III.   SOLID STATE PHYSICS

A.   PROPERTIES OF MATTER AT LOW TEMPERATURES

1.   Helium Liquefiers

Staff: R. P. Cavileer
         S. Ames
         J. Toomey, Jr.

The end of this quarterly period finds the first liquefier in the midst of a series of runs (at present amounting to 48), without any breakdowns or overhaulings. This most gratifying performance has been due mainly to oil traps placed upon the valve rods which prevent the oil from creeping down the rods from the crosshead. We can find no indication of a possible breakdown in the near future, and this comment is one we have not been able to make in a long time. A comparison with our previous record consisting of 28 runs has furnished us with much information on various components, i.e., stuffing-box packing, valve adjustments, and valve facings. A considerable amount of money has been saved for the Laboratory by the addition of these oil traps. The credit for this improvement is due to S. Ames who designed them.
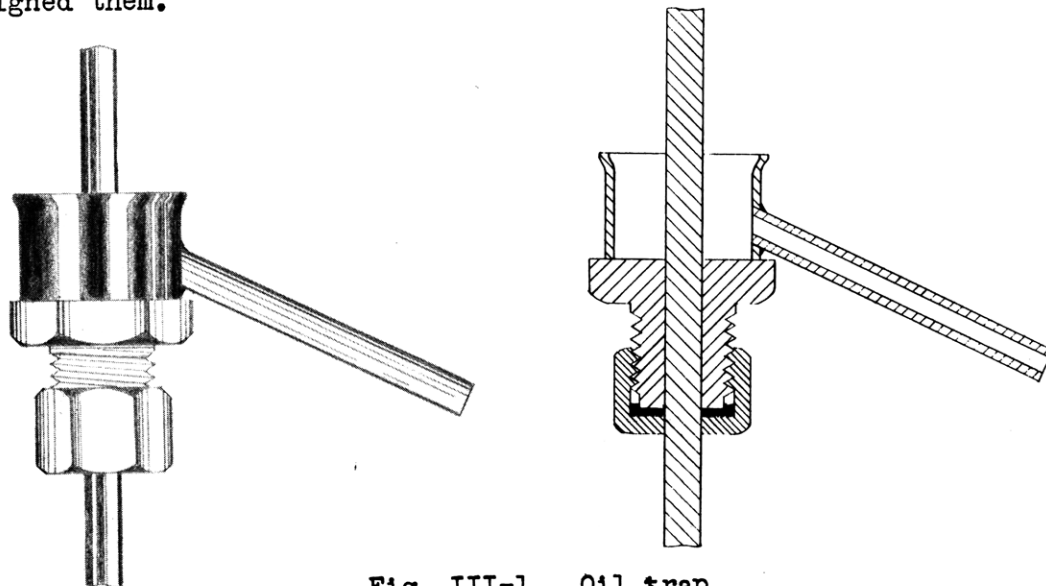

Fig. III-1.   Oil trap

Numerous tests have been conducted on the compressor which give us entirely new ideas on what may and may not be tolerated in this part of the equipment.

Work has been done with M. C. Desirant and M. J. Horvath on a transfer tube which allows liquid helium to be transferred directly from the experimental chamber, and thus eliminates the slow process of accumulating any quantity of liquid helium by condensation in the auxiliary liquefying pot. This means it is possible to transfer approximately 5 liters of liquid at one drawing instead of 700 c.c. as before.

The new super-clean helium (99.8% minimum purity), as mentioned in the previous report, has now proved itself beyond a doubt and has contributed immeasurably to a steady rate of liquefaction.

The pre-cooler being installed on the radiation shield of the second liquefier is expected to double the rate of liquefaction. Tests are to be run on this in a short time.

2. Surface Impedance of Tin

Staff: Professor J. C. Slater
Dr. P. M. Marcus
E. Maxwell

The measurements on the surface impedance of tin at 2400 Mc/sec are now virtually complete. The surface resistance of white tin has been measured from $300^\circ K$ to $4^\circ K$, and in the superconducting state from $4^\circ K$ to $2^\circ K$. In agreement with other experimenters it is found that the surface resistance approaches an asymptotic value at low temperatures, independent of the d-c resistivity. At $4^\circ K$ the apparent a-c resistivity is 60 times the d-c value. The general form of the variation follows the (unpublished) theory of E. H. Sondheimer and A. E. Reuter of Trinity College, Cambridge. Fitting the experimental data to the theoretical curve involves determining a scale factor, from which one can obtain an estimate for the number of free electrons per atom. We find a value of approximately 0.3 to 0.4.

The theory can be extended to the superconducting case by adding another term for the super-current. One can then calculate the surface impedance in the superconducting state as a function of δ and λ, the classical a-c skin depth and the superconducting skin depth, respectively. The change in Q in going through the transition is related to the change in the real part of the surface impedance. The change in the imaginary part of the surface impedance is associated with a shift in the resonant frequency of the cavity. Both the change in Q and the resonant frequency shift have been observed and by correlating these with the theory, we have been able to obtain two sets of independent data on the variation of λ with temperature. Preliminary calculations show fair agreement between these two determinations and with the results of other experimenters.[1] The penetration depth λ is of the order of 8×10^{-6} cm at $2^\circ K$ and rises to ∞ at the transition temperature. The Q increases by about a factor of 10 in going through the transition, reaching approximately 150,000. The frequency shift is of the order of a half megacycle at 24000 Mc/sec.

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1. A. B. Pippard, Proc. Roy. Soc. A 191, November 1947, p. 370.

III. A. 3. Resistivity of Normal Conductors

Staff: Professor J. C. Slater
W. B. Nowak
I. Simon

Four runs were made in which the ratio Q_o/Q_w (Q_o = unloaded Q, Q_w = window Q) was measured at 24000 Mc/sec for a copper cavity at temperatures from 300°K to 4.2°K obtained with the Collins cryostat. These runs indicate that the surface impedance of the copper at 4.2°K is 0.38 times its value at 300°K. A. B. Pippard[1] has observed a ratio of 0.23 at 1170 Mc/sec.

In order to establish the value of the surface impedance the Q_o of the cavity must be known. It is also of interest to check the invariance of Q_w with temperature. To measure Q_o with a 5 per cent precision, voltage standing-wave ratios must be measured to about 2 per cent precision and frequency differences to 0.1 Mc/sec. These techniques are being perfected.

To aid in making rapid measurements of power on and off resonance, a scheme has been successfully tested that simultaneously displays on a CRT screen two klystron mode shapes of equal amplitude and about twenty Mc/sec apart. This is accomplished by modulating both reflector and focus grid sinusoidally with appropriately adjusted phases and amplitudes.

In order to extend the measurements of r-f resistivities of metals at low temperatures to lower frequencies, an experimental set-up was prepared for 3.2-cm measurements. As it would be useful to bridge the gap between the measurements of Pippard on the one hand (at 1200 Mc/sec) and of Maxwell and Garrison on the other hand (at 24000 Mc/sec), there has been sought a type of resonator (or cavity) suitable for measurements at different frequencies with the same sample of metal.

4. Low-Temperature Velocity Measurements of Second Sound

Staff: Dr. W. J. Horvath
Dr. J. R. Pellam
Dr. M. Desirant

A project is under way to measure the velocity of second sound at extremely low temperatures. In order to extend the investigation to temperatures far below those attainable by pure pumping, provision has been made for demagnetization. At present, temperatures as low as 1.05°K have been obtained without demagnetization but second sound measurements have not as yet resulted. This is due in part to the fact that the special provisions for demagnetization limit the size and sensitivity of the second sound portion of the gear.

A rectangular chamber roughly 7 cm high by 1 cm square provides a resonant cavity in which second sound is to be excited. Excitation occurs

1. Pippard, loc. cit.

at the "floor" of the chamber, where an alternating electric current flows with uniform density through a thin platinum coating supported by a quartz plate. Accordingly a plane wave of second sound should be generated at the floor, of twice the frequency of the driving current and should undergo successive multiple reflections from the floor and ceiling. At particular frequencies for which the height of the chamber equals an integral number of half wavelengths, conditions of resonance should exist.

Temperature fluctuations at the ceiling due to the standing wave of second sound are to be detected by means of a thin layer of amorphous carbon (the ceiling is made of a square of resistance card). An externally applied constant direct current through this carbon should result in voltage fluctuations as the resistance varies in accordance with the temperature fluctuations accompanying second sound. This signal is then to be amplified and sent to a wave analyzer. The wave analyzer is necessary in order to distinguish the second sound signal (of twice the driving frequency) from the original driving frequency picked up within the gear.

Measurement of second sound velocity should result from a determination of the frequencies of maximum response (together with the known height of the resonant chamber). The sensitivity of the electronic detection equipment is such that fluctuations of one microvolt across the

sensitive element should be detectable. On the other hand the generator is driven with sufficient power that voltage fluctuations up to one or two hundred microvolts might be expected. This is for a total electrical heat input of 3 milliwatts.

It is not at present known whether the absence of a signal is of electronic origin or whether the depth and temperature control of liquid helium in the measurement container must be improved.

Adiabatic demagnetization is being withheld, pending the attainment of measurable second sound signals.

5. Mechanical Excitation of Second Sound in Liquid Helium

Staff: Dr. J. R. Pellam

Reflection of first sound in He II from a porous material should generate second sound. Consideration shows that attenuation of second sound would mask any result at the frequency originally planned, 15 Mc/sec. Accordingly, a new electronic system for 1 Mc/sec has been constructed and is ready for operation.

This experiment has been set aside for several weeks in view of the higher priority of the extreme low-temperature second sound experiment. An early test is intended.

6. Phosphor Bronze Wires

Staff: Dr. W. J. Horvath
Dr. M. C. Desirant

In order to obtain resistance thermometers with a high temperature coefficient in the liquid helium range, several samples of leaded phosphor-bronze were prepared with the cooperation of the Metallurgy Department. The melts were made at the MIT foundary by Paul F. Hughes using a method which ensured adequate dispersion of the small amount of lead (0.1 per cent) necessary for low-temperature thermometry. The melts were swaged down into thin rods and wires were drawn by the Union Plate and Wire Company of Attleboro. All wires showed an easily measurable temperature coefficient which was greatest for the smallest diameters (0.004 in.). Still smaller diameters are being prepared by Adolph Cohen and Company of New York. Chemical analysis of the wires showed the percentage of lead to vary from 0.09 to 0.15 per cent in different samples from the same melt. Metallurgical examination of the specimens did not throw any further light on the problem since no lead could be seen in the thin wires. The results are in general agreement with the results of Van Lear at Leiden who postulated that the lead was deposited at the grain boundries forming thin filaments which became superconducting as the temperature was lowered.

7. Transfer of Liquid Helium

Staff: Dr. M. C. Desirant
Dr. W. J. Horvath

A transfer tube has been constructed for the Collins liquefier to siphon out the liquid helium from the experimental chamber of the cryostat. About 20 transfers have been made to date into both pyrex and Kimball glass dewars. The dewars were pre-cooled to liquid nitrogen temperatures by keeping an exchange gas of 2 mm of air in the vacuum space. The evaporation rate of helium in the dewars was extremely low when no apparatus was present. For an 18-inch long Kimball glass dewar of $1\frac{1}{2}$ inch I.D. the liquid helium level fell at the rate of 1 inch per hour at 1.5°K and 3/8 inch per hour at 4.2°K when the dewar was half full of liquid. With apparatus in the dewars the level fell more rapidly. The rather bulky apparatus used to obtain low temperatures by demagnetization (see Sec. IIIA4) caused the level to fall about 2 to 3 inches per hour in the pyrex dewars. However, the level could be raised from time to time by siphoning more helium from the cryostat while the liquefier was kept running.

III. B. PROPERTIES OF MATTER AT ULTRASONIC FREQUENCIES

Staff: R. A. Rapuano

High-Frequency Ultrasonics. A new batch of 15-Mc/sec crystals has been obtained from the Bliley Corporation. They appear to be satisfactory in all respects.

With these crystals and the precision tank discussed in earlier progress reports, it has been possible to take measurements in highly absorbing liquids.

Measurements of the attenuation of CS_2 and glycerine were taken from 75 to 200 Mc/sec. Attenuations as high as 10,000 db/inch were measured with fair accuracy. What appears to be a deviation from the constancy of attenuation divided by frequency squared (α/f^2 = constant) has been detected in both of these liquids. These runs will be repeated as soon as a minor change in tank mounting is made.

C. CLASSIFICATION OF PHASE TRANSITIONS

Staff: Professor L. Tisza
M. J. Klein

The work on this subject previously reported (January 15, 1948 Progress Report) has been extended by statistical mechanical methods. An investigation of the fluctuations, at the critical point, of the variables characterizing the system has been carried out. The analysis by the usual method predicts infinite fluctuations at the critical point since $\partial^2 G/\partial x^2$ vanishes at this point (where G is the free energy of the system). This result, which cannot be correct on physical grounds, follows from the neglect of correlations between different volume elements in the simple theory. A more careful treatment of the fluctuation problem which takes these correlations into account has been begun. The method employed was suggested by a series of papers by Ornstein and Zernike[1] on critical opalescence phenomena which are formally similar to those entering the problems with which we are concerned.

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1. L. S. Ornstein and F. Zernike, Proceedings of the Amsterdam Academy, 17, 793 (1914); 18, 1520 (1916); 19, 1321 (1917).