LETTERS TO THE EDITOR

Superconductivity: An Explanation

VARIOUS metals when cooled below a certain very low temperature (characteristic of the metal) show the property of conducting electricity without offering any appreciable resistance to the current. Meissner and Ochsenfeld found in 1933 that a supraconductor behaves not only like an ideal conductor, but also like a very strongly diamagnetic metal. No headway at all has been made in understanding the mechanism of superconductivity. The most promising line of attack is a purely formal theory by F. and H. London.[1] The object of this note is to present a physical picture of the process that is likely to be followed during the transition to the superconducting state.

We suppose that at a temperature depending on the nature of the substance and its crystalline form, the interaction between the lattice and the conductivity electrons becomes so small that it can be neglected. The interaction represents the effect of the electrostatic field of the substance on both the charge of the electron and its spin. In other words, we assume that the interaction between the lattice and the conductivity electrons is small at low temperatures. The amount of interaction depends on the temperature and the magnetic field and it becomes practically zero when the lattice vibrations have reached a critical temperatur which corresponds to the transition temperatu for the superconducting state. Here the co ductivity electrons can be treated as relative free electrons. The motion of each of the electrons will be represented by a de Brog wave and if they are perfectly free there w be *no interaction* which will give rise to t scattering of two de Broglie waves. The co ductivity will then be infinite and the substan will behave like a supraconductor.

These free electrons will precess in a magne field and give the substance a diamagnetic su ceptibility. When the field strength is increas so that $H > H_c$ the electrons will arrange the selves with their spins parallel to the field a the energy of magnetisation $2H\mu$ is transferi to the lattice (or the interaction between t lattice and the electrons is restored) and t substance is no longer superconducting. Und these conditions the electrons also do not p cess and consequently will not show any d magnetic susceptibility. The effect of incre ing the temperature is thus the same as creasing the strength of the magnetic fi namely, to increase the coupling between lattice vibrations and the conductivity electr When the electrons are free the substance i supraconductor, and the electrons also show diamagnetic susceptibility as they can precess if they are free to move. Thus the two properties, the superconductivity and the diamagnetic susceptibility go hand in hand.

The value of the diamagnetic susceptibility will be of the order $1/4\pi$, (as observed for the supraconducting state) if we can assume[2] that the conductivity electrons are free to move over a distance which is about 100 atomic distances. This distance is of the order of the mean free path of the conductivity electrons in a metal at ordinary temperatures. At ordinary temperatures the oscillations of the lattice are far from being negligible, and even then the mean free path of the electrons is of the order of a few hundred Ångstrom units. It is therefore reasonable to suppose that the mean free path of the conductivity electrons is of the order of 100 atomic distances when the lattice oscillations play an insignificant role.

If the electrons are completely free there will be no scattering of the de Broglie waves and the conductivity would be infinite. The conductivity in the superconducting state although very large, is probably not infinite. For this purpose an extremely small interaction will have to be introduced either between the lattice which does not now execute temperature oscillations or between the nuclei which are fixed in the lattice and the conductivity electrons. Such a small, second order interaction really exists and is observed for a number of substances in the form of hyperfine structure of spectral lines. This interaction between the nuclear spins and the electron spins, which gives rise to the hyperfine structure is observed for supraconducting as well as for nonsupraconducting substances and is very small. In the supraconducting state this small second order interaction assumes a leading part because it is no longer masked by the otherwise dominating lattice-electron interaction. In the superconducting state, the electrons are free to move over about 100 atomic distances; and we may be required to consider the resultant effect of a large number of nuclear spin interactions. This fact may give us the limiting size of the aggregate of atoms which will just be large enough to show superconductivity.

On this assumption substances which have no conductivity electrons and substances in which the interaction between the conductivity electrons and the lattice vibrations is not negligible, will not show superconductivity. According to Debye[3] the effect of the lattice oscillations is very small for all temperatures below 1° K. From this we can conclude that substances which do not become superconducting by about 1° K will not at all become superconducting. This seems to agree with the observed fact that the lowest transition temperature recorded[4] is 0·6° K for cadmium.

K. R. Dixit.

Gujarat College,
Ahmedabad,
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[1] F. London, *Une conception nouvelle de la supraconductibilité* (Herman, Paris, 1937).

[2] J. C. Slater, *Phys. Rev.*, 1937, **52**, 214.

[3] P. Debye, *Ann. d. Physik*, 1938, **32**, 85.

[4] Smith and Wilhelm, *Rev. Mod. Phys.*, 1935, **7**, 237.