Nobel Prize for Physics 1970

The Royal Swedish Academy of Sciences has awarded the 1970 Nobel Prize jointly to two European physicists: to H. Alfvén for his establishment of the fundamental principles of magnetohydrodynamics which decisively influenced the development of plasma physics, and to L. Néel for his research and fundamental discoveries regarding antiferromagnetism and ferrimagnetism, which have important applications in the physics of solids. An assessment of these men and their work is given below.

Louis Néel

Louis Néel received the award in recognition of over forty years' scientific work in the domain of collective order in magnetic solids.

A list of the novel and important ideas introduced by him in the various domains of magnetism would be very long. Perhaps it matters more to note that, on antiferromagnetism and ferrimagnetism, his ideas have proved to be of greatest originality and have become classic since their formulation. Already in 1932, Néel showed that the concept of the Weiss molecular field had to be extended by introducing local molecular fields, each affecting one sublattice in a magnetic solid. From this he deduced that attractive interactions should lead to temperature-independent paramagnetism. In 1936 he concluded that solids exist in which the magnetic atoms differ in their spin orientation: below a certain transition temperature T_C they are divided into two sublattices spontaneously spin-oriented in opposite directions with respect to each other. The net spin is then zero; below T_C, the magnetic susceptibility is independent of temperature. At temperatures above T_C the solid obeys a Curie-Weiss law. At the time such solids were unknown; they were discovered in 1938 by Bizette and Tsai and called antiferromagnets by Bitter in 1939. The transition temperature T_C is now called the Néel temperature T_N. About 1950 neutron diffraction experiments on MnO carried out by Shull and co-workers showed the predicted magnetic decomposition of the solid into two sublattices.

In 1936 Néel also showed theoretically that antiferromagnetism must be characterized by the existence of a critical external magnetic field. Passing through this critical value the magnetic susceptibility exhibits a discontinuity. Sixteen years later this curious phenomenon was detected experimentally by C.J. Gorter and N.J. Poulis in $CuCl_2.2H_2O$.

In 1948, Néel succeeded in interpreting for the first time the magnetic properties of spinel structures of the ferrites, which had remained a mystery to physicists for fifty years. He published his theory of ferrimagnetism, based essentially on the hypothesis of two magnetically unequal sublattices of spins. On each sublattice the spins are parallel. Spins on the two sublattices are oriented in opposite directions and differ in magnitude, so that a net moment results. Again, this hypothesis was later confirmed by neutron diffraction experiments. The theory of ferrimagnetism at once explained many known experimental facts: the saturation value of the magnetic moment, the variation with temperature of the spontaneous magnetization below the Curie point, the hyperbolic temperature variation of the susceptibility above the Curie point, the variation with concentration of the magnetic moment of mixed ferrites, the variation with thermal treatment of the magnetic moment at saturation of zinc- and magnesium-ferrites by transfer of magnetic ions from one sublattice to the other, and other phenomena. In the same fundamental paper, Néel was the first to show that the predominant interactions in oxides and ferrites are not direct exchange interactions, but that the magnetic cations interact via the diamagnetic anions (indirect-exchange, or 'superexchange' interactions).

On the basis of the theory of ferrimagnetism many novel facts could be predicted. In a study on the possible forms of thermal variation of spontaneous magnetization, Néel showed that there could exist, below the Curie point, a compensation temperature at which the magnetizations on the two sublattices are equal in magnitude but opposite in sign, so that the net macroscopic moment becomes zero. The moment of such a permanent magnet would change its sign at that temperature. A few years later, E.W. Gorter in Eindhoven found that a mixed ferrite of lithium and chromium has this property.

The theory of ferrimagnetism enabled Néel and Bertaut to elucidate the properties of pyrrhotine, Fe_7S_8, a mysterious substance on which Weiss had already written important papers early this century. Here we encounter ferrimagnetic behaviour in which the necessary inequality between the two sublattices is caused by an inequality in vacancy distribution (1 atom of iron out of 8 is missing). Above a certain temperature the inequality disappears and the vacancies are distributed equally between the sublattices ; consequently, pyrrhotine then becomes antiferromagnetic.

In 1956, the theory of ferrimagnetism led to the discovery, by Bertaut and Pauthenet in Grenoble, of a new category of ferrimagnetic oxides, namely ferrites of the rare earths with garnet structure. Their general formula is $Fe_5M_3O_{12}$, where M is a rare-earth element. These substances immediately attracted great interest because of their remarkable properties at very high frequencies and the relative ease with which large crystals can be obtained; in general, they also possess a sharp compensation temperature. Here we have three-sublattice ferrimagnetism : two with iron and one with the rare-earth element. Multiple substitutions are possible and thus garnets are a choice material for studying magnetic interactions.

More recently (1960-1961) an application of the same ideas led Néel to predict the existence of a superparamagnetism in antiferromagnetic crystals of 20 to 400 Å diameter. In such small crystals the magnetic moments on the two sublattices are no longer completely compensated.

In closing, we note the contribution of Louis Néel to international co-operation in physics, notably his activity in the International Union of Pure and Applied Physics (IUPAP) of which he was President from 1963 to 1966. Néel also played a decisive role in the creation of the Ampère Group. As President of the Electronics Section of the CNRS he was responsible for the 1st Ampère Colloquium in Paris (1952) and scientific director of the 2nd Ampère Colloquium, held in Grenoble in 1953.

G.J. Béné

Hannes Alfvén

Hannes Alfvén's pioneering work has initiated and strongly influenced the development of plasma physics and its applications all over the world.

The Plasma State

The various states of matter are the result of a balance between the binding forces and the thermal motion of its constituents. Transformation into another state usually occurs with increasing temperature, i.e. from a solid body to a liquid and further to a gas which, at sufficiently high temperatures, is converted to the plasma state and disintegrates into its electrical constituents. These four states correspond to the ancient Greek concept of the four elements: earth, water, air, and fire. Plasma physics describes the fourth state of matter, covering the entire field of classical and much of modern physics.

It is thus characterized by a multiplicity of combinations and interactions between different physical processes. The plasma state extends over a temperature range from about 10^4 to 10^8 degrees and is, therefore, the most common state in the universe. The complexity of plasma physics is also reflected in important applications in astrophysics, geophysics, controlled thermonuclear fusion, magnetohydrodynamic power generation, space technique and aerodynamics, plasma chemistry, and the development of electric power systems.

Alfvén's Research Work

The universal importance of plasma physics was realized by Alfvén who had already treated the interaction between electromagnetic and mechanical phenomena in his earliest papers. This interaction leads to phenomena which cannot be predicted by applying previously known laws of electricity and mechanics separately.

Initially Alfvén's interests concentrated on the electrical discharge phenomena in the Northern Lights (aurorae) and their interaction with the earth's magnetic field. In connection with a theory on the aurora established in 1939, he developed a perturbation method to deduce the orbits of electrically charged particles in inhomogeneous magnetic and electric fields. Alfvén showed that the real particle orbit can very accurately be represented by a circular 'gyro' motion directed perpendicularly to the magnetic field lines, with a superimposed drift of the centre of gyration. The magnetic flux enclosed by the circular motion is conserved and corresponds to an adiabatic invariant, the 'equivalent magnetic moment'. The perturbation method greatly simplifies the study of the complicated individual particle motion in inhomogeneous fields and has formed the basis of innumerable investigations in plasma physics and its applications. Examples of this are a heating mechanism proposed by Alfvén for the acceleration of charged particles in cosmic radiation, studies of the dynamics of ionized matter near the sun and in interplanetary space, as well as investigations of the confinement and stability of a plasma in magnetic bottles for attempting to realize controlled thermonuclear fusion.

In 1908 the American astronomer Hale showed that strong magnetic fields exist in the sunspots. For 30 years following this discovery, however, interest in electromagnetic phenomena was very limited among cosmologists. A decisive change in this attitude was first brought about by Alfvén in 1942 with a theory about the action of electromagnetic forces

on solar phenomena. Alfvén pointed out that the motion of an electrically conducting fluid situated in a magnetic field induces electric currents which in their turn produce forces reacting back on the fluid motion. This may be considered the result of two simultaneous interaction processes. The first is connected with the concept of the magnetic field lines 'frozen' in the fluid and 'dragged' along by its motion. The second is due to the induced electric currents which produce a restoring force on the magnetic field lines, thus acting like elastic strings immersed in the fluid. These magnetohydrodynamic forces play an essential role in a wide range of plasma physical applications. They are also directly related to the fundamental discovery by Alfvén of the magnetohydrodynamic waves propagated along the magnetic field lines like waves along an elastic string.

Limited amounts and different forms of energy are oscillating back and forth in a wave motion. Under certain conditions, however, a disturbance in a plasma may be able to extract an increasing amount of energy from a reservoir and will then develop into an instability. Alfvén realized this possibility in his further studies of the magnetohydrodynamic forces. He found that magnetic energy could be fed into a growing, screw-shaped, so-called 'kink' instability. This mode has since attracted considerable interest in connection with the experimental work on gaseous discharges and thermonuclear fusion.

In the history of physics, numerous attempts have been made to explain the origin of the solar system and the universe. Many earlier theories on these problems were rejected after repeated analysis or comparison with later astronomical data. Alfvén's theory on the origin of the solar system is one of the attempts that are still considered possible solutions of these problems. It is based on the ionization processes and plasma physical phenomena occurring when a cosmic cloud of neutral gas falls through a plasma cloud towards a magnetized central body which represents the sun. As an important feature of the theory a violent ionization process is assumed to take place when the motion of the two clouds through each other approaches the velocity corresponding to the ionization energy. This 'critical velocity' has different values for different elements. A separation of matter is therefore expected to take place and should be evident in the chemical composition of the planets. Several laboratory experiments have confirmed the existence of the critical velocity. Its significance extends far beyond the problem of the origin of the solar system.

An early cosmological theory by Klein has been further developed since 1962 by Alfvén and Klein. It is characterized by the hypothesis that the universe as a whole consists of equal amounts of matter and antimatter. The main contribution by Alfvén is the introduction of the concept 'ambiplasma' which comprises matter and antimatter.

Since 1940 the development in plasma physics has resembled an explosion and has strongly modified important parts of cosmical physics and opened promising fields of application, such as thermonuclear fusion. To a large extent this progress was initiated by Hannes Alfvén and, in any case, no other research worker in this field has had a comparable influence on its development. Basic concepts and results due to Alfvén, already now to be regarded as classical, are the equivalent magnetic moment, the 'frozen' magnetic field lines, the Alfvén velocity of magnetohydromagnetic waves and the critical velocity for the interaction between a plasma and a neutral gas. These achievements are a monument to Alfvén's brilliance and working methods, so manysided and rich in ideas, and characterized by the ability of co-ordinating complicated systems and problems to form a logical and aesthetic entity.

B. Lehnert

EPS Individual Ordinary Member No. 1000

In the autumn of last year, just when the EPS was two years old, the 1000th Individual Ordinary Member joined the Society. He is Dr. Ing. Dipl. Phys. **Hubert Patalong** of Munich, a longstanding member of the German Physical Society. During a recent interview Mr. Patalong kindly told us about his background and outlined what prompted him to join and what he hopes the EPS might help to achieve.

Since leaving the University of Frankfurt in 1952 he has been working at research laboratories of Siemens A.G., engaged on what he terms 'development' rather than 'pure research', and, while there, he obtained his doctorate under M. Kersten at Aachen. He manages to keep in touch with the academic world by lecturing at Erlangen University.

When he received the circular in which the President K. Ganzhorn appealed to all members of the German Physical Society to support the EPS by joining as Individual Ordinary Members (see Europhysics News No. 11) his response was immediate. What impressed him in this appeal was the idea that physicists are particularly qualified to contribute to a better understanding between peoples because their scientific interests transcend political and national boundaries. The agreement on a common language (English) as a working medium for the Society, he feels, is a remarkable and gratifying achievement. In helping to bring together physicists of different nationality but common interests, the EPS can greatly promote the spiritual unification of Europe. Having lived through a period of violence and destruction engendered by strife between nations and witnessed the splitting of his country, Mr. Patalong welcomes particularly the increasing contacts in science between East and West encouraged by the EPS. He strongly supports the Society's endeavours to improve the coordination of research, which incidentally could bring about greater freedom of movement for physicists between their centres of activity. Working in industry the scientist often lacks the opportunities of his academic colleagues. Attendance at scientific conferences to make vital contacts with co-workers in the field is difficult, and time is always too short to read even essential journals. The EPS should help to restore to the industrial physicist, who often feels forgotten, the sense of belonging to the great community of physicists.

We hope that the EPS will be able to meet these expectations fully.