. 790)

Based on plasma physics, Alfvén and his colleagues for decades proposed an alternative cosmology to both the steady state and the big bang cosmologies. While the big bang theory was preferred by most astrophysicists for almost fifty years, it has been challenged by new observations, especially over the last few decades. In particular, the discovery of coherent structures of galaxies hundreds of millions of light years in length and the large-scale streaming of superclusters of galaxies at velocities that may approach 1,000 kilometers (620 miles) per second presents problems that are hard, if not impossible, to square with the big bang theory.

To Alfvén, the problems being raised were not surprising: "I have never thought that you could obtain the extremely clumpy, heterogeneous universe we have today, strongly affected by plasma processes, from the smooth, homogeneous one of the big bang, dominated by gravitation" (Peratt, 1988, p. 197).

The difficulty with the big bang, Alfvén thought, resembled the flaws in Chapman's theories, which the scientific community erroneously accepted for decades. Astrophysicists, he felt, tried too hard to extrapolate the origin of the universe from mathematical theories worked out on the blackboard. "The appeal of the big bang," said Alfvén, "has been more ideological than scientific. When men think about the universe, there is always a conflict between a fabled approach and the empirical scientific approach. In fable, one tries to deduce how the gods must have created the world—what perfect principles must have been used" (Peratt, 1988, p. 196).

To Alfvén, the big bang was a myth conceived to explain creation. "I was there when Abbé Georges Lemaître first proposed this theory," he recalled (Peratt, 1988, p. 196). Lemaître was, at the time, both a member of the Catholic hierarchy and an accomplished scientist. Privately, Lemaître acknowledged that this theory was a way to square science with St. Thomas Aquinas's theological dictum of *creatio ex nihilo,* or creation out of nothing.

But if the big bang is a myth, how and when did the universe begin? "There is no rational reason to doubt that the universe has existed indefinitely, for an infinite time," Alfvén explained. "It is only fable that attempts to say how the universe came to be, either five thousand or twenty billion years ago" (Peratt, 1988, p. 196).

"Since religion intrinsically rejects empirical methods, there should never be any attempt to reconcile scientific theories with religion," Alfvén said.

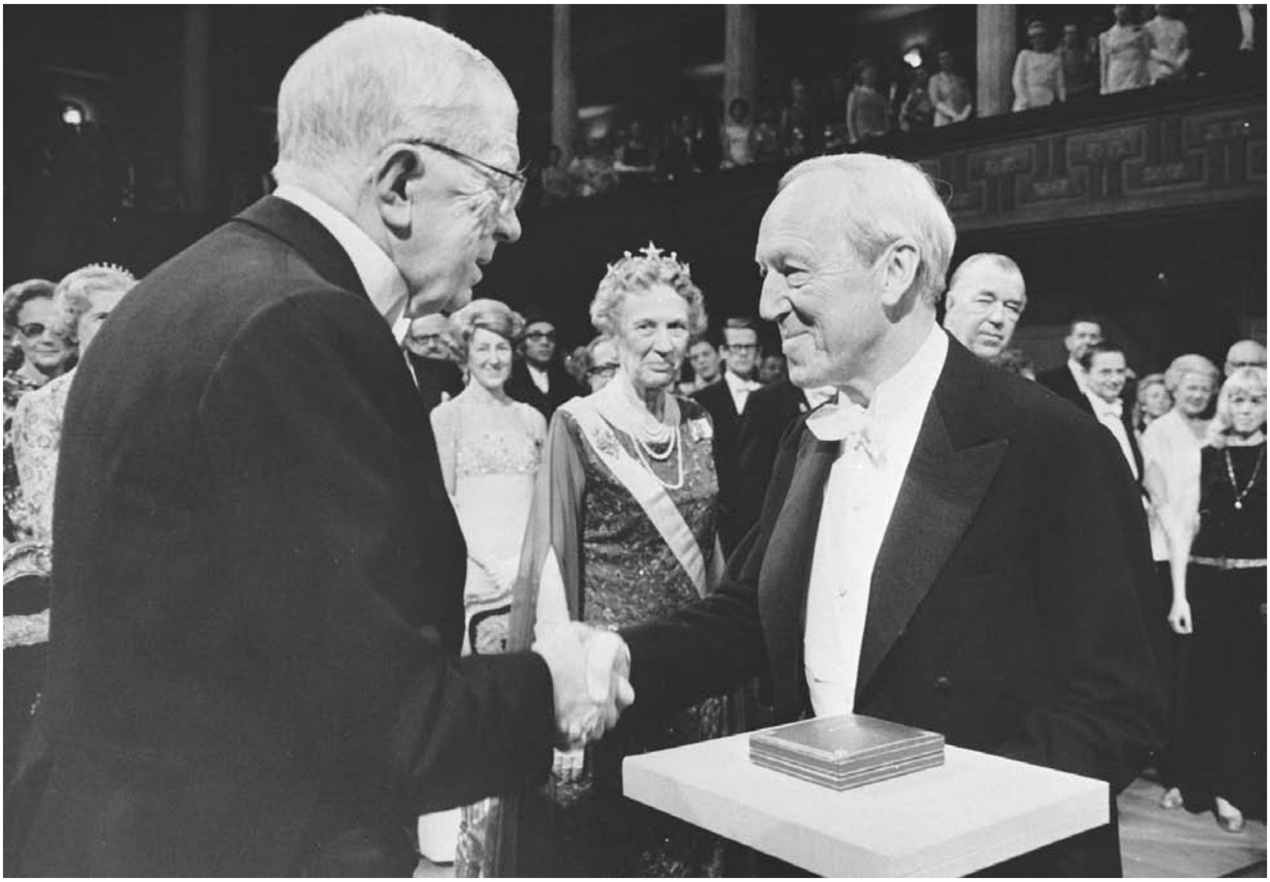
> An infinitely old universe, always evolving, may not be compatible with the Book of Genesis. However, religions such as Buddhism get along without having any explicit creation fables and are in no way contradicted by a universe without a beginning or end. *Creatio ex nihilo,* even as religious doctrine, only dates to around AD 200. The key is not to confuse fable and empirical results, or religion and science. (Peratt, 1988, p. 196)

Alfvén acknowledged that his plasma universe theory might take a long while to pierce the popular consciousness. "After all," he asserted to a group of physicists, "most people today still believe, perhaps unconsciously, in the heliocentric universe." The group, at first disbelieving, quickly nodded in agreement as Alfvén continued: "Every newspaper in the land has a section on astrology, yet few have anything at all on astronomy" (Peratt, 1988, p. 196).

Awards, Honors, and Writings. Alfvén achieved worldwide recognition in his lifetime. He received the Nobel Prize in Physics (1970), the Gold Medal of the Royal Astronomical Society (1967), the Gold Medal of the Franklin Institute (1971), the Lomonosov Medal of the USSR Academy of Sciences (1971), and the Bowie Medal of the American Geophysical Union (1988), among other awards. Several academies and institutes placed his name on their membership lists: the Institute of Electrical and Electronics Engineers, the European Physical Society, the Royal Swedish Academy of Sciences, the Royal Swedish Academy of Engineering Sciences, the American Academy of Arts and Sciences, and the Yugoslav Academy of Sciences. Alfvén also was one of the very few scientists who held foreign memberships in both the U.S. and Soviet academies of sciences.

Besides his scientific papers, Alfvén wrote popular science books. These include *Worlds-Antiworlds: Antimatter in Cosmology* (1966) and *The Great Computer: A Vision* (1968). The latter book was written under the pen name Olof Johannesson. Other popular books include *Atom, Man, and the Universe: The Long Chain of Complications* (1969) and (with his wife, Kerstin Alfvén) *Living on the Third Planet* (1972).

Career Pattern. Regardless of his basic contributions to physics and astrophysics, Alfvén—who in 1991 retired from his posts of professor of electrical engineering at the University of California at San Diego and professor of



Hannes Olof Gosta Alfvén. *Hannes Alfven receiving the Nobel Prize from King Gustaf Adolf of Sweden.* AP IMAGES.

plasma physics at the Royal Institute of Technology in Stockholm—was still regarded as a heretic by many in those very fields. Alfvén's theories in astrophysics and plasma physics have usually won acceptance only twenty or thirty years after their publication. Typically, and also concomitant with his eightieth birthday in 1988, Alfvén was granted the most esteemed prize of the American Geophysical Union, the Bowie Medal, for his work three decades earlier on comets and plasmas in the solar system. Controversial for fifty years, many of his theories about the solar system were vindicated only as late as the 1980s through measurements of cometary and planetary magnetospheres by artificial satellites and space probes.

Although Alfvén received the coveted Nobel Prize and other distinguished honors from around the world—and while a rash of scientific journals published special issues in honor of his eightieth birthday—for much of his career, Alfvén's ideas were initially dismissed or met with great skepticism. Even in the early twentieth century, physicists are little aware of Alfvén's many contributions to fields of physics, where his ideas are employed without knowledge of who conceived them.

Personal Life. Alfvén supported many social causes. He was, for example, active in the worldwide disarmament movement, having been president of the Pugwash Conference on Science and World Affairs, Leningrad, May 1970, special Board on Atmospheric Sciences and Climate, Amnesty International, Energy, Food and Disarmament International. He had significant correspondence with groups connected with nuclear disarmament as well as with people such as Ralph Nader (interestingly, one of his seminal papers was written with Edward Teller), Energy Resources Conservation and Development Commission Hearings, "Plasma Astrophysics International Conference on Conflict Resolution and Peace Studies, USSR Academy of Sciences, Committee for Soviet Scientists for Peace, 1986," Scientific Research Council on Peace and Disarmament." In addition, his son was the Swedish secretary of the Physicians for Social Responsibility. Alfvén was fond of studying the history of science and Eastern philosophy and religion.

He was known for his humor and for having an anecdote for all occasions. Alfvén enjoyed traveling to places that do not have tour guides or are not normally listed in travel guide books, especially to places such as Sri Lanka, the Fiji Islands, and the Amazon River. His residence depended on the seasons: from spring to autumn in Europe and from autumn to spring in North America. Alfvén could speak fluently in English, German, and French, and nearly so in Russian; he also spoke some Spanish and some Chinese. He stayed physically active until the last four years of his life. Even when he was eighty-two years old, he entertained guests with wine at his La Jolla apartment, hurrying them to the beach at sunset, hoping to catch a glimpse of the "green flash," the phenomenon that sometimes occurs as the sun sinks below the ocean horizon.

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Anthony L. Peratt

ALĪ AL-QŪSHJĪ (ABŪ AL-QĀSIM ALĀ᾽ AL-DĪN ALĪ IBN MUHAMMAD QUSHJĪ-ZĀDE)

(*b.* probably Samarqand, early fifteenth century; *d.* Istanbul, Turkey, 1474), *astronomy, natural philosophy.*

Alī al-Qūshjī was a philosopher-theologian, mathematician, astronomer, and linguist who produced original studies in both observational and theoretical astronomy within fifteenth-century Islamic and Ottoman astronomy. He contributed to the preparation of Ulugh Beg's *Zīj* at the Samarqand Observatory, insisted on the possibility of the Earth's motion, and asserted the need for the purification of all the scientific disciplines from the principles of Aristotelian physics and metaphysics.

Life. Qūshjī was the son of Ulugh Beg's falconer, whence his Turkish name Qushči-zāde. He took courses in the