IV. LOW-TEMPERATURE PHYSICS

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A. MAGNETIC DIPOLE INTERACTIONS IN CRYSTALS

A feedback amplifier with cathode follower output has been constructed to meet the requirements outlined in the Quarterly Progress Report, July 15, 1952. With no controlling resistance in the external circuit, the alternating current in the solenoid is
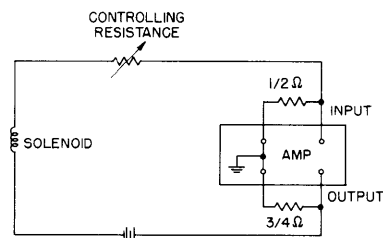

Fig. IV-1

Block diagram of apparatus.

reduced by a factor of approximately 1000 when the amplifier is turned on. No oscillation is observed with any controlling resistance. Figure IV-1 is a block diagram of the setup.

Several attempts at demagnetization were made. It is believed that these failed due to a leak of liquid helium II into the high-vacuum chamber surrounding the sample.

L. D. Jennings, Jr.

B. DETERMINATION OF THE THERMODYNAMIC TEMPERATURE SCALE AT VERY LOW TEMPERATURES BY A MAGNETIC METHOD

The measuring coils previously constructed have been tested at liquid helium temperatures with an ellipsoidal sample of potassium chrome alum of approximately the size which will ultimately be used. The mutual inductance change between 4.2°K and 1°K proved to be approximately 50 μh, which is 250 times the precision of the bridge. This accuracy is sufficient for the measurements to be attempted.

Attention has now been turned to obtaining a demagnetizing field for work in the temperature range above 0.5°K. As our method for determining the thermodynamic temperature requires the measurement of the adiabatic susceptibility as a function of field, and as the salt is anisotropic, the demagnetizing field must be in the same direction as the measuring field. Limitations of space in the dewar require that the axis of the measuring coil lie along the axis of the dewar. Hence it appears that the demagnetizing field must be produced by an air core solenoid. This solenoid must give a field of 2000

gauss, and in addition must not interact with the measuring coil. These requirements could probably be met by using an air core solenoid immersed in liquid air. The length of the solenoid is adjusted to give no interaction. (See L. D. Jennings, Jr.: Quarterly Progress Report, Research Laboratory of Electronics, M.I.T. April 15, 1952.)

However, both of these objectives may be attained if the primary of the measuring coil is wound from niobium, which becomes superconducting at 9°K and apparently has a critical field of 2000 gauss at 0°K. To investigate the feasibility of this idea it was decided first to wind a solenoid from lead wire, since lead was immediately available. The problem was then to pass 5 amp into the dewar without boiling away excessive amounts of liquid helium through conduction down the leads, and through the joulean heating of the leads themselves. Provision has been made for keeping the top of the leads at the temperature of liquid air. Initial measurements show that a current (5 amp) sufficient to produce the critical field of lead at the axis of the solenoid can be sustained. However, the loss of liquid helium through heat conduction down the leads when no current flows is excessive. Experiments are now in progress to determine the size and shape of leads which will give minimum loss of liquid helium.

J. W. Wright

C. SPECIFIC HEAT OF MAGNESIUM

Preliminary measurements have shown that it is possible to obtain accurate data on the specific heat of magnesium below the liquid hydrogen range by use of a calorimeter with a sealed-in pressure of one millimeter of hydrogen gas. By controlling the height of the calorimeter above a bath of liquid helium, the sample may be cooled until hydrogen begins to freeze on the calorimeter wall. This method is superior to that of allowing a transfer gas of helium to cool the sample, since the latter has to be pumped in order to provide effective heat insulation. At low temperatures, high pumping speeds are impossible because of the low gas current density.

Since measurements will be made above the liquid helium temperatures, work is now under way toward calibrating a standard platinum resistance thermometer in the region 10°K to 90°K. Calibration is being made by comparison with the known saturated vapor pressures of oxygen, nitrogen, neon, argon, hydrogen, and helium. It is desired to establish agreement with the International Temperature Scale to within 0.05°K. It is believed that the calibration can be extrapolated to the region 4°K to 10°K with fair accuracy by means of an analytic expression for the resistance of the form $R/R_o = A + BT^2 + CT^5$. The constants A, B, and C are determined by a fit in the region above 10°K and below 4°K. Once this calibration has been made, it will be possible to calibrate carbon resistors which can be used in the calorimeter for the specific heat determination.

E. E. Huber, Jr.

D. THERMAL CONDUCTIVITY OF MAGNESIUM

Two successful runs have been obtained, the results of which are shown in Fig. IV-2. The normal behavior for the thermal conductivity of a metal is a proportionality to the temperature. The deviation from this form of curve is slight, but in the direction to be expected from the electrical resistance anomaly in magnesium with a slight manganese impurity. It is not known yet, however, whether the observed departure from the straight line is due to slight errors in calibration or other instrumentation. When this point is checked, it is planned to measure several samples with varying manganese content and to correlate the thermal conductivity with the electrical resistivity.
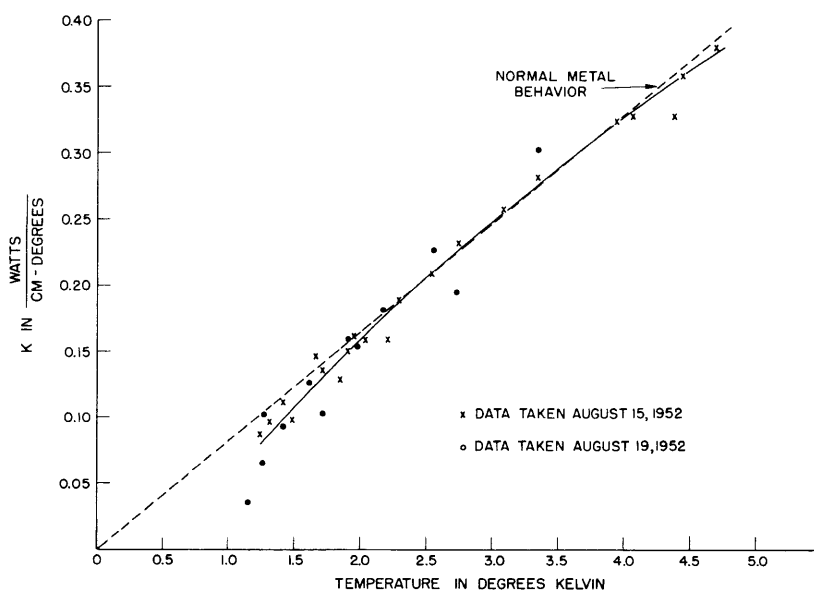
E. G. Sharkoff

Fig. IV-2

Thermal conductivity of magnesium.

E. THERMOELECTRIC FORCES

The apparatus described in previous Quarterly Progress Reports has been completed and put into operation. With careful manipulation, the potentiometer and null detector can read voltage differences of 0.005 μv. The drift in the thermocouple leads was measured in one run as less than 0.02 $\mu v/hr$. Thus, the completion of a measurement within 15 min will realize the best accuracy of the equipment, and this requirement is generally adhered to. Several runs were necessary to acquire proficiency in handling the equipment and to discover the precautions necessary to

have the apparatus function properly.

The first measurements have been carried out on a thermocouple of fairly pure tin vs an impure lead sample. Highly pure tin has been measured previously by Borelius (G. Borelius et al: Proc. Roy. Acad. Amsterdam, 35, 10, 1932). Thus, we can standardize our impure lead and measure it against magnesium. This impure standard has the advantage of a low heat leak and the absence of a contribution to the emf below 7°K where the lead is superconducting. The results are shown in Fig. IV-3. The experimental points deviate ±0.02 μv/degree K from the curves drawn through them. Our measurements for tin check those of Borelius from 4°K to 7°K.

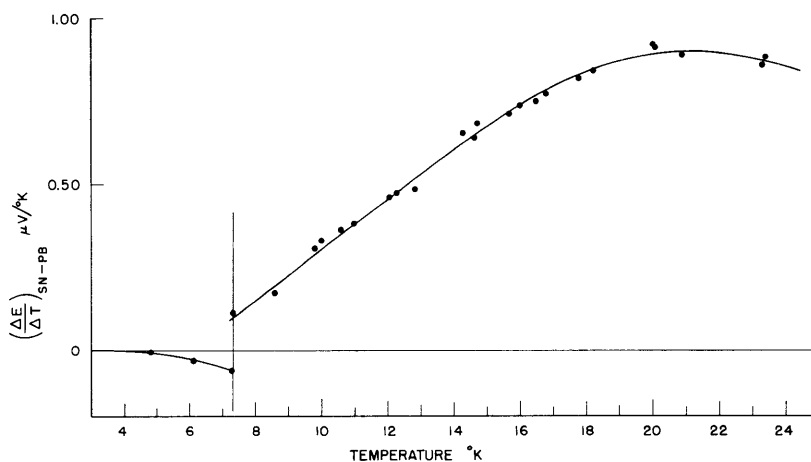<div align="right">R. D. Maurer</div>

Fig. IV-3

Thermoelectric power of tin vs lead standard.

F. STUDY OF THERMAL PROPERTIES OF SOLIDS MEASURED BY A PULSE TECHNIQUE

When the original feasibility calculations were made for this experiment, figures used for specific heat and thermal conductivity were obtained by extrapolation. On comparing subsequently measured temperature rise times with those expected, good agreement was obtained. Experiments, mentioned in the Quarterly Progress Report for July 1952, have been performed to check for possible delay of the generated thermal pulse in transferring from the heater to the sample. From these experiments it became evident that the heater-sample interface introduces a delay time long compared to the response time for heat in the sample. Recent data on the specific heat (1) of magnesium, the sample metal, and on its thermal conductivity (2) show that the measured delays are twenty times too large, being approximately two msec.

An electrical analog to this heat flow problem is the instantaneous discharge of a capacitor through a large resistor into an infinite RC transmission line. This model has been analyzed to determine how the size of the series resistance affects the response. It turns out that the ratio of the thermal conductivity to the specific heat, given directly by the response time in the ideal case, can still be derived from the data. However, with large interface thermal resistance the accuracy is poor, since the interface dominates the physical process. This thermal resistance also vitiates simultaneous specific heat measurement because the variable temperature drop across it destroys the simplicity of the mathematical model.

Friedberg et al (1) have recently shown the specific heat of magnesium to be regular, i.e. it follows the law $AT + BT^3$. The specific heat of a substance is a function of its electronic state and is insensitive to impurity content. Thus, it can be assumed to be the same from sample to sample. Hence, measurement of thermal diffusivity k alone (proportional to thermal conductivity/specific heat) would suffice to determine thermal conductivity K. The latter quantity is of interest for magnesium because it does depend on impurity content. Free electron theory predicts that $K\rho/T$ should be a constant, where ρ is the electrical resistivity and T the temperature. Magnesium is one of the peculiar metals for which ρ does not decrease monotonically with decreasing temperature. It passes through a minimum at about 10°K. This effect has been found to depend upon manganese impurity content (3). Hence data on K as a function of T and of purity would be of interest.

Although k can be measured by the pulse method, it has been decided to gain more accuracy by using sinusoidal excitation on the end of the semi-infinite rod. As the temperature variations pass down the rod, phase difference is measured between two points. The diffusivity follows from this data (4). The apparatus measures phase difference by a null method. An externally controlled phase shift is introduced to match the temperature-signal phase shift between the two thermometers. A 16 2/3 cps generator creates 33 1/3 cps temperature variations in a carbon sheet resistor. These variations are propagated at nearly 1000 cm/sec in the liquid helium temperature range, giving a phase difference of the order of 10° between two points one centimeter apart. The apparatus has been built and calibrated, and preliminary measurements are now being taken.

S. Waldron

References

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G. PRESSURE DEPENDENCE OF SECOND-SOUND VELOCITY IN LIQUID HELIUM II IN THE DEMAGNETIZATION REGION

The past quarter has been devoted largely to minor modifications in the apparatus and to elimination of superleaks and other sources of unreliability. These efforts have so far been rewarded by three data-producing runs. Warmup times of three or four minutes, depending somewhat on the pressure, are typical. The amount of data taken to date is too limited for definite conclusions to be drawn, and some new problems have been uncovered.

At low pressures and temperatures below 0.5°K, the rise time of the received pulse becomes quite long, and the position of its foot correspondingly ill-defined. This may possibly be due to the low heat conductivity of the carbon-film resistance thermometer used as the receiver, despite the fact that the film is as thin as is practical. The random error introduced is perhaps as high as three percent in the worst case, and the systematic error (in the direction of too-low velocities) possibly even higher. If the above speculation as to the cause of this effect is correct, it may be made less important by an increase in the sensitivity of the apparatus, or possibly by going to the phosphor-bronze receiver of K. R. Atkins and D. V. Osborne (Phil. Mag. 41, 1078, 1950). There is some evidence that the effect disappears at the higher pressures, but the question is still open.

V. Mayper, Jr.

H. SECOND-SOUND PULSE AMPLITUDES IN LIQUID HELIUM II

Further progress has been made in getting the performance of the amplifying and display equipment to the point where reliable measurements of the received voltage pulse amplitude can be made on the oscilloscope, by using a dc scope amplifier and dc calibration and an accurate voltage divider for obtaining sample pulses of known amplitude in the microvolt range from the pulser. It is expected that measurement runs on liquid helium will be made in the near future.

B. Bernstein

I. THERMOMECHANICAL EFFECT

In the last Quarterly Progress Report it was stated that a quantity of data had been taken, and that it was planned to take further data and include all results in this report. When the results of the data-in-hand were plotted, it was found that an error had occurred and was indicated in two ways:

(1) The plot of pressure difference vs temperature difference produced a curved line rather than a straight line. The curvature was such that for a given pressure difference the temperature difference was less than it would have been if a straight

line had been followed.

(2) The slopes of the curves at the upper end of the temperature range differed from the values reported by L. Meyer and J. H. Mellink (Physica 13, 197, 1947).

The resistance thermometers were suspected and runs were made to study their calibration in more detail. Calibration by means of a paramagnetic salt showed the resistors obeyed the semiconductor law to as low temperatures as were reached; i.e. the plot of log R vs change in paramagnetic susceptibility was a straight line. It was thought, however, that the potential difference across the resistors (and hence the power dissipated in them) had a marked effect, and changes of this potential difference due to the unbalance galvanometer currents perhaps could not be ignored. The equations connecting galvanometer deflections with temperature differences were rederived taking this change of potential difference across the resistor into account. At the conclusion of the calculation it was found that all correction terms except one could be neglected, and even this one term could usually be ignored. However, another approximation in the derivation was found to be in error, and the result was corrected accordingly. Resolution of the data using this new formula was quite laborious, but the slope of the pressure difference vs temperature difference curve at the high end of the temperature range was closer to that quoted by Meyer and Mellink.

The curvature in the plot at lower temperatures persisted, and the derivations of the temperature difference equation were checked again. The temperature difference calculated for a given galvanometer current under given conditions has been put back into the resistance thermometer law, the resulting values of the resistances put into the Wheatstone bridge equation, and the resulting galvanometer current calculated. The result agreed with the current originally given, verifying the correctness of the derived formulas.

Although the curvature of the pressure difference vs temperature difference plot is greatest at the lowest temperatures, there does not seem to be a systematic increase as the temperature is lowered. A slight curvature is found at temperatures where Meyer and Mellink report a straight line relationship, and the initial slope of this curve is greater than the slope of Meyer and Mellink's line. A change in the value of any of the experimentally measured constants (appearing in the temperature difference equation) in order to make the curvature disappear, makes the slope change away from agreement with Meyer and Mellink's value. A re-examination of the physical factors involved in the experiment is in hand.

D. H. Rogers

J. THE VISCOSITY OF LIQUID HELIUM

Preliminary experiments have been conducted in connection with the electromagnetically coupled constant rotation viscosimeter mentioned in the last Quarterly Progress
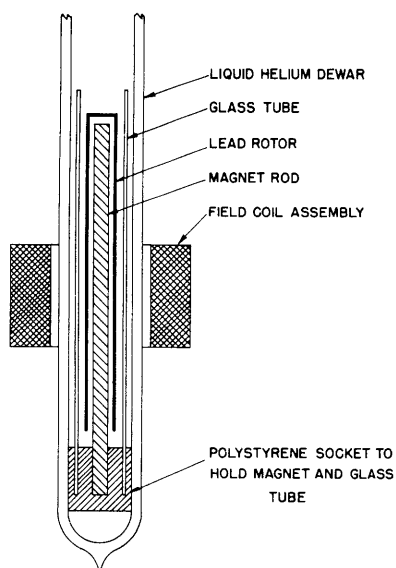
Fig. IV-4

Section through constant rotation viscosimeter using freely suspended supercon-ducting rotor.

Report. In principle, the instrument consists of a single moving part, a metallic, cylindrical rotor, which is free to rotate about a vertical axis inside a glass tube in the liquid helium bath. The rotor is driven by a rotating magnetic field generated by means of a three-phase Selsyn field coil assembly located in the liquid nitrogen dewar and surrounding the helium dewar. The slip frequency (fractional difference between rotor speed and speed of driving field) of this induction motor is then proportional to the torque exerted on the rotor, and suitable calibration of the instrument will make it possible to measure the vis-cosity of the medium between the cylindrical rotor and the surrounding glass tube.

Construction of a three-phase power supply of variable frequency (0 to 2 cps) and with an output of 2 amp has been completed.

It is necessary that the frictional torque associated with the bearings of the rotor be sufficiently small and constant compared to the viscous torque to be measured. The most satisfactory method of achieving this low friction would be to suspend the rotor in a magnetic field without using any rigid bearings whatever. After experimentation with various geometries, the following suspension was constructed. (See Fig. IV-4.) A hollow cylinder approximately 0.5 inch in diameter and 7 inches in length, closed at one end, made of electro-deposited lead, having a wall thickness of about 0.003 inch and weighing 9.56 g was placed over a rod-shaped permanent magnet. The magnet was held rigidly at its lower end by a polystyrene socket which also held a glass tube surrounding the rotor. The radial clearance was about 0.010 inch between magnet and rotor and about 0.005 inch between rotor and glass tube. It was found that the Meissner effect was not adequate to lift the rotor if the system was cooled with the rotor in place, but that the rotor remained suspended several inches above its rest posi-tion if it was lowered onto the magnet after the system had been cooled. Unfortunately the radial restoring forces were far from sufficient to keep the rotor centered, and it oscillated about its stable position enough to contact the glass tubing when the rotating field was applied.

A precision-ground, lead-plated, hollow glass rotor is now under construction and will be mounted in sapphire jewel bearings. Although the radial clearance between this rotor and the surrounding honed glass tube can be kept as small as 0.001 inch, the estimated bearing friction torque will be about two orders of magnitude greater than the

viscous torque. Nevertheless, two considerations seem to justify the attempt: the complete lack of information concerning the constancy of bearing friction at helium temperatures, and the fact that the measurement of slip can be performed over an indefinitely prolonged period of time so that high accuracy may be achieved.

H. H. Kolm