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^{3}HE EFFECT ON FLOW DISSIPATION OF SUPERFLUID ^{4}HE THROUGH A MICRO-APERTURE

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The effect (below 0.1K) of ^{3}He ppb impurities on the critical flow of ^{4}He through a micro-aperture has been studied for T < 0.05K to investigate vortex creation at a wall. The width of the phase slip probablity is found to be reduced at low temperature by 30%, implying that the ^{3}He modifies the tunneling barrier to the vortex state.

1. VORTEX NUCLEATION

The discovery [1] that a constant discrete amount of flow energy is dissipated under certain circumstances in two-hole resonators has begun a new era in the study of vortex nucleation [2] in superfluid ^{4}He. The onset of dissipation is likely due to the creation of a half vortex ring at the wall of the micro-aperture when the local flow field exceeds a critical velocity v_c. The ability to detect a single 2π phase change in the macroscopic wave function representing the flow of superfluid threading the two holes may now be used to quantitatively measure the effects of various parameters on the nucleation of the vortex ring responsible for the dissipation.

Previously, by varying the temperature of the helium at zero pressure, it has been seen [2] that two distinct vortex nucleation mechanisms exist: (1) thermal activation causes vortex nucleation above 0.147 K; and (2) a quantum tunneling regime exists below this temperature. Also, minute amounts of ^{3}He dissolved in the ^{4}He have produced a drastic effect on v_c at low temperatures [3]. This has been interpreted as a lowering of the tunneling barrier height by the presence of the ^{3}He atom at the nucleation site.

Here we present new data on the effect of ^{3}He on the width of the critical transition from flow without dissipation to flow with dissipation.

2. PHASE SLIP TRANSITION

As described previously [5], a single phase slip is a statistical event that occurs when the system either surmounts or tunnels through an energy barrier. The probablility distribution P(v) gives the dependence of the rate of phase slip occurence on the ^{4}He flow velocity v through one of the resonator holes (the same micro-aperature as ref. 2). The reciprocal of the slope of P(v) at P = ½ is defined as the statistical width of the critical transition Δv_c.

P(v), and therefore Δv_c, depend on the vortex nucleation rate Γ, which in turn depends on the height and shape of the tunneling barrier and the attempt frequency ω_0 [6]. Following ref. 5 and 7, we define $\gamma = \ln\Gamma/\Gamma_{obs}$, where Γ_{obs} is the threshold for detection of phase slips. Then for a cubic barrier [2] the critical width:

$$\Delta v_c = v_{co}\frac{2}{\ln 2}\,\frac{x(1-x^2)}{3(\frac{1}{2}+\gamma)x^2-1} \qquad (1)$$

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where $x = v/v_{co}$ and v_{co} is the flow velocity which just reduces the barrier height to zero.

3. ^{3}HE EFFECT

The nucleation rate Γ, in the presence of one ^{3}He atom, is multiplied by the factor:

$$\exp [36(\mathcal{L}_3 - E_k)/5\hbar\omega_0\} \qquad (2)$$

where $\mathcal{L}_3$- E_k is the binding energy of a ^{3}He atom to the vortex core ($\mathcal{L}_3$) reduced by its zero-point kinetic energy (E_k) when confined to the vortex. Inserting the parameters determined in ref. 3 into Eq. 2 we obtain an increase of Γ of e^{10} or an increase of γ of 10 (18→28). Using Eq. 1 we see that the full (low temperature) effect of the ^{3}He is to lower Δv_c by ~ 30%. Figure 1 shows this critical width Δv_c, and the critical amplitude, as a function of temperature, for a ^{4}He sample containing 45 ppb ^{3}He (ppb = 1 part in 10^9). The plateau between about 50 and 150 mK is the quantum tunneling regime which is unaffected by this level of ^{3}He. At high temperatures thermal activation sets in. At low temperature the effect of the ^{3}He is seen to reduce the critical width by about 30%, as predicted.

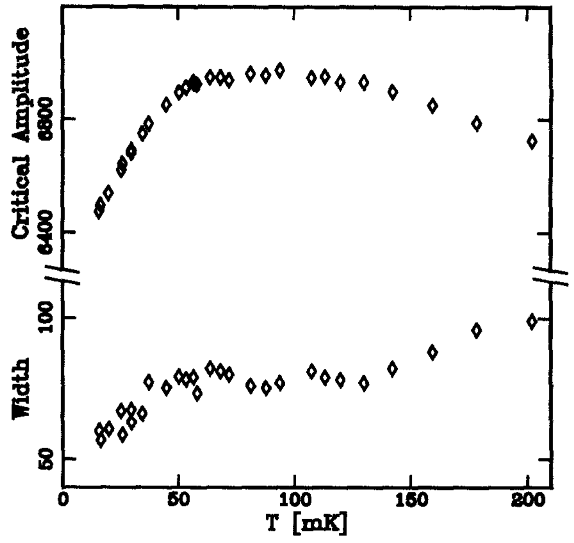

Figure 1. Critical amplitude (flow velocity v) and width (transition width Δv_c) plotted against temperature for ^{4}He flow containing 45 ppb ^{3}He. Units are arbitrary.

4. CONCLUSION AND FUTURE WORK

The theory which describes the effect of ^{3}He on the critical velocity due to the quantum nucleation of vorticity in ^{4}He [3] also predicts how the ^{3}He effects the critical width of the transition. This is further evidence that the quantum tunneling involves the nucleation of a vortex ring on an asperity in the flow channel. It would be interesting to carry the measurements to lower temperature to see if the effect does saturate. Also, these same measurements should be made at higher ^{4}He pressures to determine the effect of pressure on various parameters, such as $\mathcal{L}_3$, E_k, and ω_0.

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