

state & society

Physicists share in Nobel prizes in three disciplines



ANDERSON



MOTT



VAN VLECK

Anderson, Van Vleck, Mott split physics prize

The 1977 Nobel Prize in physics has been awarded by the Royal Swedish Academy of Sciences to Philip W. Anderson (Bell Labs and Princeton University), Sir Nevill Mott (Cambridge University) and John H. Van Vleck (Harvard University) "for their fundamental theoretical investigations of the electronic structure of magnetic and disordered systems." The three men will share equally the prize of about \$145 000, to be awarded in Stockholm on 10 December.

The Academy said that although the three prizewinners have been active in large domains of physics, this year's prize emphasizes their work on the "electron-electron interaction and the coupling between the motions of the electrons and the atomic nuclei in magnetic and disordered materials, where they—particularly in the treatment of and the emphasis on localized electronic states—have gone far beyond the conventional theories, with direct importance for experiments and technology."

Van Vleck is sometimes called "the father of modern magnetism." In his 1932 book, *The Theory of Electric and Magnetic Susceptibilities*, Van Vleck developed the general quantum-mechanical formalism for this subject. His treatment of exchange interaction in ferromagnetics was based on the form $J_{ij}S_iS_j$ of the Hamiltonian first introduced by P. A. M. Dirac.

He made calculations of molecular structure that showed the relations between the Heitler-London and bond pictures and shed light on the idea of directed valence. Building on the 1929 crystal field theory of Hans Bethe, Van Vleck developed methods to describe the behavior of an atom or ion in a crystal. The perturbing ion's electrons can enter into chemical bonding with the environment, partly because of incipient covalence. This bonding is known as the ligand field. Van Vleck did a series of calculations in ligand-field theory, using an effective field acting on the orbital angular momenta of d electrons. The Academy said that these quantum-chemistry methods have now become almost routine tools in the inorganic chemistry of the atoms of the transition group.

During World War II, Van Vleck worked on radar and showed that at about $1\frac{1}{4}$ -cm wavelength, there would be a troublesome absorption line for radar because of water molecules in the atmosphere. He also showed that at $\frac{1}{2}$ cm, there would be even stronger absorption because of the rho-type triplets of the oxygen molecule. Van Vleck recalled later, "None of us who worked in molecular spectra in the 1920's dreamed that two decades later some of the results might have military significance, and four decades later important applications to radioastronomy and astrophysics."

In 1939 Van Vleck and independently Ralph Kronig showed that the spin-lattice relaxation of a paramagnetic ion is accounted for by the modulation of the local crystal field by lattice vibrations. He also noted that the Jahn-Teller distortion in degenerate ground states, first described for molecules, could operate for ionic configurations in crystals. In 1941 Van Vleck pointed out that observed spin-relaxation times might depart from the calculated values because of an enhancement in the population of those phonons interacting with the ions (the phonon bottleneck). Twenty years later these predictions were experimentally verified in detail.

Van Vleck showed that an external magnetic field may mix excited paramagnetic states into an otherwise non-magnetic ground state, giving rise to a temperature-independent magnetic susceptibility—Van Vleck paramagnetism.

In 1948 Van Vleck wrote a paper on the dipolar line width in magnetic resonance, applying Ivar Waller's method of moments to explain the directional dependence of the line-shape in some of Edward Purcell's observations on nuclear magnetic resonance in crystals. In another paper, Purcell, Robert Pound and Nicolaas Bloembergen had found motional narrowing when they observed nmr in liquids. When C. J. Gorter was a visiting professor at Harvard in 1947, he and Van Vleck both came to the laboratory one morning with the idea that a very similar effect would occur in ferromagnetic solids because of exchange narrowing, which causes the broadening to average out. Van Vleck then developed the results in greater mathematical detail by again using the method of moments.

Van Vleck was one of the first to point

out the essential importance of electron correlation—the interaction between the motions of the electrons—for the appearance of local magnetic moments in metals. These ideas were later quantified by John Hubbard in the early 1960's.

Anderson began his career, as a student under Van Vleck, with work elucidating pressure broadening in microwave and infrared spectroscopy. He continued his interest in line broadening, later working, for example, on exchange narrowing. In 1959 he developed a theory of superexchange—the coupling of the spins of two magnetic atoms in a crystal through their interaction with a nonmagnetic atom located between them. Anderson was among the first to realize the significance of broken symmetry and collective modes and applied it during this period to antiferromagnets and soft modes in ferroelectrics, and later to the topic of superconductors.

In 1961 he conceived the by now widely used "Anderson model" for an impurity atom in a metal. In this model, the condition for the impurity to behave like a localized magnetic moment can be expressed in terms of the energy of a valence electron on the impurity, the energy broadening due to hopping to and from host atoms, and the strength of the Coulomb repulsion between a pair of electrons on the impurity. In the late 1960's and early 1970's he worked, alone and with others, on the Kondo effect for magnetic impurities in metals, and contributed concepts that foreshadowed the recent solution of this problem by Kenneth Wilson and his collaborators.

In 1958 Anderson noted that in a medium containing randomly located impurities, there is a competition between the tendency to migrate due to the coupling of neighboring spins and the impediment to migration due to random energy differences between different sites. He showed that, depending on the parameters of the problem, a spin polarization initially established in a given region might in some cases migrate eventually to infinity, but in other cases might remain (at 0 K) forever localized near its starting point. As he noted at the time, the same two possibilities exist for migration of charges (electrons or holes) in random media. This phenomenon of "Anderson localization" has led to the concept of the mobility edge. (Noting that it has sometimes taken physicists several years to understand the contents of some of Anderson's papers, particularly the 1958 paper, Anderson wryly remarked to us, "That paper had a lot in it that even I didn't understand.")

For the next ten years or so, Anderson concentrated on magnetism, especially on superconductivity and superfluidity, predicting the existence of resistance in superconductors, helping to elucidate the Josephson effect, and with Pierre Morel, pointing out the nature of possible su-

perfluid states of He^3 due to p-state pairing.

In 1971 he returned to disordered media, working on low-temperature properties of glass with Bertrand Halperin and Chandra Varma and with Sir Sam Edwards on spin glasses. In 1975 Anderson pointed out that in a glassy material, the occasional regions with somewhat indeterminate configurations could provide sites that would prefer to be occupied by electrons in pairs, rather than singly, and that this could make possible electronic structures that would be insulating and diamagnetic at low temperatures, yet have a continuous spectrum of electronic states. In the same year, Mott also took up this two-electron center idea and applied it to defects in glasses.

Mott, in the early 1930's, developed the quantum theory of atomic collisions and wrote the classic book on the subject with Sir Harrie Massey. Mott polarization-dependent scattering is still an important technical tool. Subsequently he wrote two of the first major texts of solid-state physics, with H. Jones on metals and with R. W. Gurney on ionic crystals; the former text presented many very modern concepts on band structure. In this period Mott also contributed to the theory of the photographic effect and important discussion of semiconductor phenomena, such as rectification and of defects in ionic crystals. Under Mott's leadership, a group that included Sir Frederick C. Frank did significant work on dislocations, defects and strength of crystals. Mott also made significant contributions to the theory of plasticity, especially of work hardening.

According to band theory, nickel oxide should be a metallic conductor; in fact, it is an insulator. Mott showed in 1949 that this behavior could be explained if one takes into account the electron-electron interaction. This work led to the study of metal-insulator transitions, often called Mott transitions, which occur when the electron density decreases or as the interatomic distance increases, or in other ways.

Beginning in the early 1960's, Mott called attention, especially for experimental physicists, to Anderson localization, pointing out that these localized states occur in many situations. Anderson recalls, "Mott picked up the ball and ran with it."

Over the last ten years, Mott showed the significance of localization through two of his ideas: variable range hopping and minimum metallic conductivity. In 1968 Mott considered a microscopic picture of conductivity as a function of temperature, T ; at high temperature, electrons hop to the next neighbor; at low temperature they hop to more distant centers. The conductivity varied as $\exp(-\text{constant}/T^{1/4})$. (In two-dimensional systems, the exponent of T is $1/3$.) This idea has been central to analysis of

transport by hopping. In 1967 Mott and Robert S. Allgaier described minimum metallic conductivity, which is the smallest value of the conductivity that is unactivated, so that the conductivity in the metallic regime has a minimum value, normally about $1000 \text{ ohm}^{-1} \text{ cm}^{-1}$. Mott stressed the significance of the mobility edge, which could be detected from the minimum value of the conductivity, and proposed experiments to demonstrate its existence from experimental data. He is the author (1971) with E. A. Davis of a major book on electronic properties of noncrystalline materials.

Biographies. Van Vleck earned his bachelor's degree from the University of Wisconsin in 1920 and his master's (1921) and doctor's (1922) from Harvard. After an instructorship at Harvard for one year, he went to the University of Minnesota, becoming a full professor in 1927. He then went to the University of Wisconsin, remaining until 1934. At that time, he went to Harvard, remaining there until the present. In 1951 he became Hollis Professor of Mathematics and Natural Philosophy; in 1969 he became emeritus professor. During World War II, he served as head of the theory group in the radio research laboratory. From 1945 to 1949 he was chairman of the physics department and from 1951 to 1957 he served as dean of engineering and applied physics.

Anderson obtained his BS (1943), MS (1947) and PhD (1949) at Harvard, doing his thesis under Van Vleck. During 1943-45 he was at the Naval Research Laboratory. Upon receiving his doctorate, he joined Bell Labs, where he has been ever since. His present title is consulting director in the Physical Research Division. From 1967 to 1975 he also worked part-time as visiting professor of theoretical physics at Cambridge University, often discussing problems with Mott. Since 1975 he has been professor of physics at Princeton University.

Mott took a bachelor's at Cambridge in 1927 and a master's in 1930. (He never stopped to pursue a PhD.) He was lecturer in mathematics at Manchester University in 1929-30 and had the same post at Cambridge until 1933. He then became professor of physics at Bristol University, where he stayed until 1954. Mott then returned to Cambridge as Cavendish Professor and head of the Cavendish Laboratory; he held this post until his retirement in 1971. He has been in Cambridge since then. He served as master of Gonville and Caius College during 1959-66.

—GBL

Yalow wins half of Nobel Prize in Medicine

Rosalyn S. Yalow has been awarded half of the 1977 Nobel Prize in Physiology or Medicine for her development of a pow-