EFFECT OF TURBULENCE ON RECOMBINATION LUMINESCENCE IN He II*

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In a previous communication,[1] we reported observation of a decrease in the intensity of alpha-particle-induced scintillations in liquid helium as the temperature was reduced below the λ point, and attributed the phenomenon to the superfluidity of He II. The effect has been observed by other workers,[2,3] and in further experiments in this laboratory it has been demonstrated[4] (by observing the inhibition of scintillation by a high electric field) that an appreciable fraction of the intensity derives from recombination luminescence.

In a further effort to achieve an understanding of these phenomena, we have introduced a heat-current density in the region of the alpha tracks and have observed its influence on both the scintillation intensity and the current of ions extracted from the alpha tracks by a high electric field.

The results indicate that in the He II region there is no change in either scintillation intensity or ion current at low heat-current densities, but that striking discontinuities occur when the heat current reaches a certain critical value. Moreover, a significant hysteresis effect is observed as the heat current is cycled above and below the critical value.

In the experimental arrangement, shown in Fig. 1, a small quantity of Po^{210} was electroplated onto a 1-cm segment of Nichrome wire of 0.09 mm diameter (approximately one-third the range of the emitted alpha particles). This wire was located on the axis of a cylindrical, gold-plated grid of 1 cm diameter, this assembly being near the center of a scintillation chamber of 2.5 cm diameter. A radial heat current could be produced by passing current through the Nichrome wire, and an electric field could be produced in the region of the alpha tracks by applying voltage between the wire and the grid. Provision was made, also, for measurement of the ion current collected at the grid. With 300 volts applied between wire and grid the field strength varied from 14.2 kV/cm at the surface of the wire to 2.5 kV/cm at the end of a radially directed alpha track. Reversal of the field produced no effect in the experiments to be described.

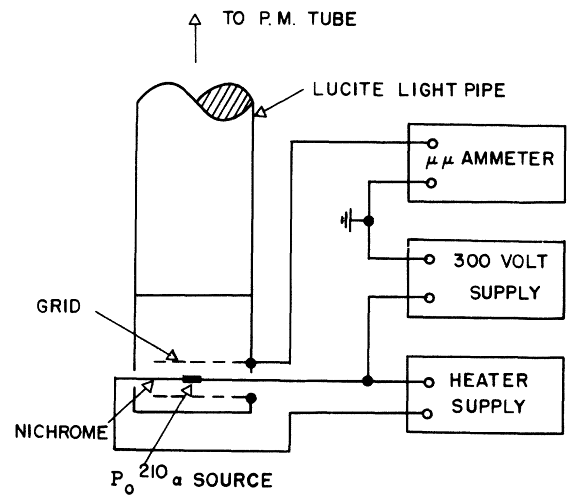

FIG. 1. The experimental arrangement, showing the Po^{210} source, wire, and grid in the scintillation chamber.

The inside of the scintillation chamber was coated with a wavelength shifter (POPOP), and the chamber was attached to the lower end of a 17-in. Lucite light pipe which was coupled to an RCA 6810A photomultiplier at the upper end. In the course of the experiment, the scintillation chamber and source remained immersed in liquid helium. Four 1/16-in. holes, two at the top and two at the bottom of the chamber, served to admit liquid and release accumulated vapor. The temperature of the fluid was monitored by a carbon resistor located $\frac{1}{2}$ in. below the scintillation chamber. Pulse-height spectra were recorded with a multichannel analyzer, and the observed peaks were sufficiently well defined (20% width at half maximum) to allow their location to within one-half channel. The peak position (proportional to scintillation intensity or photons per alpha) was observed both with and without the electric field for various values of the heat-current density (evaluated at the surface of the Nichrome wire). The liquid helium was cycled above the lambda point between each measurement of W_c in order to minimize possible persistence effects.

The results at 1.46°K with zero electric field, shown in Fig. 2(a), indicate a constant scintillation intensity up to a critical value of heat

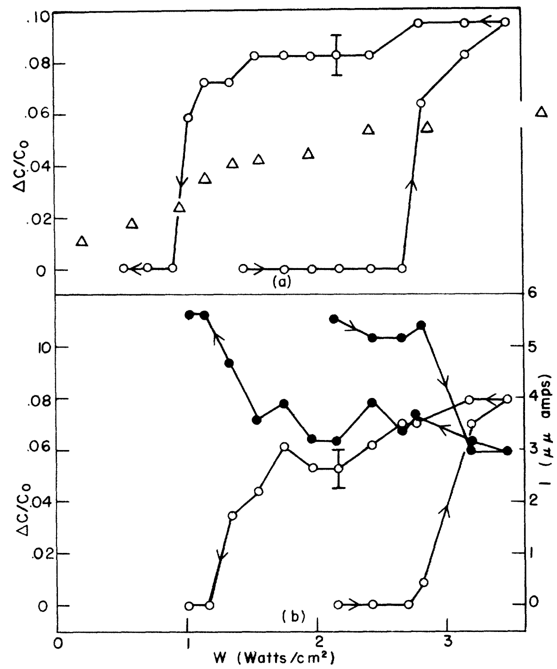

FIG. 2. (a) The fractional increase in scintillation intensity ($\Delta C/C_0$) versus heat current at 1.46°K (○) and 4.2°K (△). (b) The fractional increase in scintillation intensity (○, left scale) versus heat current and the ion current (●, right scale) versus heat current, both at 1.46°K.

current where a sharp increase occurs. Furthermore, as the heat current is reduced from above the critical value, a significant hysteresis effect is observed. On the other hand, at 4.2°K, the intensity varies smoothly with increasing heat current.

In an effort to determine the mechanism responsible for the sudden increase in luminescence at the critical heat current, an electric field has been applied (as described above). With 300 volts applied between the source and the grid, the scintillation intensity and the ion current extracted by the field were observed simultaneously as the radial heat current was increased.

The results at 1.46°K, shown in Fig. 2(b), indicate that a sharp drop in ion current occurs at the same critical heat current at which the scintillation intensity increases. We interpret this as an increase in the rate of ionic recombination in the region of the alpha tracks resulting in an enhancement of recombination luminescence.

The appearance of the hysteresis effect and the absence of a critical point in He I suggest strongly that the observed effect is due to the onset of supercritical heat conductivity involving some form of turbulence, a phenomenon observed previously in experiments on thermal conductivity in narrow channels[5] and not yet understood.

In order to investigate this possibility further, we have measured W_c, the critical heat current, as a function of temperature. The results (Fig. 3) show that W_c remains roughly constant as the temperature increases from 1.39°K to within about a tenth of a degree of T_λ, where it begins to fall rapidly toward zero.

Two particularly interesting features of these data are that (1) the observed values of W_c are at least an order of magnitude higher than those observed in narrow channels, and (2) W_c was found to depend on the level of liquid helium above the scintillation chamber and alpha source.

We believe that the higher critical currents observed are due to the radial heat current employed (as opposed to the linear currents used in experiments performed in channels). Whereas values of W_c were evaluated at the surface

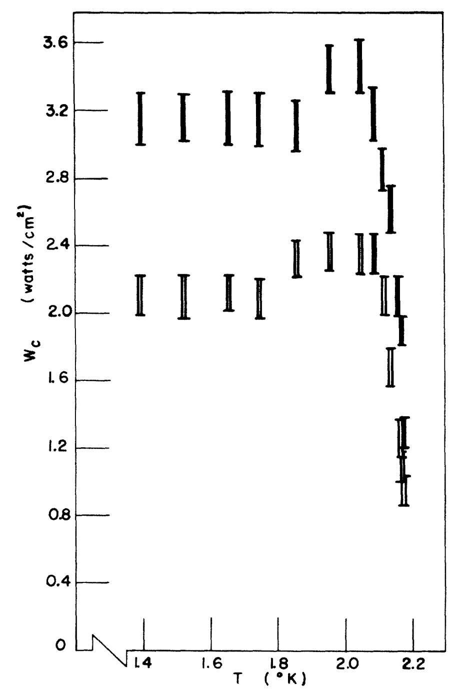

FIG. 3. The critical heat current, W_c, versus temperature for two levels of liquid helium, 7 cm above the alpha source (solid bars) and 3.5 cm above the alpha source (open bars). The bars are not error bars in the statistical sense; rather they define the absolute limits between which W_c must lie according to our measurements.

of the wire, it is clear that some finite volume of the surrounding fluid (where the current is less) must be involved in the onset of turbulence. It is possible that the absence of wall effects may also be responsible for the large values of the critical current.

With regard to the dependence of the critical current on the submersion depth of the alpha source, we have been unable to account for this as instrumental or persisting turbulent effects. No dependence of scintillation intensity nor collected ion current on submersion depth has been observed, and no change in resistance of electrical leads has been found for different liquid levels.

The pressure increase at the greater depth (approximately 0.3 mm Hg) produces a density increase of only about 10^{-6} gm/cm^3, which appears too small to cause appreciable change in fluid flow phenomena. Further experiments are being undertaken to determine whether the submersion depth in some way affects the rate of heat flow from the scintillation chamber (and, hence, the heat current distribution near the wire), or whether some more fundamental phenomenon may be involved.

The most significant result reported above is the increase in recombination luminescence at the critical current. This constitutes a new phenomenon accompanying the onset of a supercritical phase of heat conduction in He II.

A possible mechanism appears to be a trapping of ions in vortex lines which could cause them to be retained longer in the region of high ion density where recombination could take place. This suggestion is supported by the observation[6] that the mobility of negative ions decreases in the supercritical region and, also, by the recent observation[7] of the trapping of negative ions (presumably in vortex lines) in rotating He II. On the other hand, the effect may be the result of a reduction of ionic mobility in the presence of classical turbulence in the normal component.

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[1]Frank E. Moss and Frank L. Hereford, Phys. Rev. Letters 11, 63 (1963).

[2]J. R. Kane, R. T. Siegel, and A. Suzuki, Phys. Letters 6, 256 (1963).

[3]Joshua Jortner, Lothar Meyer, Stuart A. Rice, and E. G. Wilson, Phys. Rev. Letters 12, 415 (1964).

[4]Frank E. Moss and Frank L. Hereford, Proceedings of the Ninth International Conference on Low Temperature Physics, Columbus, Ohio, 1964 (to be published), paper CB16; a detailed paper is in preparation.

[5]W. F. Vinen, Proc. Roy. Soc. (London) A240, 114 (1957); C. E. Chase, Phys. Rev. 127, 361 (1962). The latter paper lists references to previous work.

[6]G. Careri, F. Scaramuzzi, and J. O. Thomson, Nuovo Cimento 18, 957 (1960).

[7]R. L. Douglass, Phys. Rev. Letters 13, 791 (1964).

GYROSCOPIC DETECTION OF PERSISTENT FLOW OF SUPERFLUID LIQUID HELIUM

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Since the discovery of superfluidity in liquid helium, it has been natural to wonder whether the superfluid flow can take place with identically zero dissipation. A particularly sensitive way of detecting any dissipation which may be present is to set up coasting flow around a closed path and to measure the rate at which the flow diminishes. A number of investigators have seen evidence that such flow may persist for minutes and even for hours.[1-6] In the present experiment, long-lived persistent currents have been observed and studied by means of gyroscopic effects associated with circuital flow. The experiment is similar to one recently reported by Reppy.[7] The gyroscopic method permits repeated direct measurements of the angular momentum of the flow to be made without destruction of the flow.

The apparatus is shown in Fig. 1. The circulating flow takes place in a thin-walled glass sphere, 3 cm in diameter, which is immersed in liquid helium. In recent work the sphere has been packed with a silica powder having particles ≈1 μ in size,[8] although a coarser powder having particles ≈20 μ in size was used earlier with success. The flow takes place