Phenomena Resulting from the Heating of Small Wires in He II*

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In a previous experiment the scintillation of He II was found to be enhanced at certain critical values of heat flux introduced into the fluid by a small heated wire. Results are presented here which demonstrate that this phenomenon is related to the formation of some form of visible turbulence or, alternatively, of a vapor bubble around the wire, depending on the depth of the wire in the He II bath. Results are presented also on the dependence of the critical heat current on wire depth and on temperature.

INTRODUCTION

UNUSUAL phenomena associated with the transport of heat in He II have been the subject of many investigations since the discovery of its superfluid properties. In a previous paper,[1] we have reported observation of sharp increases in the intensity of α-particle-produced scintillations of He II at certain critical values of heat flux in the fluid.

The experiments described below were undertaken to determine whether this observed enhancement of the scintillation intensity is related to the formation of vapor bubbles around heated objects in He II, as observed previously by several investigators.[2–6] The results indicate clearly that this is the case. Furthermore, they demonstrate the dependence of the critical value of heat flux on the depth of the heat source in the He II bath, an effect observed in the earlier studies, but heretofore not studied in detail.

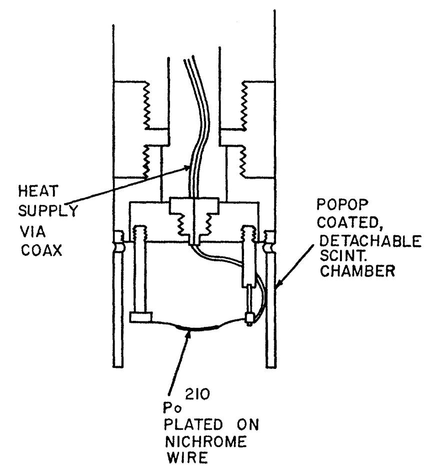

FIG. 1. The detachable scintillation chamber showing the Po^{210} α source on the heater wire.

EXPERIMENTAL ARRANGEMENT AND RESULTS

The source of heat was a 1.25-cm segment of 90-μ-diam Nichrome wire on which a Po^{210} α source (approximately 10^4 disintegrations/sec) was deposited. Flow of electric current through the wire provided a surface current of heat into the helium bath. The wire and supporting assembly shown in Fig. 1 could be used alternately in a glass Dewar (with provision for microscopic observation of the region near the wire), or in a stainless steel Dewar (with provision for observation of the He II scintillation as shown in Fig. 2).

The microscopic observations indicated a sudden onset of turbulence near the surface of the wire or the creation of a bubble at certain critical values of surface heat current W_c (I^2R divided by the surface area). The critical heat current (and whether turbulence or a

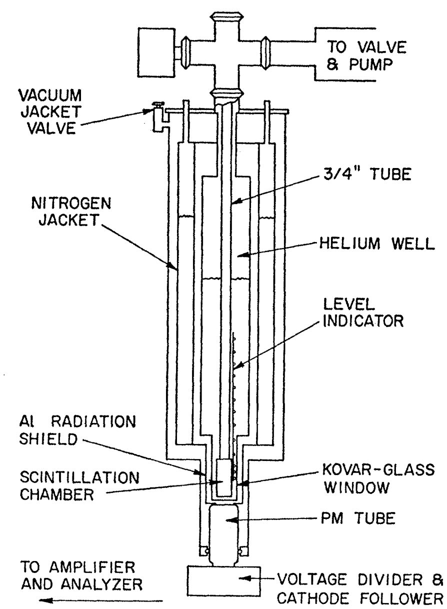

FIG. 2. Schematic drawing of the stainless steel Dewar used for scintillation measurements.

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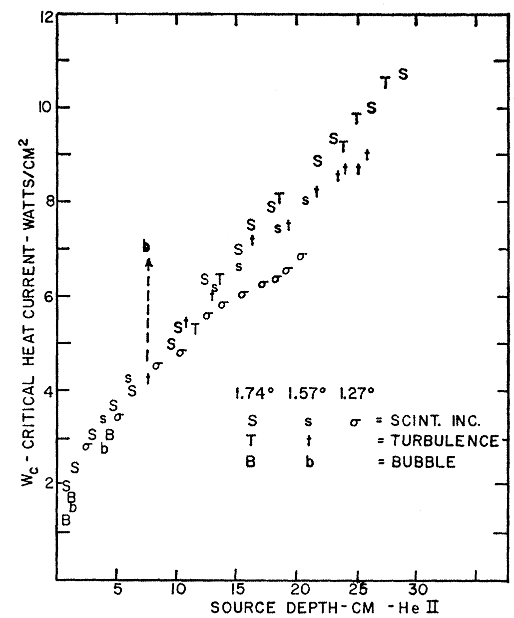

FIG. 3. The critical heat current versus source depth. S, s, and σ denote increase in scintillation intensity; T and t the onset of visible turbulence; and B and b the formation of a bubble.

bubble appeared) depended strongly on the depth of the wire below the surface of the bath as indicated in Fig. 3. In one instance, increased heating after the establishment of turbulence led to the formation of a bubble.

Following these observations, the source wire was surrounded by a cylindrical aluminum scintillation chamber, coated with a wavelength shifter, P-bis (2, 5-phenyloxazolyl) benzene (POPOP), and the scintillation intensity was measured with a photomultiplier and a multichannel pulse analyzer. Sharp increases in intensity of about 5% (in the turbulence region) and 9% (in the bubble region) were observed at critical heat currents which were in agreement with those obtained through the microscopic observations (Fig. 3).

The temperature dependence of W_c was studied, also, by observation of the increase in scintillation intensity. These measurements at a variety of source depths up to 20 cm and at temperatures between 1.4 and 2.1°K yielded the results shown in Figs. 4 and 5. Since our previous results[1] showed that W_c drops sharply toward zero between 2.1 and 2.18°K, this temperature region was not studied further. At depths below about 5 cm, where bubble formation occurs prior to the onset of visible turbulence, the data indicate that a "hysteresis" effect exists. In other words, once a bubble becomes established at a given value of W_c, the heat current must be reduced below this value to collapse the bubble.

The "bubble" and "turbulence" phenomena differed further in that a clearly audible hiss always accompanied the onset of turbulence, but not the creation of the bubble. This sound has been detected previously by Bussieres[6] who has made an inconclusive effort to analyze it.

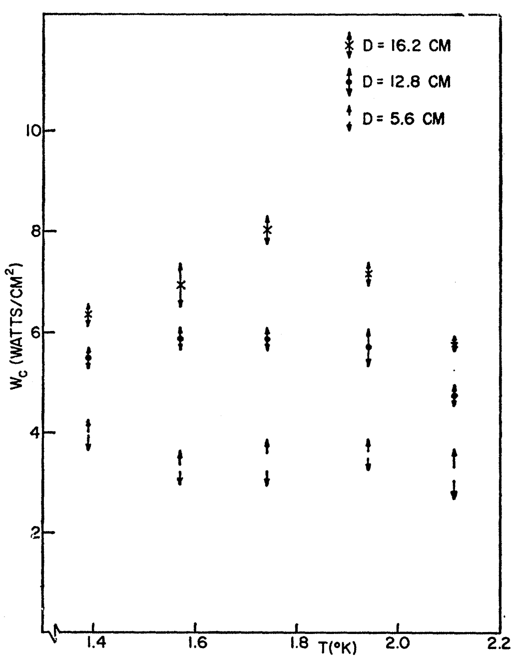

FIG 4. The critical heat current versus temperature at various source depths D. Arrows directed up denote the onset of turbulence or creation of a bubble, and arrows down the cessation of turbulence or collapse of a bubble.

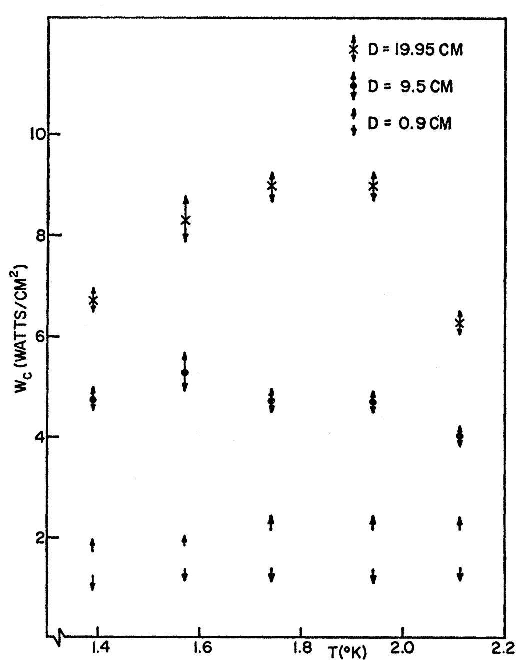

FIG. 5. The critical heat current versus temperature at various source depths D. Arrows directed up denote the onset of turbulence or creation of a bubble, and arrows down the cessation of turbulence or collapse of a bubble.

DISCUSSION

It should be pointed out first that the values of W_c are roughly two orders of magnitude greater than those associated with the onset of vorticity in the superfluid.[7] It was suggested by some of the authors previously[1] that the enhancement of scintillation intensity in the supercritical region might be related to vorticity. However, the violence of the phenomena apparent in the visual observations reported here and the high values of W_c indicate that this suggestion holds no promise.

The visual observations, however, do provide an interpretation of at least part of the increase in scintillation intensity at small source depths, where a bubble is formed at the critical heat current. It must be recognized first that the primary He radiation lies below 1000 Å and is detected by means of the layer of wavelength shifter on the inner surfaces of the scintillation chamber, which layer absorbs the extreme ultraviolet radiation and reemits in the visible region (Fig. 1). The source wire, however, simply absorbs all ultraviolet radiation falling on it without reemission. Hence, the detected scintillation intensity for a given α track will be reduced below the primary intensity by an amount proportional to the average solid angle subtended by the wire at points along the α track.

The formation of a bubble, in which an α particle loses negligible energy, simply shifts the α track outward, reducing the solid angle subtended by the wire, and increasing the detected intensity. The magnitude of the effect is easily estimated by considering the case of a radially directed α track.

As a typical case consider the wire of radius 45 μ, a radial α track of length 250 μ, and a bubble of annular thickness 135 μ. The solid angle subtended at the midpoint of the radial track can be easily calculated and subtracted from 4π. In the absence of a bubble approximately 91% of the primary He radiation misses the wire and strikes the wavelength shifter. In the presence of a bubble of 135-μ thickness 95.5% does so, resulting in an increase in intensity of about 5%. As indicated previously the increase in intensity in the bubble region is greater than that in the turbulence region by several percent. Hence, it is believed that at least this much of the increase is due to a decrease in the primary intensity absorbed by the wire.

It should be emphasized that the above figures are approximate. No data are available on correlation between bubble thickness and the magnitude of the increase in scintillation intensity. It would be impossible to measure these two quantities simultaneously, since the scintillation observations require a light-tight chamber; and in the experiments performed, the repeatability of measurements obtained with different Dewars was not good enough to extract a correlation from the data (note the spread of points in Fig. 3). However, it is reasonable to conclude that a substantial part of the bubble-induced increase in scintillation intensity is due to the solid-angle effect described above.

Whether the same effect may account for the increase in intensity in the turbulence region cannot be determined on the basis of the observations made thus far. The visibility of the turbulence indicates that localized variations in index of refraction occur near the wire. Since an appreciable change in refractive index occurs only above the λ point, the observations suggest that the onset of turbulence corresponds to the heating of fluid near the wire above T_λ, creating a region of He I, with local fluctuations in temperature and refractive index resulting in the visible phenomenon. This would be in accordance with the results of Andronikashvili and Mirskaia[3] who found that the surface temperature of a heated wire exceeded T_λ just prior to the formation of a bubble.

If the turbulence is due to a He I region near the wire, then the scintillation intensity should increase as a result of two effects. First, the lower fluid density should result in a shift of α tracks outward thus bringing into play the solid-angle effect discussed above. Second, the scintillation intensity is known to increase with rising temperature of the fluid.[8] The difficulty with this interpretation is that the existence of He I near the wire in a He II bath (at 1.5°K, for example) requires a pressure difference between the wire and the bath of approximately 30 mm Hg, which seems most unlikely.

A more reasonable interpretation suggested by Irey *et al.*[5] is that heating of the wire produces a region of superheated He II in its proximity and that bubbles form at a given degree of superheat. On this basis the results indicate that a greater degree of superheat is required for bubble formation at higher hydrostatic pressure (greater depth). On this basis the visible phenomena referred to as turbulence could be the result of the rapid formation and collapse of microscopic bubbles which could produce the hissing sound described in the previous section.

The dependence of the phenomena on the depth of the heated wire is an effect which is peculiar to He II. Since the observations performed thus far are not sufficient to establish a clear understanding of the effect, further experiments are being undertaken in which the He II bath will be pressurized at fixed temperatures.

ACKNOWLEDGMENT

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