Journal of Statistical Physics, Vol. 2, No. 2, 1970

Francis Bitter and "Landau Diamagnetism"[1]

Stephen G. Brush[2]

Received January 26, 1970

A forgotten paper by Francis Bitter on the diamagnetism of a quantum electron gas, published in 1930, is discussed. By an approximate method, later considered unsatisfactory, Bitter obtained a result qualitatively similar to the standard formula first established by Landau in the same year.

KEY WORDS: diamagnetism; diamagnetic susceptibility; quantum theory of magnetism; electron gas; history of physics.

The American physicist Francis Bitter (1902–1967) was best known for his experimental work on magnetism.[3] However, he also made at least one significant contribution to magnetic theory which deserves to be remembered, although it was omitted from the recent (and otherwise excellent) book, *Francis Bitter: Selected Papers and Commentaries*.[(1)]

Some time ago, in studying the history of modern theories of magnetism, I came across Bitter's paper "On the Diamagnetism of Electrons in Metals," published in 1930.[(2)] In this paper, Bitter proposed to calculate "the induced diamagnetic moment due to the free electrons in a metal, using, instead of the classical assumptions of elastic collisions, the recently developed wave-nature of the electron and Fermi statistics."

As readers of Van Vleck's treatise[(3)] or other standard texts will know, a classical electron gas is forbidden to have a diamagnetic susceptibility by Miss van Leeuwen's theorem (a theorem apparently first discovered by Niels Bohr in 1911[(4)]). However, when the problem is treated by quantum mechanics, it is found that the electron gas may have a finite diamagnetic susceptibility, which depends in a rather complicated way on the magnitude of the field and the shape and size of the container. This result is generally attributed to L. D. Landau, who showed that if one solves

[1] *Editor's note*: This paper is intended as an historical note and is published in keeping with our policy of publishing such documentary material from time to time.

[2] Institute for Fluid Dynamics and Applied Mathematics and Department of History, University of Maryland, College Park, Maryland.

[3] See, for example, the obituary in the *New York Times*, July 27, 1967.

the Schrödinger equation (or rather, an equivalent set of commutation relations) for an electron in a magnetic field, neglecting surface effects, the continuum of free-particle energy levels is partly changed to a discrete set, each level having a degeneracy proportional to the magnitude of the field.[5] Since the lowest energy level is slightly higher than the lowest energy level for free particles in zero field, it turns out that the average energy increases with the field, thus giving a small diamagnetic susceptibility which is one-third of the paramagnetic susceptibility calculated by Pauli in 1927.[6]

Bitter, in his paper written independently of Landau's at about the same time, obtained a very similar result by somewhat less rigorous methods. He used an approximate wave function assumed to have the symmetry of a cubic lattice, and found that the ratio of the Pauli paramagnetic susceptibility to the diamagnetic susceptibility is equal to −2.4 for a body-centered cubic lattice, and to −1.5 for a face-centered cubic lattice, compared to the ratio −3.0 found by Landau for free electrons.

Neither Landau nor Bitter gave much attention to surface effects, but later writers have found that when the solution of the Schrödinger equation is required to vanish at the boundary, a much larger susceptibility may be obtained.[7]

I wrote to Professor Bitter in 1964 about his paper, and he replied: "At the time of its publication, this paper was severely and correctly criticized for not taking into account the boundary conditions at the surface of the sample . . . . It is many years since I have interested myself in the subject and have not undertaken a detailed comparison with Landau's theory . . . ."[8]

As far as I know, he never made any attempt to claim credit for this discovery. Moreover, experts on magnetism have told me that he should not get any credit because his calculation had no legitimate theoretical foundation as compared with Landau's, and this was probably recognized at the time.

From the viewpoint of official priority, as determined by accepted criteria of the scientific community, it seems clear that Landau should continue to be regarded as the sole discoverer of the physical effect that bears his name, "Landau diamagnetism." Moreover, there is no evidence that Landau was aware of Bitter's paper at the time he developed his own theory. But for those who are willing to recognize that the history of science consists of more than a list of "firsts," and wish to understand something about the circulation of ideas that provides the background for a major breakthrough, this reminder of Bitter's work may cast a little light on the development of modern theories of magnetism.

REFERENCES

1. *Francis Bitter: Selected Papers and Commentaries*, Edited by T. Erber and C. M. Fowler (The M.I.T. Press, Cambridge, Massachusetts, 1969).
2. F. Bitter, *Proc. Natl. Acad. Sci. U.S.* **16**:95 (1930).
3. J. H. Van Vleck, *The Theory of Electric and Magnetic Susceptibilities* (Clarendon Press, Oxford, 1932), pp. 94–97.
4. N. Bohr, *Studier over metallernes elektrontheori* (Dissertation, Copenhagen, 1911).

5. L. D. Landau, *Z. Physik* **64**:629 (1930); English translation in *Collected Papers of L. D. Landau*, edited by D. ter Haar (Pergamon Press, Oxford, 1965), p. 31.
6. W. Pauli, *Z. Physik* **41**:81 (1927).
7. M. F. M. Osborne, *Phys. Rev.* **88**:438 (1952); M. C. Steele, *Phys. Rev.* **88**:451 (1952).
8. F. Bitter, letter to S. G. Brush, June 3, 1964.