III. SOLID STATE PHYSICS

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A. THE THEORY OF SUPERCONDUCTIVITY

The quantum mechanical theory of superconductivity reported earlier was based essentially on the use of many electron wave functions which correspond to covalent bond structures extending over the whole crystal. The supercurrent arises through quantum resonance between different bond structures equivalent under the translation group of the crystal.

The question arises whether such covalent bonds can be made plausible for actual superconductors on the basis of other properties of these crystals. This question could be answered in the affirmative.

Superconductors appear in two neatly separated groups in the periodic table provided the A and B elements are listed side by side rather than below each other. The so-called soft superconductors (Al, Zn, Ga, Cd, In, Sn, Hg, Tl, Pb) turn out to be identical with a class of metals delimited by Hume-Rothery (1) on the basis of their irregular structure. The irregularities have been attributed by him to a slight tendency toward covalent bonding.

A somewhat similar tendency of the hard superconductors (Ti, V, Zr, Cb, La, Hf, Ta, Re, Th) can be understood on the basis of a hypothesis of Pauling (2) according to which the d-shell of the transition elements splits up into two bands, the lower one of which contributes through covalent bonding to the cohesive energy of the crystals. L. Tisza

References

(1) W. Hume-Rothery, "The Structure of Metals and Alloys", p. 21, London (1936).

(2) L. Pauling, Phys. Rev. 54, 899 (1938).

B. SOFT X-RAY VACUUM SPECTROGRAPH

The vacuum systems for the spectrograph proper and for the x-ray chamber have been completed and are now operating satisfactorily. A vacuum of 1×10^{-6} mm of mercury can be maintained in the large spectrograph chamber, and somewhat better than this in the x-ray tube which is isolated from the chamber by the slit system.

The grating and entrance slit have been lined up optically. Some further adjustment may be necessary in order to obtain best focusing, since this has not yet been tested. The travel system for the electron multiplier carriage has been lined up, and the leads and trolleys for carrying the voltages to the multiplier installed. Parts for the multiplier itself, which will serve as the detector, are nearly ready for assembly.

A preliminary electron gun for the x-ray tube has been constructed and tested. It will probably be satisfactory for trial, but we hope to obtain higher current with a new gun. The present gun is set up for direct bombardment of the target, without deflecting plates for the electron stream, and so does not prevent tungsten from striking the target. It should, however, be satisfactory for use in checking the alignment of the grating and detector system. G. G. Harvey, E. M. Gyorgy, R. H. Kingston, A. Meckler

C. PARAMAGNETIC RESONANCE EXPERIMENTS

Equipment for studying resonance absorption of paramagnetic salts at microwave frequencies is being modified to allow experiments at liquid helium temperatures. The immediate purpose of this is to allow the study of certain rare earth salts. Conventional susceptibility measurements on these salts leave considerable uncertainty as to the details of the crystalline forces acting on the paramagnetic ions. The microwave method will separate the effects of each ion in the unit cell and will therefore add considerably to the detailed knowledge of the crystalline forces. Low temperatures are necessary in order to increase spin-lattice relaxation times, which at room temperature broaden the occurring resonances to such an extent that they cannot be detected. We are in the process of procuring single crystals of $Pr_2(SO_4)_3 \cdot 8H_2O$ and $Nd_2(SO_4)_3 \cdot 8H_2O$ for these experiments.

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D. THE INFLUENCE OF A MAGNETIC FIELD ON THE CONDUCTIVITY OF THIN METALLIC FILMS (1)

The numerical integrations necessary for the detailed evaluation of the theory are being carried out by the Joint Computing Group.

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Reference

(1) Preliminary report in "Nature", November 1949.

E. THE THEORY OF THE TRANSPORT PHENOMENA IN METALS

The theory of the transport phenomena in metals depends upon the solution of a complicated integral equation for the velocity distribution function of the conduction electrons (1). Exact solutions of this equation have been obtained by A. H. Wilson for the two limiting cases of temperatures low and high compared with the Debye temperature, and approximate interpolation formulas have been set up to join the exact solutions (2). These interpolation formulas are known to give incorrect results at intermediate temperatures (3), and the problem of determining the temperature variation of the electric and thermal conductivities of a metal in the region close to the Debye temperature presents considerable difficulties.

It seems impossible to obtain an exact solution in closed form, but recently a new line of advance has been opened up by M. Kohler who has shown that the integral equation can be transformed into an equivalent variational problem (4). A solution may now be obtained by expanding the distribution function as a power series and using the variation principle to determine the coefficients. It can be shown that, for a completely degenerate electron gas, the calculations can be carried out explicitly to any order of approximation, the conductivities being finally obtained as the ratio of two infinite determinants. (A corresponding expression has been obtained for the thermoelectric power.) The interpolation formulas find a natural place in this scheme, being obtained as the zero approximation on retaining only the lowest terms in the determinants which give a non-zero result. The higher approximations are of complicated algebraic form but are well adapted to numerical work; the first few correction terms are now being evaluated numerically with the aid of the Joint Computing Group.

The interpolation formulas were originally obtained by assuming the general validity of Matthiessen's rule concerning the additivity of the residual and ideal resistances of an impure metal. We find that the rule breaks down in the important temperature region where the residual and ideal resistances are of the same order of magnitude; and the numerical results will enable us to discuss the nature and the extent of the deviations from Matthiessen's rule. The numerical results will also be of interest in connection with the thermal conductivity K. Wilson's interpolation formula predicts that K should pass through a minimum at intermediate temperatures (5), but no such minimum has ever been observed. The exact solution is known to lead to increased values of K and may, in fact, possess no minimum.

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References

(1) A. H. Wilson, "The Theory of Metals", p. 215, Cambridge (1936).

(2) A. H. Wilson, Proc. Camb. Phil. Soc. 33, 371 (1937).

(3) G. P. Dube, Proc. Camb. Phil. Soc. 34, 559 (1938).

(4) M. Kohler, Z. Physik 124, 772 (1948); 125, 679 (1949).

(5) R. E. B. Makinson, Proc. Camb. Phil. Soc. 34, 474 (1938).

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