On the Film Transfer Rate in Helium *II*

ROBERT T. WEBBER, HENRY A. FAIRBANK, AND C. T. LANE
Sloane Physics Laboratory, Yale University, New Haven, Connecticut*

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In view of the wide disagreement between the two existing determinations of the flow rate of the Rollin film under a gravitational potential difference we have re-examined the matter experimentally. Our results are in substantial agreement with the earlier work of Daunt and Mendelssohn.

INTRODUCTION

Any solid surface in contact with liquid helium *II* rapidly becomes coated with a liquid film of the order of 100 atom layers which is mobile. It is believed that this film of superfluid helium moves from points of lower temperature to places at higher temperature (up to the λ-point) and also, in the absence of a temperature gradient, from places of higher to lower gravitational potential even if this requires that the film surmount a potential barrier. Thus an impermeable test-tube or beaker with its closed end immersed in helium *II* will either fill or empty via this surface film depending on whether the liquid level in the tube is initially below or above the level of the outer bath, and this process continues until the gravitational potential difference vanishes.

The first systematic study of this latter effect was made by Daunt and Mendelssohn and reported[1] in two papers in 1939. Daunt and Mendelssohn found that the laws governing this type of liquid flow were of surprising simplicity but at the same time highly non-classical. The rate of emptying (or filling) of the beaker depended solely on:

(1) the temperature, being zero at the λ-point and increasing with decreasing temperature, and
(2) the transfer between any two levels at a given temperature being limited by the least periphery in the connecting surface *above* the higher level.

No significant dependence of the transfer rate on the gravitational potential difference of the two levels was observed and, accordingly, no classical syphon mechanism can be involved.

In a more recent communication[2] certain phases of the Daunt-Mendelssohn experiment have been repeated by Atkins but with results which are widely different. These differences were twofold:

(1) The transfer rate (emptying and filling), at a given temperature, was found to be a function of the height of the beaker rim above the higher of the two levels ("height" of the film).
(2) Even with a comparable film height, the transfer rate found by Atkins was four or five times greater than that found by Daunt and Mendelssohn.

* Assisted by the ONR.
[1] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. **A170**, 423 (1939); Proc. Roy. Soc. **A170**, 439 (1939).
[2] K. R. Atkins, Nature **161**, 925 (1948).

In view of these disagreements between the only two existing experiments on this subject we felt that a third investigation would be in order.

NEW MEASUREMENTS

Our first approach was to make use of a glass beaker with a vacuum jacket (Dewar flask). The inner tube of this was a glass capillary (diameter ~1 mm) the closed end of which was of Kovar metal. Provision was made such that the tip of the outer jacket could be broken under liquid helium. We could, therefore, in the same experiment, observe the transfer effect with liquid in the tube which could either be thermally isolated from or else be in thermal contact with the outer bath. In this way we sought to repeat in a single run the two arrangements used by Daunt and Mendelssohn. We jacketed the helium Dewar with liquid nitrogen in the usual way and used a low power fluorescent light source with water shield for visual observation but, apart from this, took no other precautions to shield the test beaker from thermal radiation of which that coming from the top of the helium Dewar flask was the most important.

The results of the measurements made with this equipment agreed in order of magnitude with Daunt and Mendelssohn and not at all with Atkins. In particular, no dependence of the transfer rate on the height of the film (as reported by Atkins) was found for either type beaker for either an emptying or a filling process at the single temperature at which observations were taken (1.5°K). However, in the case of a beaker in

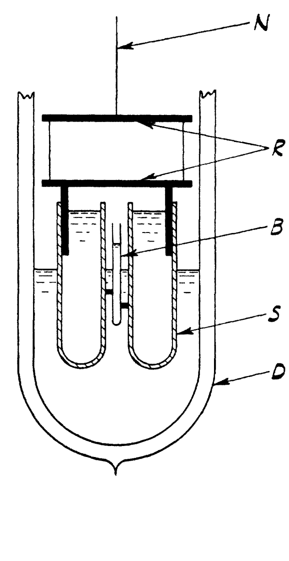

FIG. 1. Schematic drawing of the apparatus.

thermal contact with the outer bath, although the emptying rate was approximately double the filling rate the average value was in fair agreement with the Daunt-Mendelssohn rate at 1.5°K. In addition, the emptying rate for the thermally isolated beaker was found to be non-reproducible although the reproducibility for the other type beaker was excellent.

Examination of these data suggested that temperature gradients in the helium bath or in the vapor above the bath caused by a lack of adequate shielding against external thermal radiation might be responsible for these discrepancies and we therefore modified our apparatus. Figure 1 is a schematic drawing of the apparatus finally evolved.

The test beaker B consisting of a thin-walled glass capillary (0.74 mm diameter) was attached as shown in

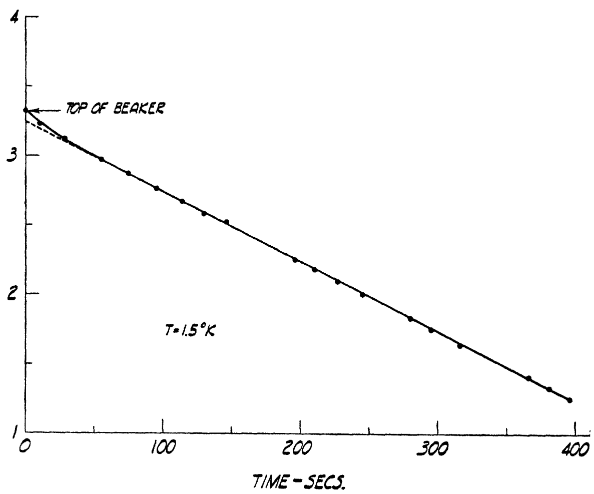

FIG. 2. The height of the liquid surface inside the beaker as a function of time during an emptying process at 1.5°K.

TABLE I. The transfer rate for various film heights H for a filling process at 1.90°K.

Rate cm³/sec. cm	H cm
5.3×10^{-5}	1.59
5.5	1.05
5.8	0.69
5.9	0.33
5.8	0.22

TABLE II. Film transfer rate (cm³/sec. cm) at various temperatures.

Temperature	Emptying	Filling	Average
2.10°K	2.3×10^{-5}	2.6×10^{-5}	2.4×10^{-5}
2.00	4.5	4.5	4.5
1.90	5.5	5.7	5.6
1.80	6.9	6.9	6.9
1.70	7.8	6.7	7.2
1.60	8.2	7.3	7.8
1.50	9.3	7.7	8.5
1.40	10.3	8.0	9.1

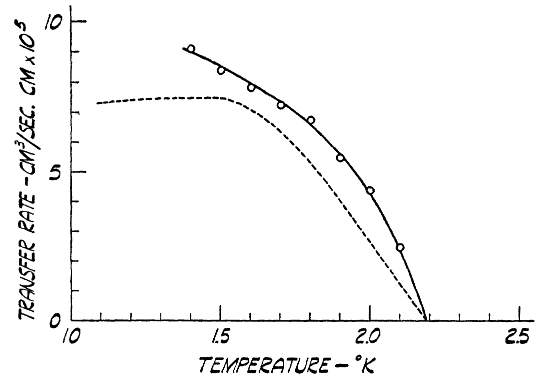

FIG. 3. The transfer rate as a function of temperature. The full curve with circles is the present experiment and the broken curve gives Daunt and Mendelssohn's results (smoothed values, reference 1).

the inner tube of an annular glass bucket S. Above the latter were two aluminum disks R, the lower of which had two aluminum prongs extending some distance into S as shown. R, B, and S formed one rigid unit and could be raised or lowered in the helium Dewar D by means of a nylon thread N attached to a small vacuum-tight winch at the top of the cryostat. Accordingly, both B and S could be filled with liquid helium from the bath in D, and S and R formed very excellent shields for B against radiation coming from the sides or top of the flask D. The latter was fully silvered except for a pair of narrow longitudinal slits and was jacketed by a similar flask containing liquid nitrogen. The liquid level in B was observed with a cathetometer and for illumination we used a low power fluorescent lamp with a filter[3] consisting of a weak aqueous solution of $CuCl_2$.

RESULTS

The experimental procedure consisted merely in observing the fall (or rise) of the liquid surface in B as a function of time at various bath temperatures below the λ-point. This was invariably a linear function except in the initial stages of an emptying process when the liquid in B was very near the rim of the tube, an effect also observed by Daunt and Mendelssohn.[1] Figure 2 shows this—at time zero the liquid in B is flush with the top of the tube. Daunt and Mendelssohn suggested that this "end effect" might be due to a thicker surface film when the inside level was very near the rim of the beaker. It is also possible that a higher evaporation rate of the liquid in the beaker at this point could be responsible.

Within our experimental error we find no such dependence of the rate on the height of the film as reported by Atkins.[2] In Table I, for instance, is a series of measured filling rates for various values of the height

[3] John Strong, *Procedures in Experimental Physics* (Prentice-Hall, Inc., New York, 1938), p. 369.

of the beaker rim (H) above the level of the outer bath at 1.90°K. The time rate of rise of the liquid surface in the beaker was, in all cases, found to be strictly linear with no "end effect" such as was found in certain cases in an emptying process and illustrated in Fig. 2. We note, however, that this end effect of increased transfer rate on emptying always occurred when the inside level was not more than about 2 mm from the top of the beaker. The smallest observed value of H for a filling process (see Table I) was greater than 2 mm and it is possible that for smaller H the end effect would be found for the filling process also. In any event, however, these results completely disagree with Atkins.

In general, at a given temperature, the emptying rate was somewhat larger than the filling rate. We attribute this to evaporation from B, since the latter will tend to increase the emptying rate and decrease the filling rate.** On this view then, an average of the two rates should be the correct one.

A complete summary of our experimental data is given in Table II and in Fig. 3 is a plot of the transfer rate *versus* the temperature. The latter was computed from the vapor pressure of the bath using the Leiden 1932 scale. For the sake of comparison we have also plotted the Daunt-Mendelssohn data (smoothed values) in Fig. 3 and the agreement between the two sets of data is seen to be reasonably satisfactory.

** In our first experiment, it will be recalled, our emptying rate was double the filling rate indicating much poorer thermal isolation in the first apparatus.

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The Angular Distribution of the Photo-Neutrons from Beryllium

B. Hamermesh, M. Hamermesh, and A. Wattenberg
Argonne National Laboratory, Chicago, Illinois
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The angular distribution of the photo-neutrons from beryllium has been studied for γ-ray energies of 1.70, 1.81, and 2.76 Mev. The distribution was found to be spherically symmetrical for the 1.70- and 1.81-Mev γ-rays. The 2.76-Mev gamma-ray yields a distribution of the form $a+b\sin^2\theta$ with $a/b=1.2$.

INTRODUCTION

The threshold for the photo-disintegration of beryllium is supposed to be 1.63 Mev. Experiments[1] indicate that the (γ,n) cross section of beryllium increases to a maximum in the neighborhood of 1.7 Mev, decreases to a minimum around 2.1 Mev, and is increasing once again at 2.7 Mev. These maxima in the cross section may be explained in a naïve way by saying that the first maximum is caused by the emission of S neutrons, whereas the second maximum is caused by the emission of neutrons of higher angular momentum. One would therefore expect that the angular distribution of the photo-neutrons should be spherically symmetric just above the threshold and then have an asymmetrical component which increases with increasing energy.

Previous studies of the angular distribution of the photo-neutrons from beryllium were carried out by Chadwick and Goldhaber[2] who used γ-rays from a radon source and found a spherically symmetrical distribution. Goloborodko and Rosenkewich[3] used γ-rays from a radium source and came to a similar conclusion. In view of the complexity of the γ-rays from the radium family, it was felt more valuable information might be obtained with monoenergetic γ-ray sources.

APPARATUS

The apparatus shown schematically in Fig. 1 was mounted eight feet above the floor in a large room.

The detector was a BF_3 pulse ion chamber embedded in a paraffin cylinder 20-cm in diameter and 20-cm long. The chamber was filled to a pressure of one atmosphere with enriched BF_3. The amplifier bias was chosen to discriminate between pulses caused by gamma-rays and those caused by neutrons.

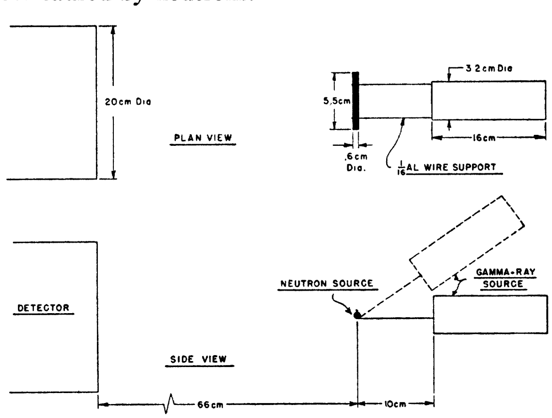

Fig. 1. A schematic diagram of apparatus.

[1] Russell, Sachs, Wattenberg, and Fields, Phys. Rev. **73**, 545 (1948).
[2] J. Chadwick and M. Goldhaber, Proc. Royal Soc. **A151**, 479 (1935).
[3] Goloborodko and Rosenkewich, Physik. Zeits. Sowjetunion **11**, 78 (1937).