

IV. LOW TEMPERATURE PHYSICS

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A. MAGNETIC DIPOLE INTERACTIONS IN CRYSTALS

A number of mutual inductance measuring coils have been constructed in an attempt to meet the requirements outlined in the Quarterly Progress Report, January 15, 1952. The design of the measuring coil was carried out by the following procedure. The field along the axis was plotted as a function of distance for the outer coil, which produces the constant field on the sample, and for various possible primaries of the measuring coil. By using these plots, a secondary of three sections and a primary were selected. The end sections of the secondary were wound in the opposite direction from the center section. The areas under the plotted curves guided the selection of the lengths and positions for the three sections, so that neither the primary nor the outer coil were coupled to the secondary. The lengths chosen are shown in Fig. IV-1.

Trial and error methods were used to find the optimum number of turns for the primary and secondary. It was found that although No. 42 copper wire could be wound without breakage at 50 feet per minute, the formex insulation was not dependable. With refined techniques, however, it was found that No. 38 wire could be wound smoothly at this speed. Equal thicknesses of primary and secondary maximized the change in mutual inductance of the measuring coil caused by a magnetic sample introduced into the center section.

Only a small primary current may be used, to keep the varying field on the sample small. It is estimated that the resulting small voltage output from the secondary can be measured with the help of a transformer to such an accuracy that the change in mutual inductance of the coil due to a change of temperature from 4.2°K to 1.25°K of

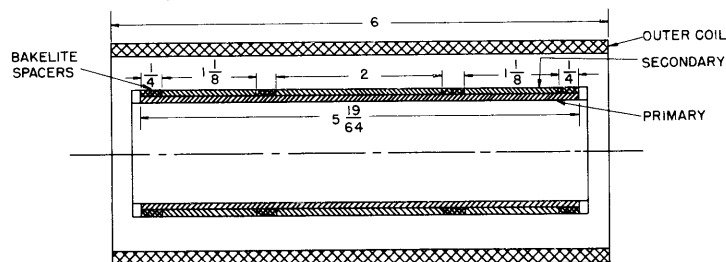


Fig. IV-1

Coils for susceptibility measurement and dc field.

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the 9-gram sample can be detected within 3 percent.

L. D. Jennings, Jr.

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

Figure IV-2a shows the mutual inductance bridge used in this laboratory for the measurement of the magnetic susceptibility of paramagnetic salts. The measuring coil contains the salt sample. These coils give mutual inductance changes of the order of hundreds of microhenrys in the 1°K to 4°K range of temperature for samples of 3/4-inch to 1-inch diameter. However, in order to obtain as low a temperature as possible by pumping, a dewar of a smaller inside diameter (approximately 3/4 inch) must be used, necessitating the use of a much smaller sample. The task of scaling the measuring equipment to the smaller sample is accomplished with the modified bridge shown in Fig. IV-2b. The limitation of the present measurement lies in the instability of the mutual inductance of the coils, rather than in voltage sensitivity of the amplifier. Therefore, the mutual inductance of the measuring coil, along with the size of its fluctuations, may be reduced and the reduction of output from the secondary compensated by a step-up transformer between the secondary circuit and the twin-T amplifier. The input impedance to the transformer is made sufficiently low by this reduction in secondary turns and by a change of the parameters in the resistance bridge as shown. The 0.01-ohm resistors are actually short lengths of constantan wire. The coil has not been tested at liquid helium temperatures, but at room temperature the bridge is capable of measuring mutual inductance with a precision of 2×10^{-7} henrys with a primary

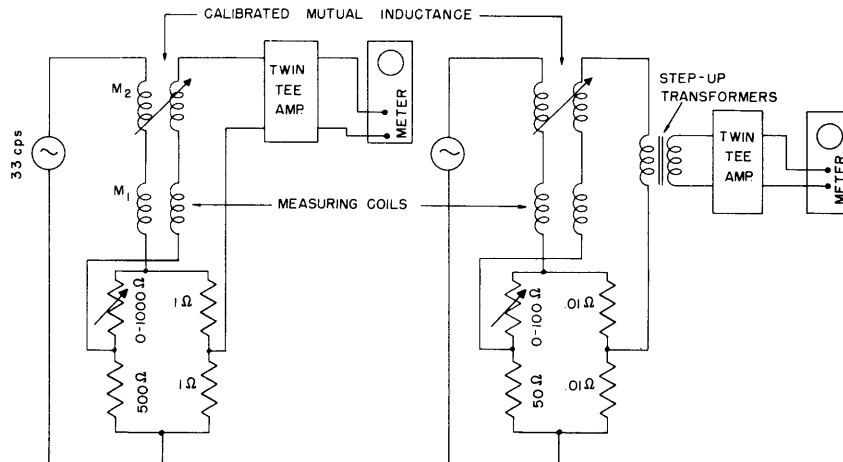


Fig. IV-2
Mutual inductance bridge.

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current which will give a measuring field in the sample of less than 2 gauss. With the relaxation of the requirement of a large number of turns, the measuring coil has been wound with little difficulty.

The iron-core magnet has been mounted on a sliding frame. Considerable progress has been made toward constructing the system for pumping on the helium bath. We are now using a Distillation Products MC275 high-vacuum diffusion pump boosted by a pump made in the laboratory by V. Mayer, in place of the usual MB200 pump which is not immediately available.

J. W. Wright, T. D. Schultz

C. GROWTH OF LARGE CRYSTALS OF PARAMAGNETIC ALUM

A number of experiments now in progress and under consideration in this laboratory require specimens of a paramagnetic alum in the form of a reasonably large single crystal. Construction of two crystal-growing devices has therefore been undertaken. The first is Valetton's arrangement of the U-tube apparatus of Krüger and Fincke (1), and the second is a small version of the apparatus developed by A. N. Holden for growing EDT crystals at the Bell Laboratories (2). Both of these devices are nearing completion.

H. H. Kolm

References

1. H. E. Buckley: Crystal Growth, pp. 49 ff., John Wiley, New York, 1951
2. H. E. Buckley: Crystal Growth, p. 57, John Wiley, New York, 1951

D. THE RESISTANCE MINIMUM IN METALS

A detailed investigation of the resistivity of available magnesium samples is being carried out, using the refined apparatus and calculations described in the Quarterly Progress Reports for January 15, 1952, and October 15, 1951. The samples have not yet been subjected to any annealing or stressing. Results have been obtained over the temperature range 1°K to 40°K for the three samples investigated. All three samples exhibit resistance minima. Sample A, believed to contain more impurities than the others, has a more pronounced minimum (see Fig. IV-3). The temperature of the minimum varies from sample to sample, being lower for samples with the smaller residual resistivity. Such behavior is in qualitative agreement with some results of de Haas and

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van den Berg on gold (1). Above 15°K, the resistivity for all three samples can be well represented by a power law, $\rho = \rho_0 + aT^b$, with b equal approximately to 3 to 3.5. Matthiessen's rule, however, is not obeyed. In fact, the ρ vs T plots for two of the samples intersect at approximately 26°K.

The data above 4.2°K was obtained in the following manner. The sample was allowed to warm up in the dewar after the liquid helium had been evaporated with a resistance heater, which was buried in activated charcoal at the bottom of the dewar. The temperature was measured with the helium gas thermometer described in the Quarterly Progress Report, January 15, 1952. The warm-up rate was kept quite low (approximately 12° per hour) by a cylindrical cup mounted in the dewar approximately 20 cm above the sample and the helium thermometer. This cup fills the cross section of the dewar and is approximately 6 cm in length. The cup apparently remains filled with helium after the rapid evaporation of the helium in the dewar and serves to keep the heat conducted down the length of the dewar to a low value. The heat conducted through the dewar walls remains as the only important source of heat. This heat leak is quite low for a freshly pumped dewar, but it increases to an excessively large value after a single run, apparently due to the contamination of the dewar insulating space by helium gas. This contamination is more evident in this experiment than in the usual "softening" of a dewar, since the heat leak down the dewar, usually of major importance in determining warm-up rates, has been largely eliminated. Measurements obtained during the warm-up have been treated as equilibrium measurements. The relaxation time, $\tau = l^2 \rho c / 4k$ (ref. 2), for heat flow should be quite low, being of the order of 0.01 sec for aluminum

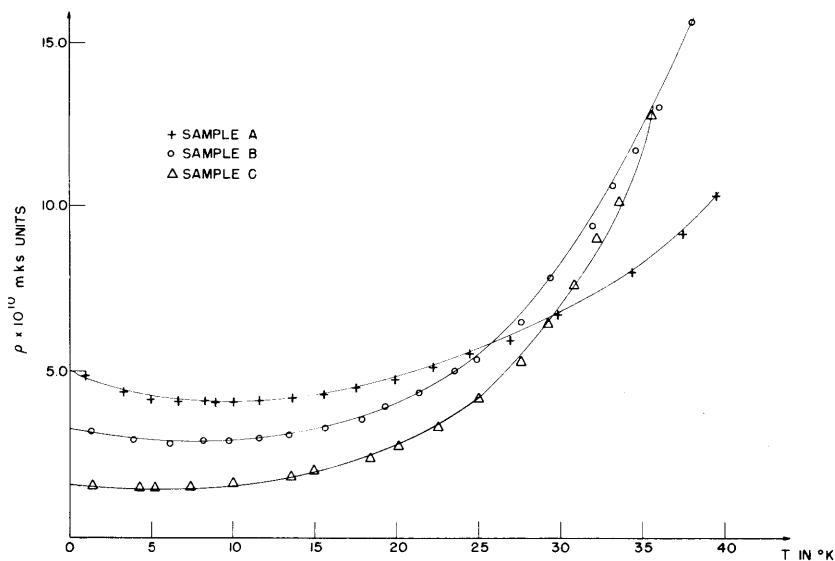


Fig. IV-3

Plot of ρ vs τ for 3 samples of Mg from various sources.

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at 20°K (ref. 3). The relaxation time for magnesium should be of the same order. The data obtained so far show good internal consistency and reproducibility.

Work is continuing on the magnesium samples available; on its completion, an attempt will be made to introduce impurities into samples not showing a pronounced minimum. The measurements on aluminum in a magnetic field (Quarterly Progress Report, October 15, 1951) have not been made, since an effective method of preventing the field-producing coil from influencing the mutual inductance measurements has not yet been determined.

H. E. Rorschach, Jr.

References

1. W. J. de Haas, G. J. van den Berg: *Physica* 3, 440, 1936
2. J. C. Slater, N. H. Frank: *Introduction to Theoretical Physics*, 206, McGraw-Hill, New York, 1933
3. τ was determined from data given by E. F. Burton, H. Grayson Smith, J. O. Wilhelm: *Phenomena at the Temperature of Liquid Helium*, Reinhold Publishing Corp. New York, 1940

E. SPECIFIC HEAT OF MAGNESIUM

Two new calorimeters for measuring the specific heat of magnesium at low temperatures were constructed. The first calorimeter was of the type outlined in the Quarterly Progress Report, January 15, 1952, except that 0.004-inch tungsten supporting leads, hard-soldered end-on to No. 22 copper wire, were used to minimize nonelastic contraction at low temperatures. It was possible to hard-solder to the tungsten without preplating it by using a very small, hot flame. The flux-coated wire was brought very slowly into the hottest part of the flame. Soft solder was again used in sealing the kovar tubes through which the No. 22 copper wires passed. The supporting wires did not pull through the soft-soldered joint as in the previous apparatus, but a vacuum leak occurred at low temperatures which made measurements impossible.

The calorimeter was rebuilt, using tungsten wires as before, but hard-soldered directly through the kovar tubing and soft-soldered over the ends. This calorimeter also leaked at low temperatures, however, due to differential contraction between the walls of the kovar tube and the glass cylinder. A new calorimeter is being constructed employing solid kovar pins, brazed end-on to tungsten supporting wires in the hope that leakage will be avoided.

E. E. Huber, Jr.

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F. THERMAL CONDUCTIVITY OF MAGNESIUM

The two phosphor-bronze resistance thermometers attached along the length of magnesium sample were calibrated roughly. Their sensitivities are in the range of 10 percent to fifteen percent resistance change per degree of temperature change. This is the order of magnitude observed by others in this laboratory for the same wire.

The above calibration procedure exposed the following weaknesses of the measurement equipment.

First, the measuring bridge became unbalanced inductively when the temperature of the sample was reduced below 2°K. On the surmise that the rings of solder joining the parts of the brass case became superconducting at a temperature below 2°K, thus making the mutual inductance between the solder ring and the measuring coil very large, a glass sample container was substituted for the brass one. The condition did not then occur. This mutual inductance had caused a quadrature signal to appear across the detector which made reading the null in the in-phase component of the signal impossible.

The second difficulty in calibration arose from using too high a supply voltage across the bridge. The heat generated in the thermometers caused the temperature drift. A reproducible change was observed in the measured resistance of the thermometer by about one part in a thousand. This difference is about that expected from the heat known to be generated in the thermometer. Reduced voltage applied to the bridge, however, reduced the sensitivity to an intolerable level. Experiments attempting to balance the bridge during intermittent applications of the measuring current are being performed. Also, the sensitivity of the null detector may be improved by addition of a battery pre-amplifier before the twin-T amplifier, but this has not been successful thus far.

Pressure regulation adequate for the calibration of the equipment used in the experiment was obtained by using the barostat equipment available in the laboratory. Until the measuring equipment is improved enough to show the pressure fluctuations in the system using the barostat, further development of the all-electronic pressure regulator has been suspended.

E. G. Sharkoff

G. THERMOELECTRIC FORCES

The vacuum system surrounding the helium thermometer bulb and high temperature end of the thermocouple (Fig. IV-4) has been completed and tested at low temperatures. The system contains a ground glass joint for facility in changing samples. This joint, coated with silicone grease, held a vacuum of 10^{-6} mm upon immersion in liquid helium II.

Wires for the magnesium-tin junction have been obtained. Attempts to have the

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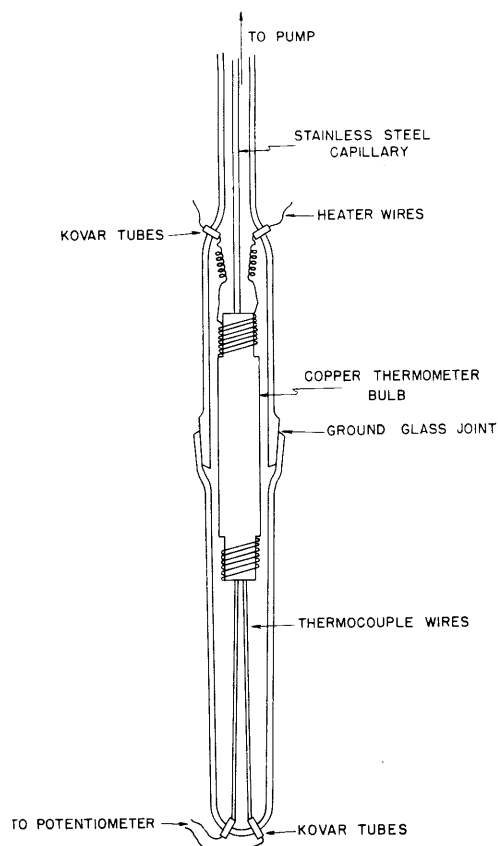


Fig. IV-4

Section of apparatus which is immersed in liquid helium bath.

ends of the magnesium-wire samples plated for soldering have not been successful because the copper deposits have not adhered to the metal. However, samples of fairly high purity tin wire have been made by casting tin in glass capillaries under vacuum.

The main effort of the project has been directed toward perfection of a helium gas thermometer for the range 4°K to 20°K. A manometer was chosen as the best pressure indicator that combined accuracy with economy. The thermometer is filled at low temperature so that the manometer need only read pressures in the neighborhood of the measuring region. The following corrections were considered in the design:

1. Thermomolecular pressure difference. For the diameter of capillary used to connect the low temperature bulb, it is known that above pressures of about 1.5 cm of mercury, the measured pressure varies by less than 1 percent from the actual low temperature pressure. Pressures above 3 cm of mercury will be used.

2. Second virial term. This correction led to the decision to use an oil rather than a mercury manometer, since the same sensitivity could be obtained with lower pressures. At the contemplated pressures to be used, the second virial term diminishes from 1 percent of the first term at 4°K to less than 0.1 percent at 15°K. Below 4°K the thermometer can be calibrated directly against the helium bath temperature.

3. Variation of the external volume. This is a parameter in the calculated equations for the thermometer.

4. Diffusion and solubility of the helium gas in the oil. This problem has recently arisen, and it is hoped that it can be solved by using capillary tubing in the manometer. Measurements indicate that the correction can be neglected for tubing of 1.5 mm diameter. The pieces of capillary were carefully chosen to match in diameter and reduce the difference between capillary attraction in the two sides.

In addition to these corrections, it was found that the following corrections were negligible: adsorption, changes in room temperature, and correction for the volume

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of the capillary leading to the low temperature bulb.

By assuming the ideal gas laws (see correction 2), we obtain for such a thermometer

$$T = \frac{P \times T_o}{\frac{P_o}{T_1^o} (T_1^o + x T_o) - P(1-a) - \frac{a P^2}{P_o}}$$

where P is the pressure, P_o the filling pressure, T_1^o the low temperature at filling, T_o room temperature, V_1 the low temperature volume, and V_2 the initial external volume. Here $x = V_1/V_2$ and $a = k P_o / 2 V_2$ where k is the manometer cross section area. All of these values were measured except "x" which has been determined from calibration at known temperatures. A preliminary manometer with large tubing (see correction 4) gave several values for "x" which agreed with one another within 2 percent.

This thermometer has a sensitivity of about $dP/dT = P_o(0.10^\circ K^{-1})$. Thus, a 150-cm manometer filled to an initial pressure of 50 cm will cover the required temperature range and will change by about 5 cm/degree. With these values, theoretically, temperature differences can be read to about $0.01^\circ K$.

A potentiometer for measurement of emf's up to $200 \mu v$ has been designed (Fig. IV-5). Principal attention was given to exclusion of stray thermal emf's by means of thermal shielding. Voltages will be obtained by measuring the battery voltage occasionally (approximately 2.1 volts) and by reading the variable resistors for each measurement.

R. D. Maurer

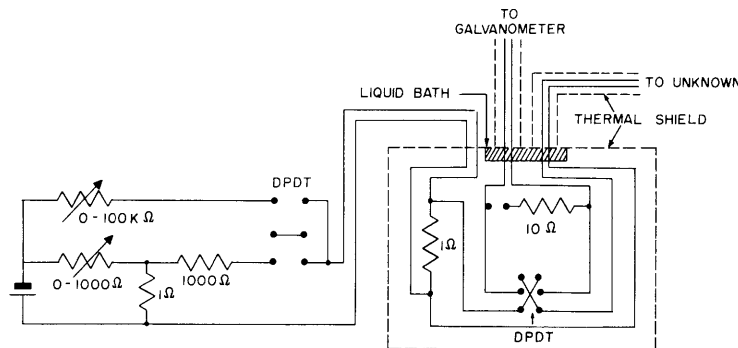


Fig. IV-5
Potentiometer.

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H. THERMAL PROPERTIES OF METALS MEASURED BY A PULSE TECHNIQUE

One particular solution of the heat flow equation, the Green's function, can be used to describe the response of a one-dimensional sample to a δ function of heat. This response determines thermal diffusivity, thermal conductivity, and specific heat of the sample. To approximate linear heat flow, a rod-shaped sample is surrounded by vacuum. The necessary vacuum system, mentioned in the Quarterly Progress Report, October 15, 1951, has consistently evacuated the sample chamber to 10^{-7} mm Hg or better. It has been observed by other workers that vacuum better than 10^{-5} mm Hg is sufficient to stop gaseous conduction of heat in the helium range of temperature.

One end of the long rod-shaped sample is in contact with the helium bath, essentially at infinity. The other end is heated $33 \frac{1}{3}$ times per second by pulses of 10 μ sec duration. Since the temperature-response time is in milliseconds, this is a fair approach to a δ function. The heater is carbon paint on bakelite. The variable energy input to the sample is currently set at 150 ergs per pulse.

The thermometer is carbon resistance paint on a 0.001-inch plastic film, sandwiched by the sample material in a plane normal to the heat flow. The carbon is in direct physical contact with the magnesium, but it is electrically isolated by a self-formed insulation on the magnesium sample. This thermometer dissipates about two ergs during each cycle. The magnitude of reflection or thermal resistance effects of the thermometer sheet have yet to be determined. In operation the maximum measured temperature rise at the thermometer is of the order of 0.1°K.

The thermometer carries constant current. Its change of resistance with temperature produces an output voltage which is amplified and displayed on an oscilloscope. Linearity and bandwidth of the original electronic amplifying system have been improved to the point where the limiting factor in the whole experiment is tube microphonics in the first amplifier stage.

S. Waldron

I. PRESSURE DEPENDENCE OF SECOND-SOUND VELOCITY IN THE DEMAGNETIZATION REGION

Apparatus construction and development have continued during the past quarter. The equipment for this experiment may be divided into two main sections: first, the refrigeration apparatus for cooling a sample of liquid helium under pressure to temperatures below 0.9°K and keeping it there long enough to measure the second-sound velocity; and second, the experimental apparatus proper (largely electronic) for actually making this measurement. Most of the effort until recently has been directed toward the development and construction of a suitable refrigeration apparatus, consisting of the following:

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mechanical pumps and a large diffusion pump for cooling the helium bath by evaporation; a capsule connected to a source of helium under a known pressure and isolated from the bath by an evacuable space; a system for filling this space with helium gas and evacuating it to make and break the heat contact between capsule and bath (with vacuum gauges); several grams of ferric ammonium alum in the capsule; apparatus for measuring bath temperature by the helium vapor pressure and capsule temperature by the magnetic susceptibility of the alum; and an electromagnet and power source for cooling the alum and hence the pressurized capsule by adiabatic demagnetization.

After considerable effort, a refrigeration apparatus was finally constructed which gave a successful demagnetization run. Starting with a bath temperature of 1.0°K and a magnetic field of about 4500 gauss, the pressurized capsule reached a temperature of about 0.2°K or 0.3°K (extrapolated from the warm-up curve) immediately after demagnetization, and it had a warm-up time-constant of about one minute. The lowest temperature measured with the available settings of the magnetic-susceptibility thermometer was 0.52°K which occurred about 45 seconds after the demagnetization. (The range of the thermometer is easily extended below this, however.) The capsule had returned to equilibrium with the bath within the precision of measurement in approximately ten minutes.

Work is now proceeding on the second-sound apparatus proper. When the electronics (an appreciable fraction of which is now working properly) has been completed, the pressurized capsule will be reconstructed to include a second-sound chamber, and velocity measurements will be attempted.

V. Mayper, Jr.

J. SECOND-SOUND PULSE AMPLITUDES IN LIQUID HELIUM II

Measurements were made on second-sound pulse amplitudes between 2.1°K and 1.6°K . Fairly flat-topped rectangular pulses of voltage across the carbon transmitter yielded received second-sound pulses with the waveform shown in Fig. IV-6. The electronic circuits are known, however, to pass rectangular pulses without appreciable distortion. Thus, the waveform change is produced in the liquid helium section of the apparatus, that is in the process of generating, propagating, and receiving the second-sound pulse.

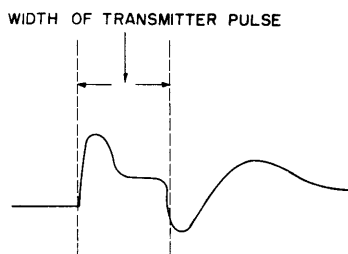


Fig. IV-6
Waveform of second-sound pulse.

It has been decided to make a detailed electronic measurement of the variation in pulse amplitude along the length of the pulse. This will be done at a constant temperature and will require better temperature stabilization. Also,

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the scanning pulse must be greatly narrowed to improve the detail of the above measurement, as its width at present is one quarter that of the transmitted pulse.

B. Bernstein

K. THERMOMECHANICAL EFFECT

A way has been found to reduce the fluctuations in pumping rate of the oil diffusion pump used in the experiment to lower the temperature of the helium bath. The worst of the fluctuations occur because the pump (a Distillation Products type MB-200) is being operated above its effective pressure range. However, at the very lowest temperatures attainable with the heat leaks normally present in the experiment and by using the MB-200 with a Kinney model CVD 8610 forepump, the pump does enter its effective range so that the worst of the fluctuations cease. The temperature of the bath under such conditions is 0.88°K or below. The corresponding vapor pressure is $30\ \mu$ or less. A constriction or baffle placed in the pumping line between the dewar and the diffusion pump allows a higher pressure in the dewar and hence a higher helium bath temperature, while the diffusion pump continues to operate in its effective pressure range. An adjustable baffle placed in this position has reduced the fluctuations to a very great extent over the temperature range in which the experiment is performed.

The remaining temperature fluctuations can be handled by the galvanometer amplifier type of temperature regulator which now functions quite well. To prevent hunting, the system is damped with a "lead" network which adds to the correction signal a portion of its derivative. The place of insertion of this lead network was found to be important; the most effective place was at the input to the galvanometer. (See Fig. IV-7.)

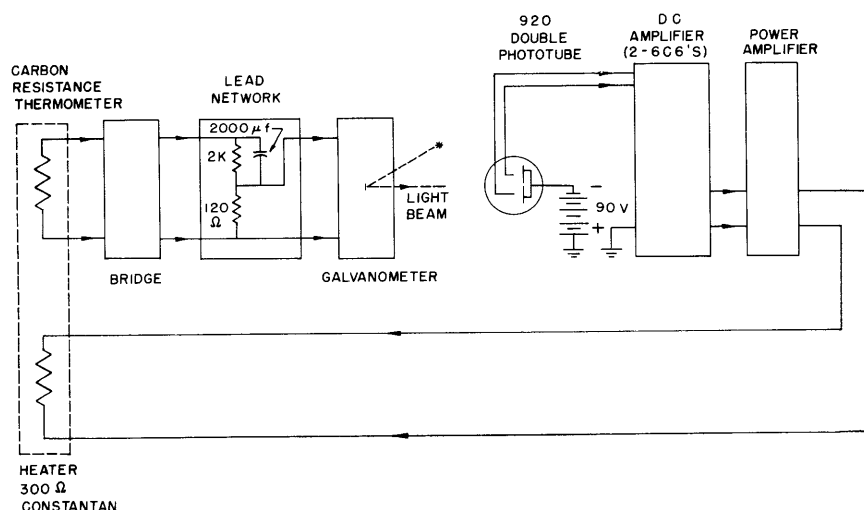


Fig. IV-7

Galvanometer amplifier-type temperature regulator.

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Allen-Bradley carbon resistors (10 ohm, one-half watt size) have been installed as resistance thermometers in place of the "old-fashioned" carbon resistors used so far. The Allen-Bradley resistors are eight times as sensitive at 1°K as the others and appear to have better stability characteristics.

D. H. Rogers

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

Evaluation of the curves obtained in the last experiment in which the frequency was varied revealed excessive viscosity values and very considerable scattering. All instrumental sources of scattering having been eliminated, it was concluded that both of the above observations are due to imperfections in the surface of the alnico disk. This explanation seems plausible in view of the extremely thin penetration depth of the oscillation into the liquid helium at the frequencies used (approximately 0.003 mm).

Two methods of improving the surface are being tried. A new disk of alloy steel has been made which has a high magnetic retentivity and which, unlike alnico, can be ground and lapped to a very smooth finish. Second, the alnico disk used at present will be lined with two mica disks. It remains to be seen whether the decrease in magnetization caused by using a steel instead of an alnico disk will lead to a serious noise problem.

H. H. Kolm