RECENT DEATHS

Louis S. Jaffe, 63; professor of epidemiology and environmental health, George Washington University; 24 July.

Riojun Kinosita, 84; retired chairman of experimental pathology, City of Hope Medical Center; 7 September.

John V. Lagerwerff, 56; soil scientist, Agricultural Research Service, U.S. Department of Agriculture; 12 September.

Edith M. Lincoln, 86; former clinical professor of pediatrics, New York University School of Medicine; 28 August.

Paul Nawiasky, 94; dye chemist and former director of research, G.A.F. Corporation; 6 September.

J. Winthrop Peabody, Sr., 94; former professor of respiratory diseases, Georgetown University; 6 September.

Bernard S. Wolf, 65; chairman of radiology, Mount Sinai School of Medicine; 16 September.

Erratum: The article by Kenneth Giles that reported the effects of altered fungal strains on pine seedlings ("Genetic engineering . . . long-distance rumor," 28 Oct., p. 388) was originally scheduled for the June issue of *Plant and Soil*; however, its publication was delayed and it has not yet appeared.

RESEARCH NEWS

The 1977 Nobel Prize in Physics

The Royal Swedish Academy of Sciences has awarded the 1977 Nobel Prize in Physics to Philip W. Anderson, Bell Laboratories and Princeton University, Nevill F. Mott, Cambridge University, and John H. Van Vleck, Harvard University, for their fundamental theoretical investigations of the electronic structure of magnetic and disordered solids.

The field of solid-state theory owes its rapid and very successful development to a relatively small number of individuals who have had a decisive influence in opening new lines of thought and in establishing dynamic schools and research groups. The names that immediately come to mind among those active before World War II are M. Born, N. F. Mott, and R. E. Peierls in Great Britain, L. D. Landau in the Soviet Union, H. Bethe, F. Bloch, and E. Wigner first in Europe and later in the United States, and J. C. Slater and J. H. Van Vleck in the United States. This very illustrious group was joined after World War II by an equally influential set of younger men, mostly students of this first group, among whom we find J. Friedel in France, M. H. L. Pryce in Great Britain, a fairly large number of Landau's students in the Soviet Union, R. Kubo in Japan, and P. W. Anderson, J. Bardeen, H. Brooks, C. Kittel, W. Kohn, F. Seitz, W. Shockley, and C. Zener in the United States. The third and subsequent generations are already too numerous to include here.

There are many Nobel laureates in this very select list, yet the winners of the 1977 prize seem to fill a void. Although the Swedish Academy has focused on specific major contributions of Anderson, Mott, and Van Vleck, it is generally believed that it is their integrated contributions that support the awards for the three men. Their influence has reached practically every area of the physics of condensed matter.

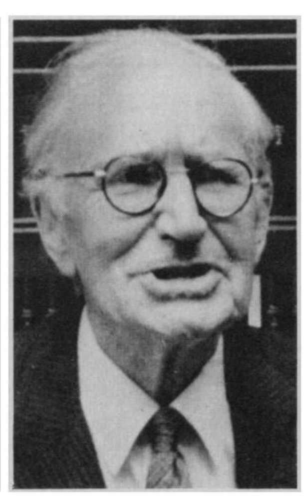
John Hasbrouck Van Vleck (A.B., University of Wisconsin, 1920; Ph.D., Harvard University, 1922) was active in physics before the emergence of modern quantum mechanics. His 1926 monograph (*1*) on quantum principles and line spectra according to the old quantum theory "appeared at a moment when the new quantum mechanics had just been born. This new theory, together with the notion of the spinning electron, provided exact derivations of the semi-empirical rules of the older theory and made the celestial mechanics type of perturbation calculus superfluous" (*2*). This monograph remains today as a most enlightening exposition of the powers and limitations of the old quantum theory.

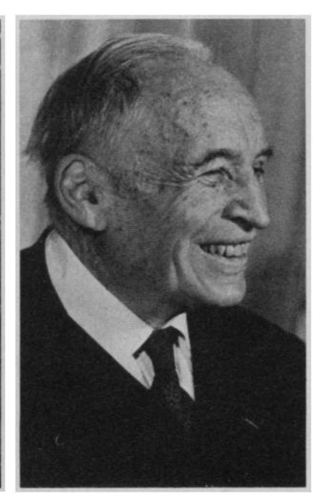
As pointed out by Van Vleck, "American theoretical physics reached maturity with the great breakthrough of quantum mechanics, when American theorists could start from scratch on equal terms with their European colleagues" (*2*). Certainly Van Vleck was, with the late J. C. Slater, a leading protagonist in this new development. His work in the late 1920's and early 1930's was focused on what was to become his main field of research, in which he made his most enduring contribution—dielectric and magnetic susceptibilities. This culminated in the publication in 1932 of a still popular book, *The Theory of Electric and Magnetic Susceptibilities* (*3*).

Van Vleck is deservedly known as "the father of modern magnetism." His work has been the foundation for understanding the behavior of foreign ions and atoms in a crystal or in a cluster in solution. His important discoveries and ideas are too numerous to be covered in a short review, but some of his major contributions are summarized below.

Van Vleck introduced the concepts of the crystal field and the ligand field—the electric fields experienced by the electrons in a foreign atom or ion because of the presence of other ions or atoms in their immediate environment. Crystal


Philip W. Anderson


Nevill F. Mott


John H. Van Vleck

and ligand fields modify the allowed energy states of the system, with consequent changes in electrical, magnetic, and optical properties. The underlying ideas are basic for understanding a large variety of phenomena and play a role in explaining the properties of solid-state lasers. Ligand field theory is an invaluable tool for understanding the chemical behavior of clusters and the bonding of molecules, and leads naturally to the idea of partial covalency. These aspects of quantum chemistry are now routinely used by researchers in physics, chemistry, molecular biology, medicine, and geology.

Van Vleck was the first to point out that the correlation of electrons in atoms or ions may lead to the formation of a local magnetic moment. This means that microscopic particles in suitable environments may act as minimagnets. The properties of such minimagnets, their strength and orientation (and ability to change either), depend crucially on the characteristics of the host in the vicinity of the atom or ion. [This was further developed by Van Vleck's former student, P. W. Anderson, in a famous paper published in 1961 (*4*).] Van Vleck extracted the basic properties of these minimagnets and reduced their descriptions to a fundamental mathematical language—the spin Hamiltonian formalism—from which direct calculations could be made.

The concepts described above are applicable to a variety of phenomena, ranging from distortions of the environment of the minimagnet (the Jahn-Teller effect) to alternating up-and-down arrangements of the magnets in a lattice (the antiferromagnetic state), and to a whole host of new ideas which are basic for the understanding of most magnetic phenomena—for example, the quenching of angular momentum and anisotropic exchange. One application is to Van Vleck paramagnetism, the idea that the crystal field leads in some cases to a magnetic susceptibility which is temperature-independent, in contrast to the ordinary, strongly temperature-dependent Curie susceptibility.

Finally, Van Vleck's lifelong interest in magnetism, combined with his activities at the Radio Research Laboratory during World War II, led to important contributions in radio-frequency spectroscopy and theoretical problems associated with magnetic resonance phenomena.

Van Vleck holds numerous honorary degrees from American and foreign universities and has received many prizes and awards, including the 1965 Langmuir Prize in Chemical Physics and 1966 National Medal of Science. He is a member of the National Academy of Sciences and a past president of the American Physical Society.

Nevill Francis Mott (B.A., St. John's College, Cambridge; M.A., Cambridge, 1930) is the most influential solid-state theorist in Great Britain. His contributions span 50 years of incredible productivity in a very broad range of areas and fields. Like Van Vleck, Mott participated in the development of quantum mechanics during the late 1920's and early 1930's. His contributions to the understanding of collisions between charged particles—what is now known as Mott scattering—are summarized in one of his early books (*5*). His interests shifted in the early 1930's to solids, in particular metals and alloys, where he was instrumental in setting the quantum foundations of this new field. This resulted in the publication in 1936 of a textbook in solid-state physics (*6*) that is still in common use today.

Mott was the first to suggest that all electrons in the transition-metal series contribute to the electrical conductivity, although not all in the same way. A particular group of electrons is primarily responsible for the current, while a second group, more sluggish and massive, accounts for the magnetic properties and acts mainly as a source of additional resistivity and scattering. The very active field of transition-metal physics today retains this point of view.

Mott's work while he was a professor at the University of Bristol (1933 to 1954) has had a strong influence on metallurgists and materials scientists. His research on the structural properties of metals and alloys, including crystal growth, dislocations, and defects, has established major directions in the field. It was also during the Bristol period that he made important contributions to the understanding of the photographic process, the phenomenon of rectification of currents passing through contacts between solids, and the mechanism for electrolytic conductivity.

One of the early successes of quantum mechanics was the explanation by Bloch, Peierls, and Wilson of the sharp distinction between metals and nonmetals; this explanation is based in the band theory of solids, and its general validity has stood well the test of time. At a conference in Bristol in 1937, de Boer and Verwey pointed out that nickel oxide, a transparent nonmetal, should be metallic according to band theory. Mott (*7*) showed how this discrepancy can be explained by means of a refined theory which takes into account the detailed interactions between electrons. This led to the study of the processes which may induce certain metals to become insulators, and vice versa. These processes are now called Mott transitions (*8*); in addition to their important conceptual implications, they are of major technological interest.

Mott has considerably advanced our understanding of the electronic properties of disordered materials. In crystalline materials the atoms are arranged in regular lattices, which greatly facilitates theoretical treatment. In disordered materials (glasses, alloys, and impure semiconductors), where no lattice exists, understanding the electrical conduction processes becomes exceedingly difficult. Mott (*9*) has introduced new fundamental concepts and contributed to understanding the principles which govern the physical behavior of these materials. These include the concepts of variable range hopping (the ability of electrons with different energies to hop between centers, atoms or impurities, with varying distances according to their energy), mobility edge (a sharp energy cutoff between mobile electrons and electrons in traps), impurity conduction (impurities in semiconductors may, under some conditions, produce their own mechanism for electrical conduction), and minimum metallic conductivity (in a disordered system, if the electrons carry any electric current at all, the current must be larger than a given value).

From 1954 to 1971 Mott was the Cavendish Professor of Physics at Cambridge University. He was elected Fellow of the Royal Society in 1936 and was knighted in 1962. He was Master of Gonville and Caius College, Cambridge, from 1959 to 1966, holds honorary degrees from many universities throughout the world, has been the recipient of a large number of awards, and is honorary fellow or associate of many societies and academies, including the National Academy of Sciences of the United States.

Philip Warren Anderson (B.S., 1943; Ph.D., 1949, Harvard University), who was a student of Van Vleck, currently divides his time between Bell Laboratories and Princeton University. Although the Swedish Academy cited two of Anderson's major contributions, concerning localized magnetism in metals and electronic localization in disordered materials, several other advances due to Anderson rank in this category of excellence. He has greatly influenced the development of our understanding of magnetism, superconductivity, quantum properties of helium, tunneling, ferroelectricity, and the electronic structure of crystalline and amorphous solids. He has developed and applied new concepts and techniques, such as broken symmetry, in such a unique and inventive manner that his ideas have found their way into many other branches of physics. He is probably the broadest contributor at the forefront of solid-state theory, and his work almost always carries his particular stamp of originality. Much of Anderson's work has been motivated by the observation of something new or puzzling in experimental data.

In 1958 Anderson (*10*) demonstrated that electrons in disordered systems could become localized because of the disorder. This theory was developed in an attempt to explain the puzzling observation by G. Feher of long diffusion times in systems where disorder would indicate strong interactions and short relaxation times. Anderson and others (notably Mott) subsequently applied and developed the 1956 theory to study the difficult subject of amorphous solids. The concepts developed around "Anderson localization" are vital to our understanding of the nature of this important class of materials.

Anderson's 1961 paper (*4*) on localized magnetism in metals (local magnetic moments or minimagnets) was also a response to an experimental puzzle. B. T. Matthias and others had found indications that some magnetic impurities caused a lowering of the superconducting transition temperature of their host, while others caused an increase. The "Anderson model" provided a technique which is considered the cornerstone of this field. It explains very complex behavior such as the abrupt change in the strength of local magnetic moments with variations of only a few percent in the impurity concentration. It also explains why iron atoms are magnetic when dissolved in a nonmagnetic host metal such as copper. This approach has been used to understand the microscopic origins of magnetism of bulk materials. Thus Anderson created a simple quantum model which can explain microscopically the basic physics of a host of problems. It is used today in a variety of problems, ranging from transition metal impurities in semiconductors and metals to impurities on solid surfaces to general theories of electron-electron correlation.

The basic interactions between minimagnets in an insulating solid are responsible for its overall magnetic properties. It is thus possible to achieve all kinds of magnetic arrangements, which depend crucially on the magnitude and sign of these interactions. It was Anderson's explanation (*11*) of the role and mechanism of superexchange—the transmission of magnetic interaction between metallic cations through an intervening nonmagnetic anion, usually oxygen—which provided a quantitative basis for all subsequent theories. This field has far-reaching practical applications.

The formulation in 1956 of the Bardeen, Cooper, and Schrieffer (BCS) theory of superconductivity, for which the authors received the 1972 Nobel Prize in Physics, produced a revolution in theoretical solid-state physics. The effect on Anderson's work was profound. He began by reformulating the BCS theory in a very elegant treatment—the so-called pseudo-spin formalism—which focused on the global symmetry aspects of the superconducting state. This led naturally to studies of broken symmetry and gauge invariance and relationships between antiferromagnetism and superconductivity.

During a year in Cambridge in 1961–1962 Anderson formed a close association with B. D. Josephson, who was then a graduate student. He played a major role (*12, 13*) in Josephson's discovery of another example of broken symmetry in superconductivity—the nonresistive flow or tunneling of electrons across a thin insulating barrier between two superconductors—which is now known as the Josephson effect, and for which Josephson was awarded the 1973 Nobel Prize in Physics. Anderson's contribution to the theory was crucial, and he and J. M. Rowell (*14*) were the first to report an experimental observation of the Josephson effect.

His other contributions in superconductivity include further work on superconductive tunneling and the possibility of using this phenomenon to measure accurately the lattice-vibration characteristics of superconducting metals; the explanation of the mysterious role of nonmagnetic impurities in superconductors (the theory of "dirty" superconductors); and the foundation for understanding phenomena connected with type II superconductivity. Anderson pointed out that when magnetic flux penetrates type II superconductors and concentrates in microscopic bundles—the flux lines—these flux lines move through the metal and produce a resistive state. This is of considerable importance in the technology of superconducting magnets. Anderson's early attempts to explore other forms of superconductivity led him to generate fundamental ideas which are basic to our present understanding of the recently discovered superfluid phases of helium 3.

Anderson's contributions in other fields are many and varied. Their implications are profound and in many cases his ideas are now being developed by other theorists throughout the world. We mention here some important specific examples by name only: spin glasses, chemical pseudopotentials, stochastic methods in line-width problems, soft modes and ferroelectricity, the scaling theory of the Kondo effect, spin polarization of photoelectron spectroscopy of ferromagnets, and technical applications of the Josephson effect.

P. W. Anderson was a tenured visiting professor of physics at the Cavendish Laboratory, Cambridge, from 1967 to 1975. He was awarded the 1964 Oliver E. Buckley Prize of the American Physical Society and the 1975 Dannie Heineman Prize of the Academy of Sciences of Göttingen. He is a member of the National Academy of Sciences of the United States.

It should be evident by now that the 1977 Nobel Prize in Physics differs in character from the classic model of an award for one specific discovery or invention. It was difficult, therefore, to single out a specific piece of research to focus on from inception and formulation to application and impact. The three physicists awarded the 1977 Nobel Prize have had an incredible influence on a very large sector of the physics community—there is hardly an area in the physics of solids in which some of the basic roots cannot be traced to Anderson, Mott, or Van Vleck.

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