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Helium Film Flow below 1°K

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The critical transfer rate of the helium II film was measured at temperatures between 0.3°K and the lambda point. Filling rates of a small beaker enclosed in a sealed glass capsule which could be tipped as a whole were studied. A technique was developed whereby the glass capsule could be sealed off at room temperature with 750 psig of helium gas, sufficient to provide enough liquid within the capsule at the low temperatures. It was found that the rate of flow at 0.3°K rises 25% above the value at the flat minimum near 1°K, in approximate agreement with the results of Ambler and Kurti.

INTRODUCTION

AMBLER and Kurti[1] were the first to measure the rate of flow of the helium film below 1°K. They succeeded in obtaining relatively long warm-up times in an open helium bath containing a glass beaker imbedded in a paramagnetic salt. Their results showed an interesting rise in flow rate above the previously measured values of Daunt and Mendelssohn[2] as the temperature was reduced below 0.8°K. The general course of the curve of flow rate *vs* temperature was in fact reminiscent of the curve for the velocity of second sound *vs* temperature. The desirability of further experiments, particularly with different geometry, was suggested. It is also to be noted that in this first arrangement only emptying rates of the beaker could be measured and the presence of any anomalous evaporation could not be detected by a comparison with filling rates.

Lesensky and Boorse[3] attempted further measurements below 1°K using copper surfaces and a capacitive method of measuring levels which obviated the need for visual observations. Their results seemed to confirm a rise in flow rate below 1°K but difficulties in obtaining a sufficiently long warm-up time prevented their going below about 0.75°K.

During the course of the present work, Waring[4] reported measurements on glass, again using an open helium bath. While he noted again a rise below 0.8°K, the amount of this rise above the value near 1°K was only about 10%, rather than the 30% observed by Ambler and Kurti. Waring further suggested that there might be a difference between gravitationally induced flow rates and thermally induced flow rates. This suggestion apparently depended mainly on the results of a single observation above 1°K, however. In view of numerous other observations indicating no such difference[5,6] and the known difficulty of repeating flow rate measurements from day to day, this suggestion seemed open to question.

EXPERIMENTAL METHOD

The method adopted in the present investigation was designed to eliminate the difficulties associated with obtaining a long warmup time in an open bath and also to provide a direct measurement of filling rate of a beaker. Sufficient helium gas was sealed off at a high pressure at room temperature in a closed glass capsule, or bomb, so that on subsequent cooling to 4°K sufficient liquid would condense to perform the experiment in the closed chamber without any pumping tube connecting it to the warm regions above. Such an arrangement, but using cupro-nickel for the capsule, was first used by Kurti, Rollin, and Simon[7] in an experiment on thermal relaxation times.

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[1] E. Ambler and N. Kurti, Phil. Mag. 43, 260 (1952).

[2] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. (London) A170, 439 (1939).

[3] L. Lesensky and H. A. Boorse, Phys. Rev. 87, 1135 (1952).

[4] R. K. Waring, Jr., Phys. Rev. 99, 1704 (1955).

[5] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. (London) A63, 1305 (1950).

[6] K. L. Chopra and J. B. Brown (to be published).

[7] Kurti, Rollin, and Simon, Physica 3, 266 (1936).

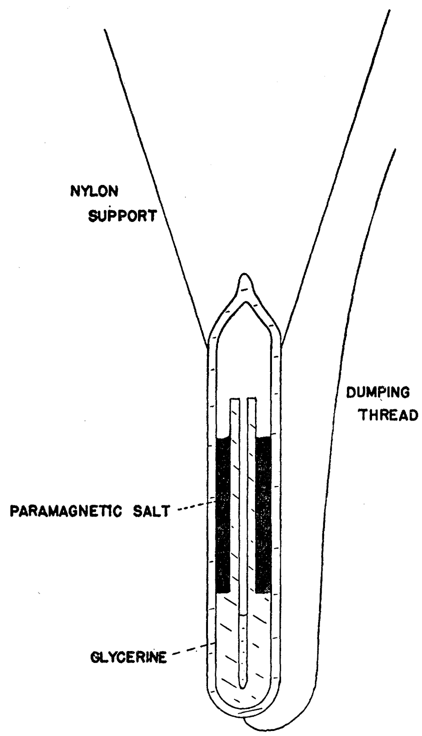

FIG. 1. Pyrex capsule, or "bomb," shown in filling position. To avoid strains in the glass the beaker insert is not fused to the wall. A film of glycerine in the gap between the two reduces the amount of helium required to be sealed into the capsule.

The difficulties involved in the sealing-off of a glass capsule in this way are obvious but a successful method, to be described in detail in a separate note, was developed. It consisted in placing the 8-mm o.d. Pyrex glass capsule, complete except for a minute hole at one end which had been drawn down to 2-mm diameter, in a brass case to which clean helium gas could be admitted to a pressure of 750 psig. A conical tungsten heater surrounding the tip of the capsule was then heated hot enough to seal off the end, the progress of the operation being observed through a thick glass port. After the heat had been turned off and the whole apparatus cooled, the pressure in the outer brass case was reduced to atmospheric and the finished capsule removed.

Every effort was taken to keep the capsule and its contained beaker clean, but of course the presence of the paramagnetic salt for cooling inside the capsule placed a limitation on the methods which could be employed. The salt used, manganous ammonium sulfate, could be pumped at salt ice temperatures without decomposition. The possibility of some impurities being produced at the time of the heating of the glass cannot be overlooked, but in any case the effect of surface impurities is greatly reduced if a beaker of sufficient length is used.[8] It will be seen further that the absolute flow rates obtained were in good agreement with previous results on glass above 1°K.

The bomb so produced was then suspended in the cryostat by nylon threads as shown in Fig. 1. Sliding O-ring seals at the top of the cryostat enabled the bomb to be raised from the tail in which the demagnetization was carried out to the observation position, where it could be tipped to empty the beaker. The measurement of flow rate was made visually usually a cathetometer with a built-in eyepiece scale. The light from a 6-watt electric bulb controlled by a variac was filtered through a cuprous chloride, infrared absorbing cell and focused in a line on the glass capillary below the salt. The temperature (Scale T_{55}) of the bomb was measured by the change in mutual inductance of the solenoid around the tail of the inner jacket immersed in liquid helium, by means of the ballistic galvanometer method.

PROCEDURE

The usual procedure in observations consisted in demagnetizing the bomb in the "dumped" position in the tail, immediately measuring the temperature, raising the bomb, and tipping it into the upright position in which the flow rate could be measured by observing the rise of the liquid meniscus in the capillary, the use of the light being restricted to the minimum. The times of passing at least four major scale divisions were taken on a split-second hand stop watch, the total time being of the order of one minute. The bomb was then dumped again and lowered into the tail for a final measurement of temperature. After a minute of draining in this position, which appeared to be required because of a drop forming on the end of the beaker, the cycle of raising and measuring could be repeated at a slightly higher temperature. In good runs, warmup periods of about a half hour were obtained, which appeared to be quite satisfactory for only one-half gram of paramagnetic salt. The effect on the temperature of moving the bomb was noticeable, however, on some occasions more than others, as was also even the sparing use of the light source, and if such an experiment were to be repeated, especially for lower temperatures, it would be desirable to use a larger bomb mounted in an elliptical tail Dewar where it could be tipped with a minimum of disturbance.

RESULTS

The transfer rates observed are plotted against temperature in Fig. 2. The data represented are from a number of runs on two different days, but no normalizing factor was found to be required. For the sake of comparison, flow rates obtained by the other investigators below 1°K are shown on the same graph. Above 1°K the curve through the present results seems to be identical with the curve of Mendelssohn and White.[9]

[8] R. Bowers and K. Mendelssohn, Proc. Phys. Soc. (London) **A63**, 1318 (1950).

[9] K. Mendelssohn and G. K. White, Proc. Phys. Soc. (London) **A63**, 1328 (1950).

The general shape of the present curve is like that of Ambler and Kurti. Below approximately 0.3°K, however, our curve shows a possible indication of a slight flattening in contrast to the complete flattening in Waring's case and no flattening at all in that of Ambler and Kurti.

We feel that the discrepancy between Waring's results on the one hand, and those of Ambler and Kurti and the present work on the other, might be explained, at least insofar as the fractional increase in flow rate at the lowest temperatures is concerned, as a consequence of Waring's method of measuring flow rates induced thermally. While it is known that above 1°K film can evaporate at a temperature very close to that of the bulk liquid, such may not be the case in the region below about 0.6°K where the vapor pressure falls to very small values. In fact, a rough calculation of maximum evaporation rate based on kinetic theory indicates that the liquid carried by the film at the observed transport rates could be evaporated within a few centimeters only when raised to about 0.5°K. Thus in Waring's arrangement a constriction near 0.5°K would effectively limit flow rates to that corresponding to this temperature even though the bulk liquid were at a temperature below 0.5°K.

As regards the differences between the absolute values of flow rate, the weight of evidence in other experiments is against the explanation in terms of a difference between gravitationally and thermally induced flow rates. A more likely explanation of the higher rates observed by both Ambler and Kurti, and Waring is possible in terms of some surface effect, possibly impurities or irregularities over the short section of limiting cross section. Even in the case of the sealed capsule used here it was noted that a first bomb, on which measurements had been made above 1°K before it was accidentally exploded at room temperature, gave results approximately 50% higher, presumably due to sealed-in impurities.

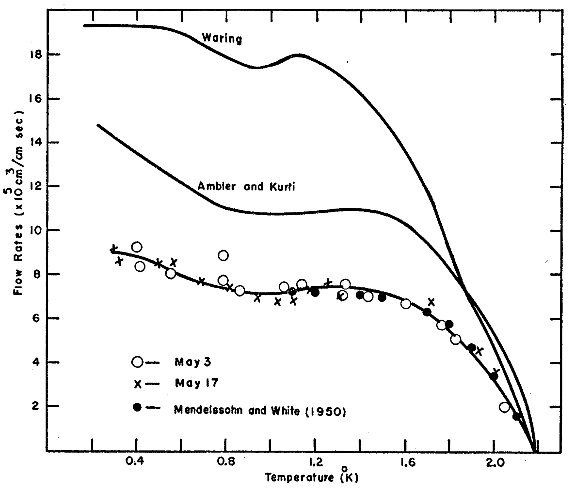

Fig. 2. Helium film flow rates as a function of temperature. The upper curves show the results of two previous investigators below 1°K, while the bottom curve fits both the results of Mendelssohn and White above 1°K and the present results obtained on the two separate dates shown.

DISCUSSION

It seems clear that there is a real rise in flow rate of 25 to 30% at about 0.3°K over that at the minimum near 1°K. Now the flow rate is given by $(\rho_s/\rho)v_c d$, where (ρ_s/ρ) is the superfluid fraction, v_c the average critical velocity, and d the film thickness. Above 1°K the variation in flow rate is readily explained by that in (ρ_s/ρ), but since this fraction is practically unity at 1°K any further increase in flow rate could only be explained by a variation in the product $v_c d$. A variation of d seems probable in the light of data on measurement of film thickness.[10,11]

It is well established, however, that the behavior of bulk liquid helium as regards specific heat, thermal conductivity, and second sound shows a marked change at or below 0.6°K. This change in behavior has been explained in terms of a Debye-like structure of the liquid in Landau's theory. The present investigation confirms the change in the rate of film flow also in this same region, but this phenomenon lacks theoretical explanation as yet. It is worth noting that the second sound velocity curve and the film flow rate curve are similar in general shape, although the fractional increase below 1°K is different in the two cases. Further measurements on the film flow rate below 0.2°K should therefore prove interesting in disclosing how far the similarity between the two curves persists.

ACKNOWLEDGMENT

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[10] E. J. Burge and L. C. Jackson, Proc. Phys. Soc. (London) **A205**, 270 (1951).
[11] R. Bowers, Phil. Mag. 44, 1309 (1953).