

III. SOLID STATE PHYSICS

Prof. W. P. Allis
Prof. S. C. Brown

Prof. G. G. Harvey
Prof. L. Tisza

J. M. Goldey
J. B. Thomas

A. ON THE THEORY OF SUPERCONDUCTIVITY

Several years ago, the author advanced some speculations on the nature of the superconducting state (1). It was conjectured that superconductivity is a superstructure effect somewhat similar to that encountered in order-disorder transformations, but complicated by quantum mechanical resonance between equivalent ordered structures. Although attempts were made to obtain some results concerning the symmetry properties of the wave function of a superconductor, the discussion was largely phenomenological, and no progress was achieved in integrating these ideas into the framework of the conventional quantum mechanical theory of metals. In fact, consideration suggested that this theory might be too narrow to account for the phenomena in question.

One of the defects of the conventional theory is connected with the separation of the electronic and nuclear motion as provided by the adiabatic approximation developed for molecules by Born and Oppenheimer. The validity of this method is assured only for nondegenerate electronic eigenfunctions. However, in the case of metals, a degeneracy results from the symmetry with respect to the reversal of the direction of time. For every wave function corresponding to a current, we have another wave function with a current flowing in the opposite direction. Such a situation may lead to an unusually strong interaction between the electronic and the vibrational states. This has been shown to be the case for linear molecules (2).

A generalization in the case of metals is suggestive, but by no means obvious. The difficulty stems from the ordinary procedure of building up the wave function of the metal out of single particle functions.

The problem has now been taken up from a new point of view. Instead of building up the wave function of the metal from single particle functions, one starts, rather, from a unit cell. The dynamic variables entering the wave function specify the center of charge in each unit cell and the state of elastic compression. We may note that, in general, the unit cell consists of several crystallographic unit cells, a situation usually arising in the description of superstructure.

It is premature to size up the value of the method advanced, but it seems to offer possibilities that are beyond the scope of the band theory. The two approaches may turn out to account for complementary aspects of the many-body problem.

L. Tisza

References

1. See, particularly, National Bureau of Standards Circular 519, Proc. N. B. S. Symposium on Low Temperature Physics, March 27-29, 1951.
2. R. Renner, Z. Physik 92, 172 (1934).

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B. MICROWAVE STUDY OF SILICON CARBIDE

For the measurements of the dielectric constant and the conductivity of silicon carbide at microwave frequencies, a re-entrant cavity was constructed. Disc-shaped samples of silicon carbide crystals were mounted with a silver conducting paint beneath the center post of the cavity, in the region of high E-field.

If a perturbation theory is used, the dielectric constant is related to the shift in the resonant wavelength and the volume of the sample by (see ref. 1)

$$1 - \frac{1}{k} = \frac{\frac{d\lambda}{dv} \Big|_{\text{dielectric sample}}}{\frac{d\lambda}{dv} \Big|_{\text{metal sample}}}$$

For material in which the conductivity cannot be neglected, this equation must be considered as complex.

$$k = k_r + i k_i = \left(k_o - \frac{\sigma_i}{\omega \epsilon_o} \right) + i \left(\frac{\sigma_r}{\omega \epsilon_o} + k_r \tan \delta \right)$$

where k_r includes the dielectric constant of the lattice and the out-of-phase components of current, and k_i consists of the real conductivity and the dielectric loss.

$$1 + \frac{1}{k_r - i k_i} = \frac{1}{\frac{d\lambda}{dv} \Big|_{\text{metal sample}}} \left[\frac{d\lambda}{dv} \Big|_{\text{dielectric sample}} + i \frac{2\lambda_o}{Q_\epsilon \text{ vol}} \Big|_{\text{dielectric sample}} \right]$$

where

$$\frac{1}{Q_\epsilon} = \frac{1}{Q_s} - \frac{1}{Q_o}$$

and Q_s and Q_o represent the cavity Q with and without the sample.

Measurements between 77°K and 300°K were made on several samples. It was found that at 300°K the conductivity of the silicon carbide was large enough to behave as a metal with respect to its effect on the resonant cavity. The equation given above was, therefore, simplified to the following:

$$1 + \frac{1}{k_r - i k_i} = \frac{1}{\Delta\lambda \Big|_{300^\circ\text{K}}} \left[\Delta\lambda + i \frac{2\lambda_o}{Q_\epsilon} \right]$$

Preliminary measurements indicate that the dielectric constant at 77°K is approximately 7, which is in agreement with the value determined by optical methods.

J. B. Thomas

References

1. H. Bethe, J. Schwinger, National Defense Research Committee, Report No. D1-117, March 1943.