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Rollin Film Rates in Liquid Helium

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Quantitative measurements have been made on the flow of the Rollin film out of a cylindrical vessel containing liquid helium. The range of temperature studied extends from 1.34 K to the λ-point. It is found that the film transfer rate is somewhat greater than that observed for isothermal flow under a gravitational potential difference. Evidence is presented tending to show that the film can evaporate at temperatures near those of the parent liquid.

INTRODUCTION

IN 1936 Rollin[1] suggested that the observed high evaporation rate from vessels containing liquid helium II was due to a thin surface layer of liquid helium on the walls of the container. In subsequent experiments Rollin and Simon[2] established this high evaporation rate as due to an actual transport of the liquid, via the surface film, up the wall to the higher temperature region where evaporation of the film occurs. This type of film transport, referred to henceforth as Type A, is illustrated schematically in Fig. 1.

A similar transport of liquid by means of the film occurs from regions of higher to lower gravitational potential in the absence of any measurable temperature gradient. We shall call this case Type B. Thus in Fig. 1, the liquid level in the two impermeable beakers, partially immersed in liquid helium II, will assume the level of the outside bath due to this film transport process. This type of film transport was first studied systematically by Daunt and Mendelssohn[3] in 1939. The mass rate of flow of the film was found to be independent of the gravitational potential difference between the levels, and a function only of the temperature of the liquid and the minimum periphery in the connecting surface above the higher level. Recently Atkins,[4] using similar techniques, has reported experimental values of this film transport velocity several times larger than those of Daunt and Mendelssohn. In view of this wide disagreement, Webber and the authors[5] re-examined this case experimentally and found results in substantial agreement with the earlier work of Daunt and Mendelssohn. Bowers and Mendelssohn,[6] in a brief note recently received, present evidence that the high creep velocities such as those observed by Atkins are due to adsorbed or frozen air on the walls of the vessel over which the film creeps.

In view of the above discrepancies in experimental results in the B type of creeping film (Fig. 1) it seemed to us highly desirable to obtain more information about the behavior of the film under conditions represented in A (Fig. 1). The early work of Rollin and Simon[2] established the general character of the creeping film but did not give quantitative values of film transport velocity.

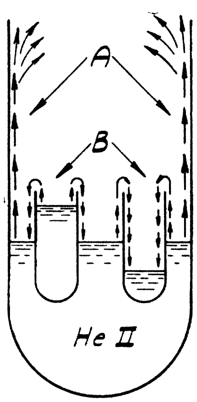

FIG. 1. A schematic representation of the two types of film transport phenomena.

EXPERIMENTAL PROCEDURE

The apparatus is shown schematically in Fig. 2. A 1.7-mm diameter U tube is immersed in a bath of liquid helium connected to a vacuum pump and manometer for control and measurement of the temperature. A

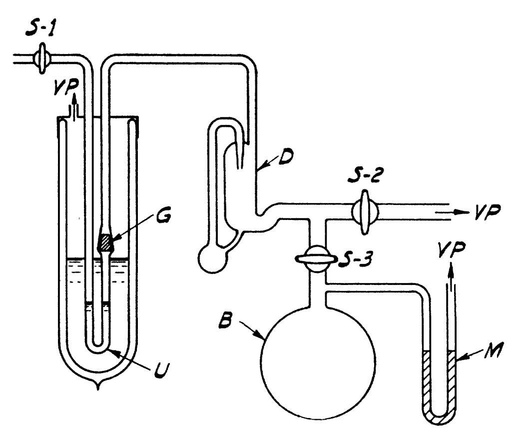

FIG. 2. A schematic drawing of the apparatus used in the present experiment.

* Assisted by the ONR.
[1] B. V. Rollin, Proc. VII Int. Congress of Refrigeration 1, 187 (1936).
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[3] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. A170, 423, 439 (1939).
[4] K. R. Atkins, Nature 161, 925 (1948).
[5] Webber, Fairbank, and Lane, Phys. Rev. 76, 609 (1949).
[6] R. Bowers and K. Mendelssohn, Nature 163, 870 (1949).

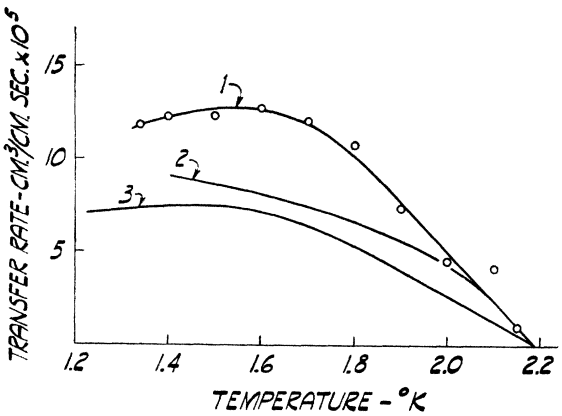

FIG. 3. The film transfer rate as a function of temperature. Curve 1 is the present experiment (Type A creep). Curves 2 and 3 give the results of Webber, Fairbank, and Lane and of Daunt and Mendelssohn, respectively, for gravitational film transport (Type B creep).

small amount of helium is condensed in the U tube via stopcock S-1. The tightly fitting ground glass plug G isolates the vapor space above the liquid in the tube from the rest of the system but the gap is large enough to allow the creeping film to pass the plug unhindered. Thus it is possible to pump off the gas from the evaporating film above the plug G with the mercury diffusion pump D without withdrawing any appreciable amount of the vapor from the vapor space below G. Hence the mass rate of flow of gas through the diffusion pump equals the mass rate of flow of the creeping film. This rate was measured by closing stopcock S-2 in the fore-pump line and measuring the rate of increase of pressure in the previously evacuated 2-liter bulb B by determining the time rate of fall of the oil manometer M. A simple calculation converts the rate of pressure increase into mass rate of flow from which the film transport velocity may then be found.

By measuring the rate of flow of vapor through the ground plug just above the λ-point, and using the equation for Poiseuille viscous flow through an annular gap given by Lamb,[7] the mean width of the channel was estimated to be of the order of a few microns, which is of the order of 100 times the film thickness as determined by Daunt and Mendelssohn.[3] The flow rate of the vapor past the plug was negligibly small compared to that of the film.

RESULTS

Film transfer rates were obtained at temperatures from 1.34°K to the λ-point. The average values of the measurements taken at each temperature are given in Table I, and represented graphically in Fig. 3, curve 1. Following Daunt and Mendelssohn we have given the creep velocities in the units cm³ of liquid flowing per cm of periphery per sec. For comparison purposes the transfer rate curves (smoothed values) for the gravitational case (B in Fig. 1) obtained by Daunt and Mendelssohn[3] and by Webber, Fairbank, and Lane[5] are included (curves 2 and 3).

In performing these measurements the following variations were made:

(a) At the start of the measurements the liquid level of the outside bath was even with the top of the ground plug G and about 13 cm above the liquid level inside the U tube. In the course of the experiment this outside level gradually dropped until it was even with the inside level. Within the accuracy of the measurements the transfer rates obtained at the same temperature under these changing conditions were identical. This would suggest that the transfer rate for a given surface depends primarily, and perhaps uniquely, on the temperature of the bath, which, as discussed below, is probably also the temperature of the film for a tube of this geometry.

TABLE I. Film transfer rate *versus* temperature (Type A creep).

Temperature (°K)	Film transfer rate (Cm³/cm sec.)
2.15	0.96×10^{-5}
2.1	4.1
2.0	4.5
1.9	7.3
1.8	10.7
1.7	12.0
1.6	12.7
1.5	12.3
1.4	12.3
1.34	11.8

(b) The previous experiments on Type A creep have given no clear indication as to the temperature of the film where final evaporation occurs. (See references 2 and 3.) In the present experiment we wound a small electrical heating coil on the outside of the U tube just below the glass plug and some distance above the surface of the liquid in this tube. With the bath temperature set at 1.5°K, we supplied various amounts of heat to this coil. With no heat applied the creep rate was 12.3×10^{-5} cm³/cm sec., but with 0.22 milliwatt the creep rate was found to decrease to 6.5×10^{-5} cm³/cm sec. Finally at 0.4-milliwatt heat input the creep rate was observed to vanish.

The plug permits only film, as such, to pass through it; vapor created by evaporating the film, or in any other way, cannot pass the plug. Hence the decreased creep rate with some heat supplied indicates that, while some evaporation has occurred, the remaining film continues to creep up the walls past the source of heat. This could happen only if the evaporation occurred below the λ-point and suggests that the film evaporates at a temperature near that of the liquid, i.e., the vapor pressure of the film is not drastically different from that of the parent liquid.

Returning to Fig. 3, there is seen to be a fair agreement between the film transfer velocities measured

[7] Horace Lamb, *Hydrodynamics* (Cambridge University Press, 1906), p. 545.

under the conditions A and B. The simplest conclusion that might be drawn would be that these cases are not fundamentally different and that the limiting film transfer velocity in all cases depends, for a given surface,

(1) on the temperature
(2) on the minimum periphery in the connecting surface above the higher level.

The suggestion of Bowers and Mendelssohn that adsorbed air on the surface is responsible for anomalously high transfer rates would not appear inconsistent with this picture.

Finally, we are grateful to Dr. C. A. Reynolds and Mr. E. A. Lynton for their assistance with the experiment.

Note added in proof.—Professor F. Simon, at the recent Conference on Low Temperatures at M.I.T., has kindly drawn our attention to the fact that an estimate of the Type A film transfer rate may be computed from data given in reference (2). These measurements extend down to about 1.6°K and give a transfer rate of approximately 8×10^{-5} cm^3/cm·sec. at this temperature, which is somewhat less than the value observed by us above.

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Collision Theories of Pressure Broadening of Spectral Lines

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It is shown that in the calculation of absorption in the Lorentz collision theory, it is essential to include the work done impulsively by the electric field during the sudden changes of position at collision. This work was implicitly included in the theory of Van Vleck and Weisskopf, but these authors did not give the breakdown into work done between and at collision. It is verified that the shapes of spectral lines for a classical harmonic oscillator and also a Debye slow rotator are the same in absorption and spontaneous emission, provided the energy density obeys the Rayleigh-Jeans law. The usual proofs of equilibrium simply establish equality of the integrated absorption and emission, without examining the detailed balancing at individual frequencies, not necessarily near resonance.

A COLLISION or impact theory of the width of spectral lines is one which conceives of the frequency distribution within a line as resulting from interruptions of the radiative process by collisions with molecules. The exact form of the resulting line width depends in a rather critical way on the detailed assumptions that are made about the nature of these interruptions, and there seems to be some confusion both as to concepts and terminology concerning the subject of impact broadening. The present paper attempts to clarify this situation.

A. LORENTZ THEORY OF SPONTANEOUS RADIATION

As it is usually understood, the Lorentz[1] formula for line breadths results from simple Fourier analysis of a finite wave train radiated by a harmonically moving charge. Let the radiative frequency be ω, and suppose that the radiation goes on for a time θ. Then, if the amplitude is x_0, the Fourier analysis of the displacement is

$$x(t)=\frac{1}{(2\pi)^{\frac{1}{2}}}\int_{-\infty}^{\infty}x(\omega')e^{i\omega' t}d\omega',$$

$$x(\omega')=\frac{1}{(2\pi)^{\frac{1}{2}}}\int_{0}^{\theta}x_0\cos(\omega\lambda+\phi)e^{-i\omega'\lambda}d\lambda.$$

When $|x(\omega')|^2$ is averaged over a random distribution in the arbitrary phase constant ϕ, the result is

$$|x(\omega')|^2=\frac{x_0^2}{4\pi}\left[\frac{1-\cos(\omega'-\omega)\theta}{(\omega-\omega')^2}+\frac{1-\cos(\omega'+\omega)\theta}{(\omega+\omega')^2}\right].$$

This expression must be integrated over all collision times θ with a weighting function $ae^{-a\theta}$, where a is the mean collision frequency. One thus obtains

$$|x(\omega')|^2=\frac{x_0^2}{4\pi}\left[\frac{1}{a^2+(\omega-\omega')^2}+\frac{1}{a^2+(\omega+\omega')^2}\right].$$

According to classical mechanics, the power radiated by a charge e oscillating in one dimension is

* Assisted by the ONR.
[1] H. A. Lorentz, Proc. Amst. Akad. Sci. 8, 591 (1906).