A pioneer in modern plasma physics

An obituary of Hannes Alfvén

Professor Hannes Olof Gösta Alfvén, a renowned space physicist and a prime contributor to the field of magnetohydrodynamics, died on 2 April 1995 at his home in Djursholm, Sweden, at the age of 86. With his passing away, the world of physics has lost a highly creative and original physicist. He can justifiably be called one of the pioneers of modern plasma physics – a field of study that finds applications in a wide range of areas such as cosmology, astrophysics, controlled thermonuclear fusion, radio communication, etc. Alfvén's contributions and insights into the field, especially during its infancy, are many and bear the stamp of his remarkable physical intuition. He developed very powerful tools which greatly aided the analysis of complex physical phenomena and advanced the field in giant steps.

An early example of such a powerful idea is that of the concept of frozen-in flux, where the plasma is considered to be tied on to the magnetic lines of field that pass through it. Alfvén discovered this theorem in the early 1930s and used this simplifying tool to great advantage in solving many space physics problems. In fact, so successful was this paradigm that it began to be used indiscriminately by many later workers in the field, who applied it to situations where its validity conditions were often violated. Alfvén expended considerable effort in educating the scientific community about the proper validity conditions of this theorem. Another simplifying notion that Alfvén invented was the guiding centre approximation, by which the complex orbit of a charged particle in a magnetic field could be calculated in a very simple manner in terms of the motion of the centre of the Larmor motion and its drifts. The physical notion underlying this idea is that of the equivalent magnetic moment associated with the spiral motion of the charged particle. This concept helped him understand many complex phenomena associated with auroras, magnetic storms, cosmic ray generation in the solar system and in the interstellar space. In the laboratory, this concept helped in the development of some early practical devices like the trocholron, a high vacuum switching tube, and in later years the idea of the invariance of the magnetic moment was at the heart of the plasma confinement in mirror machines. Today some of these tools invented by Alfvén have become such standard repertoire of plasma physicists that we hardly pause to contemplate their power and simplicity or to imagine the difficulties of working without their aid.

His most well-known discovery – that of hydromagnetic waves, which are commonly called Alfvén waves – is another prime illustration of the power of his physical intuition. In thinking about the problem of sunspots, he reasoned that they consisted of magnetic fields embedded in the highly conducting solar plasma. These magnetic fields must arise from currents flowing in the plasma and the mutual interaction between them must make both the currents and the fields to move. Thus on purely physical grounds he worked out the theory of this movement – that of an electromagnetic wave – propagating through a highly conducting medium. At the time when he published his theory in *Nature* in 1942, nobody believed it. It took many years for scientists to accept this idea. The common notion at the time, from the well-known Maxwell's theory, was that an electromagnetic wave could scarcely penetrate a conductor. Thus, Alfvén's proposition of an electromagnetic wave propagating in a perfectly conducting medium with no attenuation seemed physically impossible. It was only in 1948 when Alfvén visited the United States for the first time and lectured about his work at a number of places that the correctness and significance of his work was recognized. According to an apocryphal story, when Fermy heard his lecture at the University of Chicago, he nodded his head and said, 'Of course'. The next day the entire world of physics said, 'Oh, of course'.

Alfvén was also the first person to suggest the existence of large-scale magnetic fields in the galaxy. This was soon after it was discovered that cosmic rays were charged particles and not gamma rays filling the entire universe. This spurred Alfvén to create a self-consistent picture of electrical currents flowing in a low-density plasma pervading the galaxy, giving rise to large-scale magnetic fields and the cosmic ray particles moving in spiral orbits about these fields. These ideas, which are well proven and accepted today, were way ahead of their times in the late 1930s when interstellar space was supposed to be a vacuum and could not support any currents. In 1939, he also proposed a remarkable theory of magnetic storms and the aurora in which he introduced several novel concepts, including that of the guiding centre approximation, the concept of electric field drift for plasma within the geomagnetic field and the concept of a ring current formed from quasi-trapped radiation. He preceded Fermi in suggesting a mechanism for cosmic ray acceleration and also provided the right tools for understanding phenomena such as the Van Allen radiation belts.

Alfvén's intuitive approach was often in conflict with the prevailing style of doing science with idealized mathematical models which could be solved exactly. Thus, he often faced difficulty in publishing his papers. But his first book, *Cosmical Electrodynamics*, published in 1950, in which he collected much of his early work, had a great impact in the development of space physics and plasma physics. This development also vindicated many of the fundamental concepts introduced by him. Thanks to his pioneering contributions, the theory of magnetohydrodynamics has today become an established and well-developed branch of physics and is widely used in the field of astrophysics and fusion physics.

Alfvén was acutely aware of the importance of technological developments leading to the creation of new fields for scientific investigations and believed that 'the centre of gravity of the physical sciences is always moving'. He was thus an active supporter of newer space experiments and advances in fusion devices. He also believed in small-scale laboratory experiments to test basic concepts and promoted actively the development of such programmes in the institutions that he was associated with. Some of them carried out remarkable fundamental experiments in plasma physics, often in the form of verification of some of his own ideas. For instance, in developing a comprehensive theory for the evolution of the solar system, Alfvén intuitively proposed the concept of a critical relative velocity between a neutral gas and a magnetized plasma. Beyond this velocity the gas would ionize rapidly and the resulting plasma cloud would form the starting point for the process of condensation and accretion, leading to the formation of secondary bodies like planets and satellites. The value for the critical velocity was proposed to be $(2eV_i/M)^{1/2}$, where V_i and M are the ionization potential and mass of neutral atom. This limit has been experimentally verified in a number of experiments, including some carried out at the Royal Institute of Technology in Stockholm under his active encouragement. Likewise, he inspired a series of experiments and developments on the Marshall gun – a plasma device to create a minimum magnetic energy plasma configuration which he had theoretically proposed. This concept in the advanced form of a Spheromak configuration is today considered to be an attractive fusion confinement geometry. His original idea of intense electric field structures in space led to a large body of theoretical and experimental investigation into the so-called potential double-layer formations. Alfvén also helped inspire some early plasma physics work in India when he visited the Tata Institute of Fundamental Research, Bombay, in 1958 at the invitation of Homi Bhabha and gave a series of lectures on plasma physics to the then fledging plasma physics group.

Not all his ideas are accepted even today. He has put forward his own theory of cosmology, opposing the big bang model, and leaning towards the cosmology of Oscar Klien, with a universe oscillating between expansion and contraction. He believed that the universe was formed as an ambiplasma (i e. with equal amounts of matter and antimatter) and suggested clever mechanisms for their segregation into separate worlds. He also emphasized the importance of dust in the universe and talked long time ago about 'dusty' plasmas. Cast in the role of an iconoclast, during his early struggles with the established scientific views in space physics, Alfvén continued to question the established doctrine and always fought for his own 'wild' ideas. In the words of his friend and associate, Gustaf Arrhenius, Alfvén was a 'gentle wild man'. He was also an active campaigner against nuclear warfare and participated in the East–West 'Pugwash' conferences that sought to prevent such confrontations. Originally a strong promoter of nuclear power generation, he later grew apprehensive about the long-term safety of reactors and sought to highlight the problem of nuclear wastes. He continued to be active in research till fairly recently, sharing his time between the Royal Institute of Technology and the University of California in San Diego.

Alfvén was the recipient of several awards, including the Nobel Award in physics in 1970 (shared with Louis Neel), the Lomonosov Gold Medal of the Soviet Academy of Sciences, the Franklin Gold Medal of the Franklin Institute in Philadelphia and the Gold Medal of the Royal Astronomical Society, UK. He was a member of the National Academy of Sciences in the United States and a Fellow of the Royal Society in Britain. His books included: *Cosmical Electrodynamics*, 1950; *On the Origin of the Solar System*, 1954; *Cosmical Electrodynamics: Fundamental Principles* (with C. G. Fälthammar), 1963; *Worlds–Antiworlds*, 1966; *Structure and Evolutionary History of the Solar System* (with G. Arrhenius), 1975; *Cosmic Plasma* (monograph), 1981. He also wrote several popular scientific books, many of them in collaboration with his wife Kerstin Maria Erikson and often assuming the pen name of Olof Johannesson.

Alfvén has given the world of physics a rich legacy of ideas and tools. They have helped us reach out and understand many complex phenomena in the sun, the stars and the space beyond. They are also the basis on which one hopes to create the first star in the laboratory – and harness the energy of fusion reactions. Such is the power and reach of the field he helped create and which reflects in a striking way the true measure of his amazing genius.

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Remembering Hannes Alfvén and his work

'You know I love your country and I do Yoga everyday', Professor Hannes Alfvén was telling me this in a conversation in Gothenburg, Sweden, at a Plasma Physics conference in 1988. He further added, on seeing the book *The Alfvén Wave*, the first book on this topic written by Akira Hasegawa from Bell Laboratories, NJ, USA and myself and dedicated to him, 'You both seem to know more these waves than myself'. This was the highest complement coming from Hannes Alfvén, who discovered the Alfvén waves in 1942.

He can be justifiably considered as the father of space plasma physics and astrophysical plasmas. He originated many key theoretical ideas which opened a new vision in understanding of the plasma universe. Hannes Alfvén received his Doctorate from the University of Upsala in 1934 and was appointed as Professor of electromagnetic theory and electric measurements at the Royal Institute of Technology, Stockholm, in 1940, at the age of 32. From this date to almost the end of his life, Alfvén was an active scientist of this laboratory. His vigorous scientific and administrative activities led to the creation of several new departments within the Royal Institute of Technology. Three of these, Plasma Physics, Fusion Plasma Physics and Accelerator Technology Departments now constituted a separate entity called the Alfvén Laboratory. His own chair evolved correspond-