

IV. LOW TEMPERATURE PHYSICS

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A. MAGNETIC DIPOLE INTERACTIONS IN CRYSTALS

Preliminary runs have indicated that the heat leak into the dewar was small enough to permit at least a three-hour run. With two forepumps on the helium system, it was possible only to reach 1.25°K. Turning on the diffusion pump had no effect because the forepressure was not low enough for the diffusion pump to take hold. Qualitative results could not be obtained because of the interaction of the measuring coil with the coil used to produce the constant field on the sample and because of an instability of the electronic equipment. The latter difficulty has been removed by replacing some tubes. To stop the interaction, a coil has been designed whose secondary will be astatic with respect both to its primary and the field-producing coil. It is estimated that a magnetic temperature of approximately 0.2°K was reached, using about 5700 gauss on the demagnetizing magnet.

L. D. Jennings, Jr.

B. RESISTANCE MINIMUM MEASUREMENTS

Measurements have been continued on the resistivity of magnesium in the liquid helium temperature range. The uncertainty in the temperature determination above the λ point (see Quarterly Progress Report, October 15, 1951) has not been remedied by the use of an agitator, as previously proposed, but by the following means. Four strands of 0.0075-inch manganin wire have been run the length of the dewar, and the warm-up has been accomplished by passing current through the wire. Measurements made during the pump-down (cooling) process yield correct temperature values, since thermal convection currents are set up in the helium column, leading to thermal equilibrium. During the warm-up process, however, before the installation of the heater wire, a temperature gradient was found to exist in the helium column; the top was warmer by as much as 0.3°K. The warm-up rate in this case is very slow; it is as much as 4 or 5 hours from 1°K to 4.2°K. By use of the heater wire, the warm-up time can safely be reduced to one hour, and the thermal gradients eliminated. By passing current through the manganin wire, heat can be supplied to the entire length of the helium column, rather than to the top only, as occurs in the case of normal heat leaks down the dewar. Resistivity measurements have shown that this heating method has been effective in eliminating thermal gradients.

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A new helium gas thermometer has been constructed, using a commercial bourdon-type vacuum gauge having a constant volume. It has been calibrated, and measurements will be undertaken on the various magnesium samples above the liquid helium range. These measurements should yield absolute values for the resistivity that will be accurate to better than 4 percent. Calculations yield an expected accuracy of 0.1 percent for relative resistance values. The scatter in experimental points is consistent with these expectations.

The calculations relating mutual inductance changes to conductivity have been sufficiently refined to permit a summary of the chief results. As described in previous Quarterly Progress Reports, the conductivity of a nonmagnetic metallic core can be determined by measuring the change in mutual inductance upon the insertion of the core in an air core transformer. In actual practice a cylindrical sample is most conveniently used, and the transformer consists of two coaxially wound coils. The theoretical problem involved is thus one of calculating the contribution to the mutual inductance of a finite length core in a coil of finite length.

The calculation involves several approximations, and is most conveniently approached by first performing the calculation for an idealized case with an infinite length core and coil. This problem has been solved by others (N. W. McLachlan: Bessel Functions for Engineers, Oxford Univ. Press, 1941), and the solution can be stated as follows

$$(\Delta M)_{\infty} = \pi \mu_0 N_s n a^2 \left[M_R'(ma) - i M_I'(ma) \right]$$

where ΔM is the change in mutual inductance observed upon inserting the metallic core in the coil; N_s is the number of turns in the secondary of the coil; n is the number of turns per unit length in the primary of the coil; a is the radius of the metallic core; and $m = \sqrt{\mu_0 \sigma \omega}$, with σ the conductivity of the core and ω the frequency used in the mutual inductance measuring bridge. The two functions $M_R'(ma)$ and $M_I'(ma)$ represent, respectively, the shielding effect of the core and the losses dissipated in the core. They are plotted in Fig. IV-1 as a function of ma .

To generalize the calculation to the desired case, that of a finite-length core and coil, requires several approximations. The method used consists of replacing the eddy currents in the core by a line of dipoles along the axis of the core. The flux linking the finite-length coil due to this finite dipole line can then be calculated, and the mutual inductance determined. The result of the calculation can be quickly summarized. A geometrical factor $I(K, \ell/L)$ is introduced which depends upon the ratio of the diameter of the coil to its length, $K = D/L$, and upon the ratio of the core length to the coil length, ℓ/L . The change in mutual inductance is then given by

$$\Delta M = I\left(K, \frac{\ell}{L}\right) (\Delta M)_{\infty}.$$

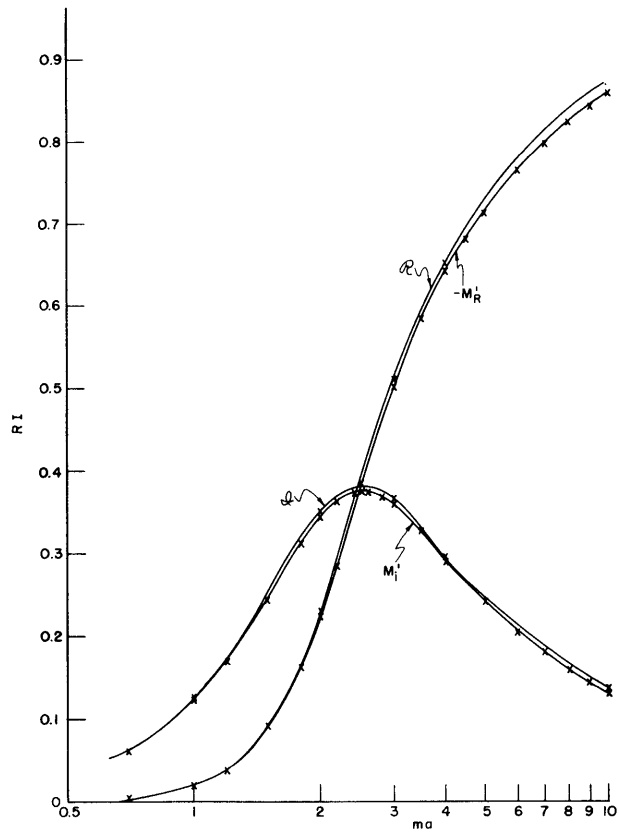


Fig. IV-1
 M_R' , M_i' , M_R and \mathcal{I} vs Ka (for 0.5-inch
by 3-inch sample).

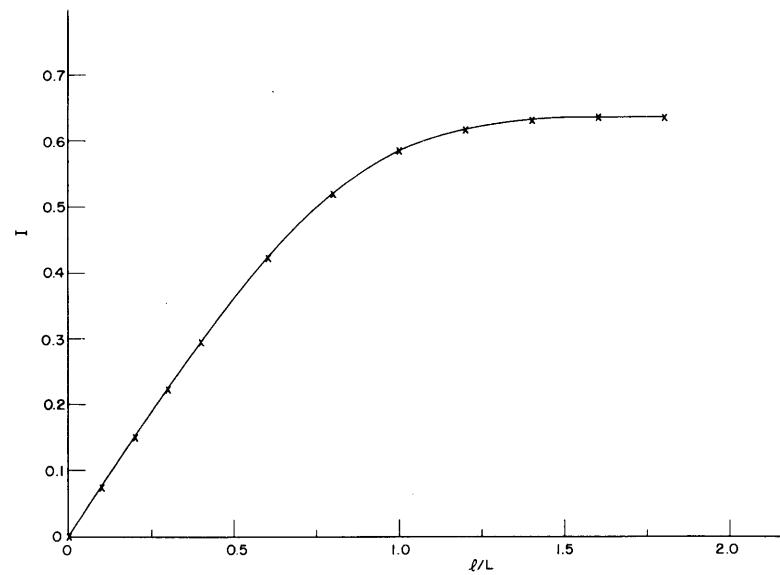


Fig. IV-2
Plot of $I(K, l/L)$ vs l/L .

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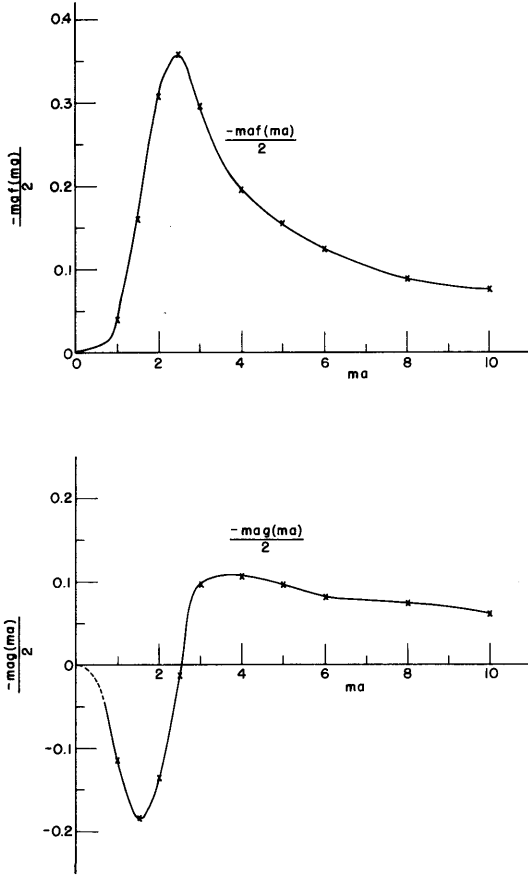


Fig. IV-3

The sensitivity functions $(-mag(ma)/2)$ and $(-maf(ma)/2)$.

The function $I(K, \ell/L)$ is plotted as a function of ℓ/L with $K = 0.563$ in Fig. IV-2.

The mutual inductance calculation can be further refined. Actually, the current loops induced in the core, which have been replaced by dipoles, have higher order multipoles which will contribute to the mutual inductance, especially for cores of large diameter. The quadrupole contribution to the mutual inductance turns out to be zero, but the octapole term yields a non-zero contribution. This term has been calculated for a core 0.5 inch in diameter and 3 inches long, in a coil with a length of 3 inches and a $K = D/L = 0.563$. The corrected functions M'_R and M'_I are indicated in Fig. IV-1 as the functions \mathcal{J} and \mathcal{K} . Thus

$$\Delta M = I\left(K, \frac{\ell}{L}\right) \pi \mu_o N_s n a^2 \left[\mathcal{K} - i \mathcal{J} \right]. \quad (1)$$

The changes in the real and imaginary components of mutual inductance, as measured by a bridge, can thus be converted into values for \mathcal{K} and \mathcal{J} through Eq. 1, and a value for the conductivity obtained from Fig. IV-1. Measurements on cores of

known conductivity check closely with the above relation.

Expressions for the sensitivity of the apparatus are also of importance to conductivity calculations. The conductivity calculation has been carried out, omitting the octapole correction terms. The quantity of interest is $S = \rho(dM/d\rho)$, the change in mutual inductance per fractional change in resistivity. The quantity can be determined for both real and imaginary mutual inductance changes by finding the slopes of the M'_R and M'_I curves. The results can be summarized as follows

$$\text{Imaginary component: } S_I = \pi \mu_o N_s n a^2 I\left(K, \frac{\ell}{L}\right) \left[- \frac{mag(ma)}{2} \right]$$

$$\text{Real component: } S_R = \pi \mu_o N_s n a^2 I\left(K, \frac{\ell}{L}\right) \left[- \frac{maf(ma)}{2} \right]$$

with the functions $g(ma)$ and $f(ma)$ plotted in Fig. IV-3. These relations for sensitivity

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yield the previously quoted figures for the equipment in use.

It is hoped that the details of the above calculation will soon be available as a Technical Report.

H. E. Rorschach, Jr.

C. THERMOMECHANICAL EFFECT

Work has been centered on the temperature regulation problem; lately a galvanometer and a d-c resistance thermometer bridge have been used. The problem has been to change a deflection on the galvanometer into a current through the heater placed in the helium bath and thus effect a balance between the heater and varying heat leaks, on the one hand, and the pump, on the other. The first system designed to do this consisted of two 930 phototubes which operated two thyratrons in a relay circuit. Current was supplied to the heater with the closing of the relay. The light intensity available from the galvanometer was not strong enough to drive the 930 tubes.

They were replaced by 931A tubes, operated from 900 volts a-c. The thyratrons had to be replaced by two small relays because of capacitative effects. A system of interlocking relays was constructed to turn off the voltage on each 931A as soon as it had actuated the relay, so that the tubes would not be fatigued by the rather high currents that had to be drawn from them. The result was that if the light beam entered both tubes at once a rapid clicking on and off of the relays ensued; the alternative was to put the tubes far enough apart so that the light did not enter both at once. Even though this method brought delay into the system, it was chosen, and the delay partially compensated by discharging a capacitor through the heater when the apparatus called for heat instead of supplying a steady current. It was possible to achieve excellent regulation with this system as long as the average pumping rate remained constant. But it was a long (and therefore wasteful of helium) and difficult process to find the correct setting of the potentiometer through which the capacitor was charged, since this setting is different for each temperature and each average rate of pumping. It also developed that the average pumping rate sometimes changed and the regulator would then lose control.

Attention has been turned to the possibility of a galvanometer-amplifier type of regulator. One has been built, using a 920 twin phototube and two 6C6 tubes as pentode amplifiers. Preliminary tests are in process and it appears that the system will work very well.

D. H. Rogers

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D. TEMPERATURE AND PRESSURE DEPENDENCE OF THE VISCOSITY OF LIQUID HELIUM

The present investigation has been described in previous Quarterly Progress Reports.

Measurements made after installation of the new suspension frame revealed that the noise level was increased considerably by cooling the apparatus, even without introducing liquid helium to the inner chamber; this increase was accompanied by a visually observable slackening of the suspension wire and vanished when the equipment was again warmed up to room temperature. At one time the effect was ascribed to differences in contraction of the suspension wire and plexiglass frame which are too large for the leaf spring to take up (see Quarterly Progress Report, October 15, 1951). It has been found, however, that the actual cause was slippage of the suspension wire in the soldered connections to the mounting capillaries at low temperatures. Disappearance of the slack at room temperature was simply due to relative expansion of the plexiglass during the warming-up process after slippage had ceased.

Several other methods of mounting the suspension wire were tried; the only suitable one was the method of silver-soldering the wire to the stainless steel capillary. The difficulty of this operation will be realized if one bears in mind that four successive soldering operations, two of them within 1 cm of the alnico disc, must be successful, and that the 2-mil nichrome wire must be heated to red incandescence without being permitted to burn through or become brittle at the joint.

Several runs were made with a suspension of this type, and the mechanical noise level decreased markedly; the limiting source of noise is now clearly microphonic noise introduced by the battery preamplifier.

Examination of the data of several runs indicated that scattering of the experimental points exceeds the variation of viscosity between four degrees and the λ point, that the damping is affected by the amplitude of oscillation (although amplitudes remained below the limit of laminar flow), and that there is a reproducible increase of damping below the λ point.

These observations suggest that there might be slip between the surface of the disc and the helium, a phenomenon which has not been observed by previous investigators who used considerably lower frequencies of oscillation. One series of measurements was therefore made in which the damping was measured at only four temperatures but at three different frequencies in each case. The curves obtained in this run have not yet been evaluated.

H. H. Kolm

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E. MEASUREMENT OF SECOND SOUND PULSE HEIGHTS IN LIQUID HELIUM II

The pulser output has been changed from positive to negative pulses. The calibration pulses at the output of the video amplifier are then negative, as is the case with the signal pulses. The arrangement for detecting when superimposed noise swings the top of the pulse into the nonlinear region of the keyed amplifier will then apply to the calibration as well as to the signal pulses. The calibration will also be direct rather than by extrapolation and thus may yield a possible increase of accuracy.

A successful attempt has been made to eliminate a good deal of the internal hum (arising from the equipment itself) formerly present in the calibration procedure. This was accomplished by isolating the calibration voltage divider from other chassis and breaking certain duplicate ground connections.

Much trouble has been experienced with external hum (pickup that seems to arise from outside the equipment). Attempts to trace its source to nearby specific machinery were not successful. Latest observation of this pickup indicates that it may be essentially microphonic in the video amplifier. An attempt will be made to lower it to a non-interfering level by placing the amplifier on sponge-rubber padding.

B. Bernstein

F. THE SPECIFIC HEAT OF MAGNESIUM

A search for a suitable carbon resistance thermometer has been made and a new calorimeter has been constructed for measuring the specific heat of magnesium at low temperatures.

It was found that a 5000-ohm (at room temperature) carbon resistor of the usual radio variety (Allen Bradley was used) has a resistance of the order of magnitude of 1 megohm between 3° and 4°K. The values of resistance are quite reproducible within one liquid helium run after the resistor has been cycled one or two times between 1°K and 4°K. It is felt that after cycling the resistor a few more times the data will be reproducible from one run to another, since present agreement is within ± 20 percent. The change of resistance in this range is roughly 400 percent per degree, enabling one to measure 0.001° temperature differences with less than four-place bridge accuracy and only 10^{-8} watts power dissipation in the resistor.

The resistor was mounted inside a magnesium sample and used in the new calorimeter in conjunction with an induction heating coil surrounding the inner dewar. A heat leak of the order of 5×10^{-5} watts was found to exist with a temperature difference of only 0.1° between the bath and the sample, thus making specific heat determination impossible. This leak was probably due to one of the current leads pulling through a soft solder seal and allowing helium gas to leak into the calorimeter. The old

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calorimeter is being rebuilt, using smaller current leads of nichrome wire in the hope that the relative shrinkage of the leads will be smaller.

E. E. Huber, Jr.

G. THERMAL CONDUCTIVITY OF MAGNESIUM

All electronic measuring equipment has been put in sufficiently good operating order to make the necessary measurements of the resistance of the two phosphor-bronze thermometers. This measurement is accurate to the order of one part in one hundred thousand. This accuracy will allow temperature differences to be obtained to the order of one percent accuracy.

Progress has been made in the construction of a system for regulating the pressure over a helium bath in such a manner that the pressure is the result of a continuous flow. The valve mechanism itself has been constructed.

The entire temperature-measuring apparatus was determined to be stable, in that results were reproducible under the same conditions in the liquid nitrogen range.

E. G. Sharkoff

H. THERMOELECTRIC FORCES

An apparatus for the measurement of thermoelectric forces at low temperatures has been designed. A procedure similar to that of Borelius et al (G. Borelius, et al; Comm. Phys. Lab. of Leiden, No. 217, 14, 1931) will be followed. One junction will be in contact with the helium bath; the other will be heated and its temperature measured by a helium thermometer. Changes in emf and temperature will thus give $\Delta E/\Delta T$ and hence the difference of the Thomson coefficients. By using a superconductor, which has no Thomson coefficient, the Thomson coefficient for the unknown will be given directly.

The physical apparatus is under construction with the vacuum part of the system nearing completion. The next major step will be the construction of the potentiometer.

R. D. Maurer

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

The construction of a measuring coil for use with the mutual inductance bridge used in this laboratory has been continued. Space requirements dictated by the use of a small inner dewar necessitated the use of very fine wire in the secondary of the coil. To obtain maximum space economy an attempt was made to wind the secondary uniformly, instead of employing the usual "jumble-wound" method. A coil winder

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for this purpose was constructed and refined but an attempt to wind the coil in this manner was only partially successful.

Consequently attention has been turned to the construction of a mutual inductance bridge of higher sensitivity than had heretofore been employed. The bridge was first assembled in its standard form and now works satisfactorily. Work on the bridge is continuing: the present plan is to investigate the use of a step-up transformer and/or a battery-operated preamplifier followed by the selective twin-T amplifier in the null-detector of the bridge.

J. W. Wright

J. PRESSURE DEPENDENCE OF SECOND SOUND VELOCITY IN THE ADIABATIC DEMAGNETIZATION REGION

The small iron-core electromagnet (see Quarterly Progress Report, October 15, 1951) has been completed and tested; continuous operation at fields of 4500 gauss or more is possible with a 3-inch gap. The remainder of the apparatus being complete, several attempts were made to carry out a magnetic cooling operation on a sample of liquid helium under pressure, resulting in considerable redesign of the capsule to keep the salt cooler during soldering operations and to increase the length of the heat-flow path from the liquid helium bath to the inner capsule.

Rough calculations had shown that it would probably be impossible to perform the experiment if the liquid helium bath temperature was over 1.10 °K, since the heat leak to the inner capsule is critically dependent on the bath temperature. It proved impossible to refrigerate the original apparatus this far with available vacuum pumps, so the apparatus has been reconstructed to allow the use of a smaller-diameter, longer dewar. The smaller absolute values of conduction, radiation, and Rollin-film heat input to the smaller dewar will allow the present pumps to reach a lower bath temperature. The smaller dewar will necessitate a smaller amount of salt in the inner capsule and hence a lower heat capacity and a faster warm-up bath, but this is negligible in comparison with the reduction in heat leak caused by the lower bath temperature. The first attempt with this apparatus was halted by a blown diffusion-pump heater, but before the heater blew the temperature showed signs of reaching a sufficiently low value.

V. Mayper, Jr.