Difference in Viscosity of *Ortho-* and *Para-*Deuterium at Low Temperatures

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In a recent paper we reported that at low temperatures *para*-H_2 has a greater viscosity than *ortho*-H_2.[1,2] This result is in contradiction to the quantum-mechanical theory of Halpern and Gwathmey.[3] We suggested that the viscosity difference observed originates essentially from a difference in the *dynamic* properties of the H_2 modifications not discussed in the theory.[2] A dynamic difference can be derived from the fact that in the ground state an *ortho*-H_2 molecule rotates while a *para*-H_2 molecule does not. According to this conception, no appreciable viscosity difference arises from the different symmetry properties of the eigenfunctions.

We have checked our conclusion by comparing the viscosity of *ortho-* and *para*-deuterium. Since deuterium, contrary to hydrogen, obeys Bose-Einstein statistics, *para*-D_2 rotates in the ground state while *ortho*-D_2 does not. The experimental results (Fig. 1) show greater viscosity for *ortho*-D_2, confirming our suggestion mentioned above. It remains unexplained why the kinematic

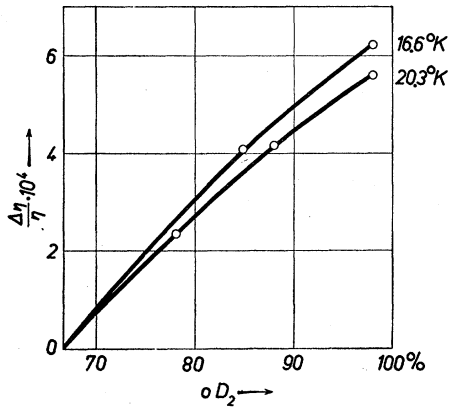

Fig. 1. Relative viscosity difference $\Delta\eta/\eta=(\eta-\eta_n)/\eta$ of deuterium with variable *ortho*-D_2 content and normal deuterium (66.7 percent *ortho*-D_2).

effect expected from the different symmetry properties of the eigenfunctions does not occur. Experimental details will be given in the *Zeitschrift für Physik*.

[1] E. W. Becker and O. Stehl, Phys. Rev. **87**, 525 (1952).
[2] E. W. Becker and O. Stehl, Z. Physik **133**, 615 (1952).
[3] O. Halpern and E. Gwathmey, Phys. Rev. **52**, 944 (1937).

Thermal Resistivity of Superconducting Mercury in the Intermediate State

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Early measurements[1,2] of the thermal resistance of superconductors in the intermediate state at temperatures fairly near the transition temperature showed the thermal resistance to be nearly a linear function of the applied magnetic field. In 1950, Mendelssohn and Olsen[3] found that impure lead and lead-bismuth alloys showed a thermal resistance that was markedly higher in the intermediate state than in either the superconducting or normal state. This anomalous behavior has since been found in pure lead,[4] tin,[5] and indium.[5]

We have recently completed a series of measurements on the thermal resistance of several cylindrical specimens of pure mercury in transverse magnetic fields. The techniques were similar to those of Hulm[6] except that we determined the temperature and temperature gradient by means of carbon-composition thermometers.[7] Figure 1 shows the reduced thermal resistivity as a function of the reduced magnetic field of one of the specimens at several temperatures. The absolute values of the thermal resistivity in the superconducting state (W_s) and in the normal state (W_n) agree well with the values given by Hulm.[6]

The dashed line in the figure represents the linear variation of thermal resistance that would be expected in a simple model of alternate, transverse laminations of normal and superconducting material, each with a characteristic thermal resistivity. At the higher temperatures (2.4° and above), the measurements follow this linear variation quite well. At lower temperatures, the observed thermal resistivity in the intermediate state appears to consist of the sum of the linear variation discussed above and a resistivity which is roughly independent of the magnetic field at any given temperature but which increases sharply with decreasing temperature. In its field dependence, mercury behaves similarly to tin[5] and rather differently from lead.[4]

Elementary arguments can be used to show that behavior of the magnitude and form shown in Fig. 1 can be explained by assuming that the laminar boundaries scatter either the electrons or the lattice vibrations. If the effect is due to scattering of lattice vibrations, however, it can be shown that, as a corollary, the thermal conductivity of mercury in the superconducting state at 2°K and below must be due almost entirely to lattice conduction, with the electrons playing a minor role. Since this conflicts with the conclusions drawn by Hulm[6] from his measurements of the thermal conductivity of mercury alloys, we tentatively conclude that the extra thermal resistance in the intermediate state is due to scattering of electrons at the superconducting normal boundaries.

From the theory of laminar structure in the intermediate state,[8,9] we would expect the thickness of the laminae to be proportional to the square root of the diameter of the cylindrical specimen. This should be reflected in a marked size dependence of the thermal resistance in the intermediate state.[4] However, careful comparison of the thermal resistance of two specimens of mercury of diameters 0.2 inch and 0.1 inch shows almost identical behavior in the intermediate state in the temperature range from 1.4 to 2.5°. A wider range of specimen diameters must be examined before we can conclude with certainty that there is no size effect. Nevertheless, this preliminary result leads us to consider the possibility that the excess thermal resistance in the intermediate

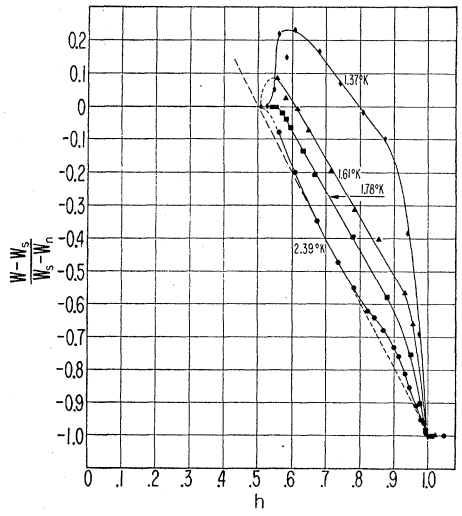

Fig. 1. Reduced thermal resistance of mercury as a function of the reduced magnetic field at several temperatures. The reduced field h is the ratio of the applied magnetic field to the critical field. W is the observed thermal resistivity. W_s and W_n are the thermal resistivities in the superconducting and normal states.