Letters to the Editor

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Theory of Superconductivity

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IN a previous note,[1] it was pointed out that a charged boson gas below its condensation point is a superconductor. This shows that a theory of superconductivity is established if it can be shown that in a metal at low temperatures charge-carrying bosons occur which condense at a critical temperature T_C. The purpose of this note is to point out that if the total interaction between electrons (Coulomb-interaction, interaction by lattice vibrations[2] and other effects) is such that it produces resonant states of electron pairs, then one should expect the onset of superconductivity.

In a rough way one might try to describe a resonant state as a bound state of two electrons with negative binding energy, i.e., ignore the width. Assuming such a state at an energy $\zeta_0(1-\delta)$ per electron (ζ_0 being the Fermi energy of the free electron gas at absolute zero) the theory of chemical equilibrium applied to the equilibrium between electrons and these "bosons" yields qualitatively all the essential equilibrium features of superconductivity. At a critical temperature T_C given by

$$\delta=6.54(kT_C/\zeta_0)^{\frac{3}{2}}+0.824(kT_C/\zeta_0)^2+O((kT_C/\zeta_0)^4), \quad (1)$$

a transition of the second kind occurs with a discontinuity in the specific heat. Below T_C, the Meissner-Ochsenfeldt effect is exhibited; the number of superconducting (i.e., condensed) bosons at absolute zero is

$$n_{s0}=N\cdot\tfrac{3}{4}\delta. \quad (2)$$

(The penetration depth is determined by inserting (2) into London's theory[3]); the contribution of the noncondensed bosons can be neglected.

Quantitative agreement can, however, not be reached by this simple approach. The discontinuity in the specific heat is $\gamma\delta^2$; the difference in free energy between the normal and the superconducting state is of order $\zeta_0\delta^2$. If δ is computed from formula (1) by using the experimental T_C, both these quantities turn out to be much too small. Moreover, the trend of the specific heat curve below T_C is still essentially linear with almost the same slope as for the normal state.

Thus the description of the resonant state in terms of a single parameter δ is sufficient to give the qualitative features of superconductivity, but insufficient for quantitative purposes. In a quantitative treatment, the width of the resonance must play a crucial role. Furthermore, the problem has to be looked upon as a self-consistent one: the form of the resonance depends critically on the occupation of the electron states, and only in the vicinity of the Fermi surface can such resonances occur at all. At higher energies they will be too wide to have any effect; at low energies where all electron states are occupied, the resonances will be quenched by the Pauli principle. Qualitative considerations seem to indicate that the trend of these effects is indeed in the right direction for improving the agreement between theory and experiment.

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[1] M. R. Schafroth, Phys. Rev. **96**, 1141 (1954).
[2] H. Fröhlich, Phys. Rev. **79**, 845 (1950).
[3] F. London, *Superfluids* I, (J. Wiley and Sons, Inc., New York, 1950).

Exponential Temperature Dependence of the Electronic Specific Heat of Superconducting Vanadium

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THE specific heat of a specimen of vanadium has been measured in the superconducting state from its transition temperature, 5.05°K, down to 1.2°K. Vanadium lends itself well to the study of the electronic specific heat of a superconductor because, in this metal, quite low values of T/T_c are easily attainable and the lattice contribution to the specific heat is small compared with the electronic contribution.

The specimen, a cylinder of mass 85 g, was prepared by arc-melting crystals of vanadium which had been made by the van Arkel iodide process. The specimen was annealed in vacuo ($p<3\times10^{-6}$ mm) for 3 hours at 850°C and then cooled slowly at about 50°C per hour. No quantitative estimates of the purity of the specimen have been obtained yet, but for the purpose of comparing the present results with previous work[1] its hardness (121±11, diamond pyramid hardness) and its residual