IX. TRANSPORT PHENOMENA IN SOLIDS

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A. SURFACE THERMAL ENERGY TRANSPORT

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1. Approach

Technical heat transport parameters are usually determined from thermometry on a system with a known thermal flux. Elements of virtuosity are required to make these measurements useful, since the temperature drops at the surfaces are very small. The fluxes at low temperatures must be milliwatts or less so as not to overload the refrigeration system. The thermal conductance is of the order of 0.1 W/°K-cm^2. Hence we must measure tens of microdegrees.

We have been studying the time behavior of the temperature of a block of insulating crystal when it is disturbed from equilibrium with a thermal reservoir by a heat pulse. The time decay of the temperature of the block to equilibrium can be interpreted to yield a value for the surface thermal conductance. The transient temperature of the block can be measured easily even in the presence of slow drifts in the temperature of the reservoir. To check these data, we also measure the influence of the thermal impedance of the block on the electrical impedance of a tiny bolometer which has been evaporated on the block to monitor the temperature of the block. The frequency dependence of the electrical impedance of the bolometer then varies because of the frequency dependence of the thermal impedance of the block. This in turn depends on the boundary thermal conductance of the block.

Once a thorough understanding of the thermal properties of the block has been established, other materials, metals, for example, can be studied by evaporating a film on the block, or otherwise establishing thermal contact between the metal and the block. The perturbation of the thermal properties of the block produced by the foreign material then gives information about the thermal properties of the foreign material.

2. Progress

We have finished preliminary measurements on quartz, sapphire, and NaCl from 1-3.6°K. The thermal impulse response of the block temperature as determined with a superconducting bolometer has been measured and partially analyzed. Impedance studies have also been started.

We are now searching for the most efficient method for reducing these data. Above

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JSEP the lambda point, 2.17°K, the relatively small thermal diffusivity of helium I adds a characteristic feature to the temperature decay signal, a long time-constant tail. Having available the different time behavior of the various components of the temperature transient signal in the long time interval that we record, we are able to separate the various components readily. By going below the lambda point in bath temperature, we are able to increase the helium diffusivity by a factor of more than 6 orders of magnitude, so that the component arising from the helium I diffusivity vanishes dramatically. Our method thus allows us to gather data above the lambda point. This temperature region must be avoided in the alternative stationary-flux method because of the small diffusivity of helium I.

In order to confirm our present understanding of the observed phenomena, we have recently made a series of measurements of the Kapitza resistance, that is, the boundary thermal conductance between a solid surface and liquid or vapor helium. These measurements were made with a set of NaCl blocks of different volume-to-surface ratios. Since the decay time of the block temperature that indicates the thermal energy in the volume of the block depends on the surface area, the observed decay of the temperature of the block will have one time constant that depends on the volume-to-surface ratio; hence, it is geometry-dependent.

The situation that we have studied is analogous to the situation that occurs when measuring the surface impedance of a microwave cavity resonator by recording the time decay of the electromagnetic energy in the cavity after an impulse excitation of the cavity. The energy stored in the volume of the cavity is lost through the walls in an amount given by the integral over the cavity surface of the electromagnetic Poynting's vector. Changing the geometry of the cavity while holding the resonance frequency constant then leads to a system in which the decay times are geometry-dependent.

In the case of the transport of thermal energy, the block is resonant at innumerable acoustic frequencies, so it is really an untuned resonator. The crystal can be made more or less pure so that volume scattering can be varied at will. For a pure crystal, the mixing of modes will only occur at the surface. The three acoustic branches can thus be thought of as three nearly independent acoustic energy reservoirs. The decay of the block temperature, as monitored by a tiny thin-film bolometer evaporated on the block could therefore indicate several rates of decay of the thermal energy of the block, if the phonon transmission coefficient depended on frequency.

The data indicate that we can determine the Kapitza resistance from the time-domain transient and that the Kapitza transient decay time constant scales properly with the sample volume-to-surface ratio. JSEP