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VAN VLECK AND MAGNETISM

Through his work on crystal field theory, paramagnetism, resonance spectroscopy and quantum theory, one man turned magnetism into a field too large for any one man.

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A FEW YEARS AGO there would have been little need to distinguish between the two halves of my title: John H. Van Vleck and magnetism, as a field of theoretical physics, were practically synonymous. Now the field has expanded so much that no one man can overwhelm all of its branches in the way Van did when my generation was being introduced to it. While I can safely assume that all physicists know some parts of Van's career in magnetism, I suspect few appreciate the whole of it.

John Hasbrouck Van Vleck is the son of the eminent mathematician Edward Burr Van Vleck. The only story about our Van that is not true is that the mathematics building at the University of Wisconsin is named after him: It is named for his father. Van's grandfather, John Monroe Van Vleck, was also an eminent mathematician: The observatory at Wesleyan University bears his name.

Our Van Vleck received his AB at Wisconsin in 1920 and his PhD at Harvard only two years later at the age of 23. He went to Minnesota in 1923, becoming a full professor in 1927. That same year he married Abigail Pearson. A year later he moved to his father's university, Wisconsin, as professor of theoretical physics; then in 1934 he returned to Harvard where he became a full professor the following year.

At Harvard during World War II he headed the theoretical group at the Radio Research Laboratory. After the war he became chairman of the physics department, serving until 1949. Then he became the first dean of engineering sciences and applied physics, a position he held until 1957. In 1951 he also became Hollis Professor of Mathematics and Natural Philosophy. He plans to retire next June.

Visiting professor

In the midst of this busy schedule, he found time to be a visiting lecturer on eight separate occasions, including the Eastman Chair at Oxford (one of the most universally envied positions in England, since it comes with a centrally heated house) and the Lorentz professorship at Leiden. He also has been a councillor and president of the American Physical Society and a vice-president of the American Academy of Sciences, the American Association for the Advancement of Science and the International Union of Pure and Applied Physics.

I shall not recite the full list of his remaining honors, merely noting that they are uniquely multinational: He is a foreign member of no less than five national academies. The Universities of Grenoble, Paris, Oxford and Nancy are among those that have awarded him honorary degrees; so is Harvard, where he earned his real one. He was the first recipient of Case Institute's Michelson Award and the APS Langmuir Prize and last year received the National Medal of Science.

The reader may ask: "What has he done for us lately?" A great deal, it happens. For the past several years he has been working on the clathrate compounds in which the gas molecule is caught in a cavity or "cage" rather than chemically bonded, so that it can exhibit its free magnetic or other rotational behavior while conveniently trapped at the disposal of the experi-

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menter. He also has been working on magnetism in the rare earths, among other things.

Enormous influence

My emphasis, however, is on the past: the enormous influence Van has had on the study of magnetism, viewed as an enterprise in the quantitative understanding of the real properties of magnetic materials in microscopic terms.

Van's first work was on optical spectra and dispersion relations in the old quantum theory, and his first book[1] is the most complete and elegant exposition of the old quantum theory ever produced. Unfortunately it was published in 1926, just as the new quantum theory appeared. This monumental piece of bad luck did not faze him; Van was already learning and using the new quantum theory as it came out, and his courses at Minnesota in that period are remembered by his students—including among other notables Walker Bleakney and Walter Brattain—as the most scientifically exciting courses of their lives.

Apparently Van chose almost immediately to study electric and magnetic susceptibilities, an area in which the old quantum theory gave tantalizingly good results in many cases, and to see whether the new theory was definitely in better agreement. This point of view, though now unfamiliar to us, nonetheless gives his book[2] a sense of direction and cohesion that is very welcome. He did conclude that the new quantum theory is much better, incidentally. His ability to carry along an idea in each of three languages, classical and old and new quantum theory, is one of his greatest and most baffling strengths.

Bare bones fleshed out

It is a pleasant and fascinating task to go back and reread that book. One sees how even those basic ideas originated by others are illuminated and their bare bones fleshed out by Van's special point of view. One of these is the "Heisenberg exchange Hamiltonian," so-called. It is true that Werner Heisenberg first pointed out the connection of statistics, electron exchange and ferromagnetism, and that P. A. M. Dirac introduced formally the connection between exchange and a dot product of spin operators, but really it is Van Vleck who is responsible for the Hamiltonian of the form $J\ \Sigma(\mathbf{S}_i \cdot \mathbf{S}_j)$ that we now use to describe magnetic insulators and who expanded this method into the Dirac–Van Vleck vector model, a method capable of treating the complicated coupling of the various angular-momentum vectors within atoms and molecules as well. Again, Felix Bloch's spin waves take on a much clearer form when discussed by Van.

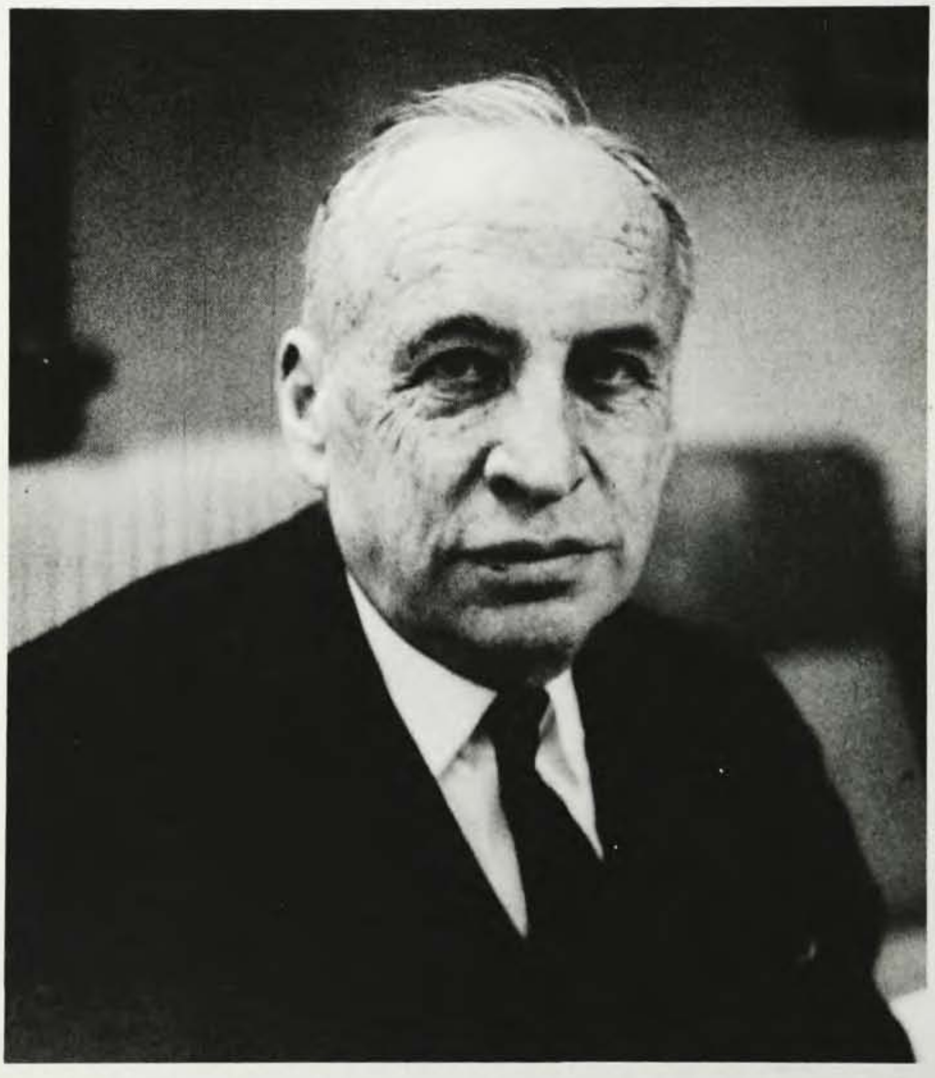
Crystal field theory as introduced by Hans A. Bethe was mainly an abstruse exercise in group theory; as done by Van Vleck it took on the form we still use—an effective field acting again on those angular-momentum vectors, in this case the orbital angular momentum of d electrons. In that form it becomes delightfully clear why, in some cases, the orbital angular momentum cannot respond at all and the susceptibility is given by "spin only"—the ubiquitous idea of "quenching" orbital angular momentum.

Two things strike one in looking back at the book from today's point of view. Again and again the great developments of the next decade or so, in which Van himself often participated, were very specifically hinted at: Antiferromagnetism and the covalent explanation of crystal fields are two examples.

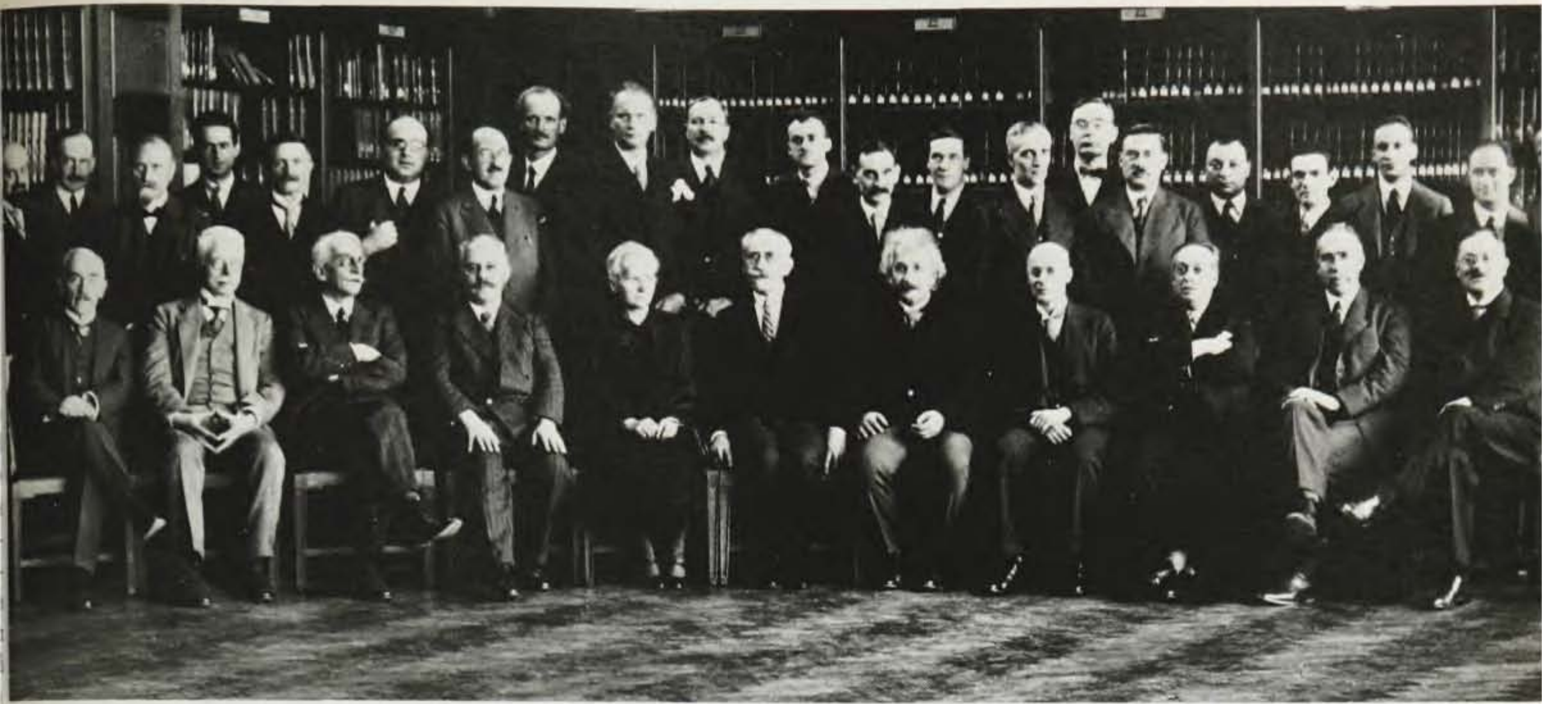
Van says he overlooked the possibility of an ordered state when the sign of the exchange-integral J is negative and so did not anticipate Louis Néel and Lev D. Landau by years in the theory of antiferromagnetism. As it is, the proper formal theory of this effect had to wait until he wrote it down in 1940, six or seven years after their rather obscure remarks.

Major contribution

The theory of crystal fields as originating from more-or-less weak covalent bonds of the magnetic ion to its ligands, now accepted as one of Van's most important contributions to magnetism (after some rather regrettable reversals), was foreshadowed in the



JOHN H. VAN VLECK, Hollis Professor of Mathematics and Natural Philosophy at Harvard, in a photo taken last year on his 68th birthday. He will retire next June.



THE ONLY AMERICAN at the Sixth Solvay Conference at Brussels in 1930 was Van Vleck. Here he is third from the right in the back row. Seated in front are, left to right, Théophile de Donder, Pieter Zeeman, Pierre Weiss, Arnold Sommerfeld, Marie Curie, Paul Langevin, Albert Einstein, Owen Richardson, Blas Cabrera, Niels Bohr and Wander de Haas. In back are E. Herzen, E. Henriot, Jules Verschaffelt, C. Manneback, Aimé Cotton, Jacques Errera, Otto Stern, Auguste Piccard, Walther Gerlach, Charles Darwin, P.A.M. Dirac, Hans Bauer, Peter Kapitza, Léon Brillouin, Hendrik Kramers, Peter Debye, Wolfgang Pauli, Jakov Dorfman, Van Vleck, Enrico Fermi and Werner Heisenberg.

book and very soon formally written down by Van Vleck, though it had to wait 15 years to be picked up again.

Of course, I have not mentioned many useful and important things that *are* in the book. Van Vleck paramagnetism is one. Another is that the book is not "dated;" it does not attempt or accept a wrong explanation for anything, but leaves subjects open for further ideas. A contribution deserving special mention is the only really clear exposition in existence of the meaning of Maxwell's equations in a medium, in terms of the actual atoms and molecules and the real microscopic electromagnetic fields.

A second look back at Van's career also came from my bookshelf: a Japanese reprint collection on the origins of the field of microwave and resonance spectroscopy. Virtually all of the basic papers that were not written by Van acknowledge his advice and contribution of ideas, and of course these we are using still. Van Vleck in his contacts with the Dutch low-temperature group was clearly the most important figure in understanding the nature of the relaxation of magnetic vectors, spin–spin and spin–lattice. He was the central figure in carrying these concepts into radiofrequency spectroscopy after the war.

His great papers applying Ivar Waller's moment method to spin–spin relaxation and pointing out the vital phenomenon of exchange narrowing were of great importance; so was his recognition of the importance to magnetism of the abstruse ideas of Kramers (time-reversal) degeneracy—that an odd number of electrons always has a free spin—and of the Jahn–Teller effect of distortion of the system in the presence of orbital degeneracy.

Information, stimulation

Most impressive during and after the war was his role as an information post and stimulant for this immensely important new field. To chat with him at a meeting in those days was to be interrupted by an endless parade of experimentalists asking for an idea or two on their latest results—and getting them.

Three separate efforts stand out in a very long career. All of them are relevant to today's events, and two of them are cases in which Van played a role he particularly likes: that of mediator between two valid points of view, emphasizing that common results of the two approaches indicated that in the end they would turn out to be compatible.

The first of these mediation efforts occurred in the early days of what is now called "quantum chemistry." Seemingly, two ideas that earned Nobel Prizes many years apart—the Slater–Pauling valence-bond idea, now often called Heitler–London, and the Hund–Mulliken molecular-orbital concepts—conflicted in their explanations of the chemical bond. Van Vleck played a considerable role not only in emphasizing that this incompatibility need not be absolute, but in demonstrating that both schemes could be used to explain certain results. One of the most important of these is that carbon exhibits tetrahedral bonding: The only valid discussion of this vital fact to this day, in my opinion, was in his papers in the *Journal of Chemical Physics* during this period.

Results not incompatible

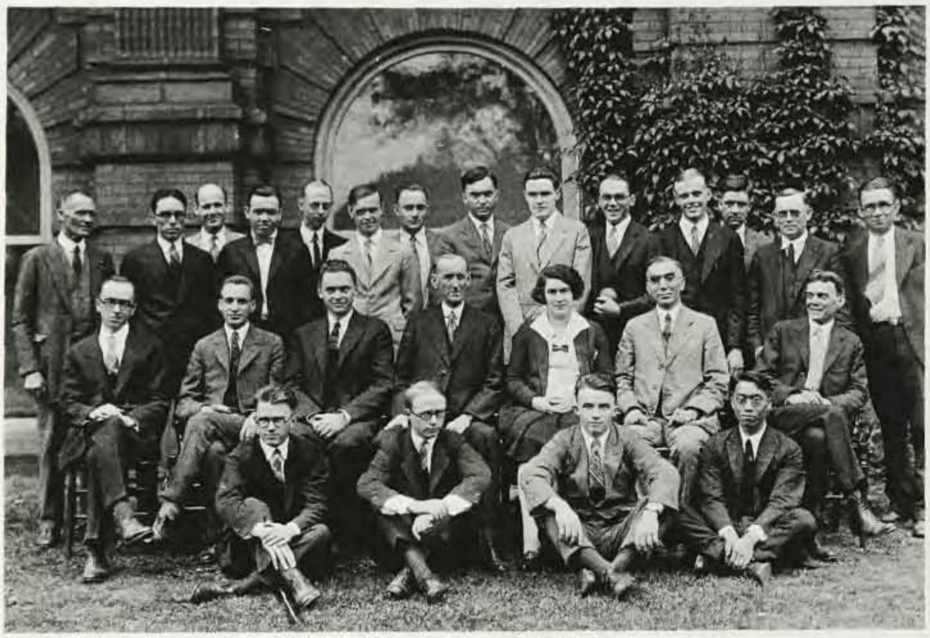
A second instance involved the series of papers and reviews he produced, from the late 1930's onward, emphasizing that the local spin and itinerant models of ferromagnetism need not be incompatible, and gave many similar results. In fact, with our present understanding of spin waves as collective excitations of the itinerant model and of the nature of spin phenomena in metals and insulators, this must be described as the only possible point of view. Either perfect itineracy or perfect localization is very rare, and no magnetic phenomenon should be looked at exclusively from one point of view or the other. As Conyers Herring put it in a famous review, it is all a matter of how you mix your cocktails, but neither pure gin nor pure vermouth is very satisfactory.

A final contribution that crops up these days in such diverse areas as intergalactic hydroxyl-maser effects and satellite communications is Van Vleck's yeoman work over the years on molecular spectra in all their fascinating complication. It is his work on lambda doubling on which our knowledge of the hydroxyl spectrum is based, and it was his calculations on O_2 that explained the opacity of the atmosphere in certain millimeter-wavelength regions of the spectrum that otherwise would be ideal for satellite communications.

The teacher and the person

Then there is Van the teacher and Van the person. Almost all the stories about him are true: He does own a great collection of Japanese wood-block prints, inherited from his father, many acquired from Frank Lloyd Wright. He was for years the world's greatest expert on obscure railway timetables.

It is true that he once rode to Bell Laboratories from New York in the cab of the Phoebe Snow. I am particularly grateful for one of his rides: When I graduated from Harvard, Van took the Phoebe Snow to Bell Labs and talked them into taking a chance on me. It is also true that he has had two papers published in the *Annals of the National University of Tucuman* in Mexico.



AT MINNESOTA in 1925, Van Vleck (second from left in second row) is flanked on the left by Joseph Valasek and on the right by John Tate. Others in the picture include J. William Buchta (eighth from left in back row), Elmer Hutchinson (ninth from left, back row) and Walker Bleakney (tenth from left, back row).

AT WISCONSIN about 1929, Werner Heisenberg (first row, center) posed with the physics faculty. Van Vleck sits next to him at left. Also in picture are Leland Howarth (seventh from left, back row) and Albert Whitford (second from right, back row).

Students challenged

Many of his students remember his habit of asking the class for a response —typical was the day when he came into class and started his lecture with: "A clever trick is what?" We also remember his group-theory course in which we learned most of the subject through a diabolical series of problems. He once wrote a problem on the blackboard as DOOCS and it took us a while to realize that he meant: "Do the molecule OCS."

The problems usually were short but had terribly long hints. We learned early that you should read the hint only after doing the problem, when it very likely would give you an entirely new insight in what you had done. But we ordinary mortals seldom were able to do the problems that way.

No one I have ever heard of came out of a Van Vleck course without having learned, usually having learned a great deal. The list of his students is so large and so eminent that it is hardly fair to pick out any suitable subset of names: Let me drop the names of, say, Robert Serber, John Bardeen and Harvey Brooks at random.

John Van Vleck laid the foundations in a field that has kept a generation of physicists busy. Many in the field owe the beginnings of their careers to him. This article is an attempt to show our appreciation.

References

1. Van Vleck, *Quantum Principles and Line Spectra*, National Research Council, Washington (1926).
2. Van Vleck, *Theory of Electric and Magnetic Susceptibilities*, Clarendon Press, Oxford (1932). □