

III. SOLID STATE PHYSICS

Prof. J.C.Slater	N.I.Adams III(guest)
Prof. P.G.Bordoni(guest)	R.P.Cavileer
Prof. S.C.Collins	R.J.Harrison
Prof. L.Tisza	P.L.Nicholas
Dr. M.A.Herlin	W.B.Nowak
Dr. L.A.Siegel	J.W.Toomey, Jr.
Dr. I.Simon	

A. PROPERTIES OF MATTER AT LOW TEMPERATURES

1. Helium Liquefiers

During the past quarterly period considerable progress has been made in servicing more experiments with liquid helium per run of the helium liquefier. Also, the time required per run has been greatly shortened.

The reason for the increase in potential servicing power is threefold:

- (a) The performing of experiments in external Dewars.
- (b) Special emphasis being placed upon preparation of the experiment prior to transfer. This includes the proper gauging of time for having the experiment ready for transfer when a sufficient amount of helium has been liquefied.

(c) Extension of microwave superconductivity experiments into external Dewars. This is possible because it has been shown that the thermal conductivity of certain metals is so small at liquid helium temperatures that there is only a very small heat leak through the waveguides.

The second liquefier is used exclusively for the transfer of liquid helium into external Dewars because (a) it is so constructed that all of the helium liquefied can be transferred; (b) due to the liquid-nitrogen precooling coils on the radiation shield of the Dewar, the liquefing time is shortened and the production rate is doubled. These factors are responsible for shortening the time required per run. They also allow for a longer experimental time within the confines of normal working hours.

Steps have already been taken to increase further the potential servicing capacity of liquid helium, such as installing another compressor and low-pressure gas holder. This will make each liquefier an independent unit. The ultimate with these liquefiers will be reached when another Dewar can be procured and installed on the first liquefier in a similar manner to the one now on the second liquefier. The liquefiers will not be able to operate simultaneously and as independent units until the already-

assigned larger working space is made available; the present quarters do not have sufficient floor area to accommodate a second compressor and gas holder. This additional equipment, by smoothing the statistical variation of productivity caused by mechanical failure, will be an extra safeguard against the possibility of a period when liquid helium is not available (although this possibility should not be overlooked completely).

2. Microwave Surface Impedance of Normal Conductors

Several low-temperature runs at 24,000 Mc/sec have been made on a composite cylindrical cavity of fairly smooth stressed copper for the flat walls, and smooth annealed copper for the rim. The curve of Q versus temperature has been established to ± 6 per cent from 300°K to 4.2°K . The flat walls will now be annealed and further polished, low-temperature runs being made after each operation.

The last sources of error are being tracked down. Errors due to thermal lags between cavity, cryostat, and resistance thermometer have been found to be less than those of the r-f measurement scatter as long as the rate of temperature change is $2^{\circ}\text{C}/\text{minute}$ or less. Rates of $1^{\circ}\text{C}/\text{minute}$ or less are used.

An effort has been made to measure the d-c resistivity of copper from 300°K to 4.2°K . In order to utilize the available equipment (L.N. type-K potentiometer), a rather large sample resistance is convenient. Therefore 48 feet of 0.015-inch diameter wire was drawn out of high-purity vacuum-cast copper (as used in the r-f cavity) and wound on a mica cross. The voltage across this coil and across a standard 10-ohm resistor (at room temperature) connected in series was measured. Care was taken to avoid undue heating of the copper by the current. Data were taken with the coil as wound, in a stressed condition, and after a half-hour annealing in a hydrogen atmosphere at 400°C . The following values were some of those obtained:

	$T^{\circ}\text{K}$	$\rho \times 10^6$ (ohm-cm)
Stressed	299	1.728
	77.6	0.293
	20-4.2	0.0930 (residual)
Annealed	298	1.693
	77.3	0.237
	15-4.2	0.0397 (residual)

The high value of the residual resistance indicates either insufficient annealing or insufficient purity.

(III. SOLID STATE PHYSICS)

3. Microwave Surface Impedance of Superconductors

The measurements of surface conductivity of tin and lead at 10,000 Mc/sec have been extended into the superconducting region. Measurements below the temperature of 4.2°K were performed mostly in a bath of liquid helium transferred from the liquefier into an external Dewar. The resonator under test, immersed in liquid helium, was connected to the r-f measuring equipment by means of a waveguide made of Monel (standard cross section 0.900 x 0.400 inch, 0.014-inch wall thickness). The mean heat conductivity of Monel for a total temperature difference of 63 to 3°K was found to be about 0.0053 cal cm⁻¹ sec⁻¹ deg⁻¹. It was possible to keep liquid helium in the Dewar of a net volume of about 300 cm³ for five hours or more although the length of the waveguide was relatively short (45 cm).

Six low-temperature runs were made. Several coaxial resonators of 3/4 and 1/2-wavelength type as well as one rectangular TE₁₀₁ mode cavity were used. Curves showing the change of surface conductivity of tin and lead with temperature in the region of normal conductivity are shown in Fig. III-1 in terms of the ratio of unloaded Q's.

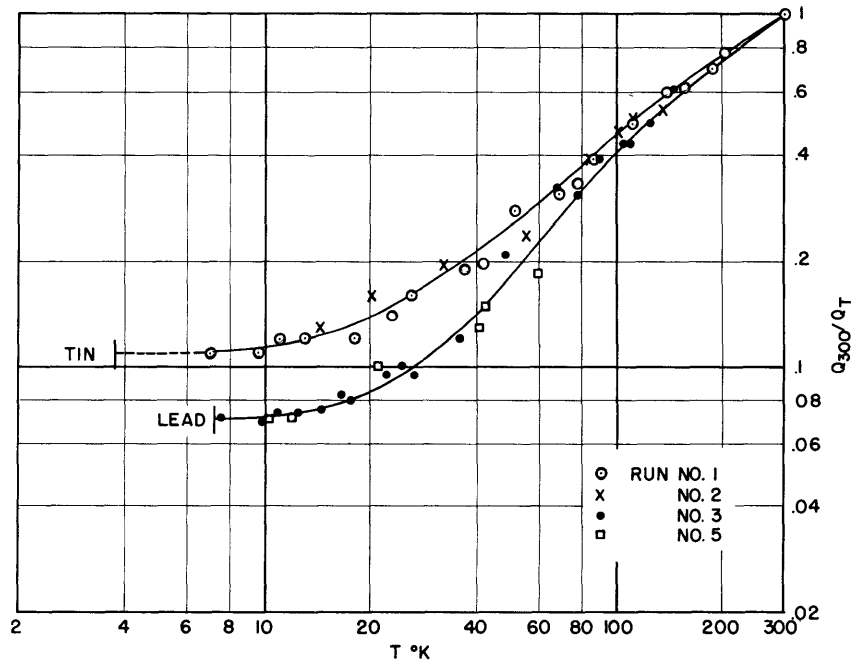


Fig. III-1. Surface conductivity of tin and lead as a function of temperature in the region of normal conductivity.

In the superconducting region, the increase in Q_0 as obtained with coaxial resonators was systematically less than what could be expected

according to the previous work done in this Laboratory. The rectangular tin cavity, however, showed a change of expected magnitude as indicated in the following table.

$T^{\circ}K$	3.85	3.75	3.63	3.59	3.50	3.48	3.23
Q/Q_{trans}	1.05	1.00	0.86	0.55	0.32	0.10	0.085
$T^{\circ}K$	3.04	2.96	2.79	2.29			
Q/Q_{trans}	0.064	0.048	0.020	0.012			

The reason for the apparent additional losses in coaxial resonators is being investigated.

4. Elastic and Inelastic Behaviour of Metals at Low Temperatures (In Cooperation with M.I.T. Acoustics Laboratory)

The elastic parameters and internal friction of lead are measured by a vibration method⁽¹⁾ as a function of temperature and at different frequencies.

Polycrystalline lead has been chosen as the first material to be studied because of the striking change which it exhibits in its elastic properties when the temperature is lowered. Samples having different impurity contents and grain structures have been investigated.

In addition to several preliminary measurements in the range from liquid-air temperature to room temperature, three runs have been made down to the boiling point of helium and one of these has been extended down to the lambda-point.

The results obtained show that at room temperature the large internal friction of lead is probably due to viscous relaxation at intergrain boundaries. This cause of internal friction ceases to be important when the temperature is lowered to about $200^{\circ}K$, the relaxation time being then large in comparison with the vibration period.

From $200^{\circ}K$ to about $30^{\circ}K$ the internal friction decreases slowly, its average value being about one-hundredth of the value at room temperature.

Below $30^{\circ}K$ a more rapid decrease of internal friction takes place, the value reached at the boiling point of helium being about one-quarter of the value at 30° . The sound velocity does not change in this temperature range.

1. M.I.T. Acoustics Laboratory, Quarterly Progress Report, July - September 1948.

(III. SOLID STATE PHYSICS)

5. Magnetic Cooling

Apparatus is being constructed to avail the Laboratory of the techniques of adiabatic demagnetization to produce temperatures below 1°K . A program for the use of these temperatures is not yet fully formulated.

6. Theory of Liquid Helium

Measurements⁽¹⁾ of heat conductivity and thermomechanical effects in helium II, for slits from about .1 to 19 microns in width, show that in the wider capillaries the heat current remains proportional to the measured fountain pressure, although at large gradients it fails to increase linearly with temperature gradient. We have analyzed the experimental results on the basis of the two-fluid model of helium⁽²⁾ comparing the proportionality constant between heat current and pressure gradient with theory. London and Zilsel have published a similar analysis⁽³⁾ for the narrowest slits where the heat current stayed proportional to the temperature gradient. We shall see that this restricted their results to cases where experiment and theory disagree markedly, and excluded those cases where agreement with theory is quite good. Thus we find that the experiments fall into two categories. For the slits of widths 5 to 19 μ agreement with theory is very good, both with respect to temperature dependence and to the absolute magnitude of the proportionality constant. For slits of one micron or narrower, the measured heat conductivity becomes larger than theory by factors of about 100 to 1000 at temperatures near 1°K , and of about 3 to 10 near 2.19°K . The conclusion we draw is that theory gives a fairly good description of the heat transport properties of helium II for capillaries of moderate width, but that in extremely narrow slits, special effects involving the modified state of the liquid near a wall become important and modify the behavior considerably.

After the above analysis was made, Gorter⁽⁴⁾ published a letter describing similar calculations to appear in detail in *Physica*. His conclusions are in general agreement with ours. Gorter attributes this

-
1. W.H.Keesom and Duyckaerts, *Physica* 13, 153 (1947); Mellink, *Physica* 13, 197 (1947); L.Meyer and Mellink, *Physica* 13, 197 (1947).
 2. L.Tisza, *Phys. Rev.* 72, 838 (1947)
 3. F.Londen and P.R.Zilsel, *Phys. Rev.* 74, 1148 (1948).
 4. C.G.Gorter, *Phys. Rev.* 74, 1544 (1948).

continued proportionality of heat flow to fountain pressure instead of to temperature gradient to the fact that the former proportionality is more fundamental. However, just the contrary seems to be indicated by the two-fluid theory, and some other explanation of the experimental results is needed, perhaps that suggested by Meyer and Band⁽¹⁾. They suggest the temperature difference between the ends of the slit may possibly differ from the measured temperature difference between the two helium baths, with both the fountain pressure and the heat current proportional to this "effective" temperature gradient, and hence to each other. (Meyer and Band⁽²⁾ also attempt, using a similar scheme, to explain anomalous heating effects found by Meyer and Mellink⁽³⁾. However, in this case we believe that their explanation is not valid, and in fact that the experimental results they try to explain are possibly erroneous in part. This conclusion follows from applying the laws of thermodynamics to the irreversible process, and finding relations which must exist among the heating effects.)

Prof. L.Tisza, R.J.Harrison

B. HIGH-FREQUENCY ULTRASONICS

Transducer crystals are now the main obstacle in the course of extension of the useable frequency range. Two of the Bliley ground-surface crystals were etched for ten seconds with ammonium bifluoride. No appreciable effect upon the activity as indicated by Q-meter and "echo-box" tests was noted.

The crystals were then optically polished. A tremendous increase in activity became apparent. With such a crystal, useable echoes of frequency 550 Mc/sec were obtained through water. A series of measurements has been taken, the results of which will be compiled in a Technical Report.

R.A.Rapuno

C. PHASE TRANSITIONS

The study of phase transitions (see Progress Report of October 15, 1948) has been extended by thermodynamic methods. On the basis of an analysis of positive semi-definite quadratic forms, a classification of critical points has been developed. While this classification is thermodynamic in character and so cannot determine the molecular mechanism in any given case, it nevertheless allows one to exclude certain types of mechanisms on the basis of the behaviour of the thermodynamic properties near the critical point. Further

-
1. L.Meyer and W.Band, Nature 162, 67 (1948).
 2. L.Meyer and W.Band, Physica 14, 63 (1948).
 3. Meyer and Millink, op. cit.

(III. SOLID STATE PHYSICS)

study of special cases by these methods is now being made and will be reported later.

Prof. L.Tisza, M.J.Klein

D. ULTRASONIC SCATTERING

A tank has been made for investigating scattering of ultrasonic waves in liquids. The sound beam is propagated by one quartz crystal, and a second quartz is placed away from the beam in such a manner as to catch any beam scattered at right-angles to the main beam.

The dependence of scattering on frequency, temperature and the nature of the liquid will be investigated.

Dr. R.Parshad

E. A VACUUM SPECTROGRAPH

A vacuum spectrograph is being constructed to study energy levels of the conduction or valence electrons in the spectral region of 40-500Å.

Dr. E.R.Piore