MEASUREMENT OF THE HEAT CAPACITY OF HELIUM UNDER SUPERFLUID FLOW CONDITIONS NEAR THE LAMBDA TRANSITION

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A proposed experiment to measure the heat capacity of helium under superfluid flow condition near the lambda transition is discussed. This experiment would clarify the role of the superfluid density depression versus the role of the intrinsic critical velocity, in the description of the property of helium.

Recently, there are considerable interests in the nature of the lambda transition under superfluid flow conditions. Onuki\textsuperscript{1} has predicted that the transition becomes first order and hysteresis in the normal-superfluid interface would be observed if heat is used to create counter flow in the superfluid phase. Also predicted is that the transition temperature $T_\lambda$ would be shifted under a heat flux $Q$. The shift is given by $\Delta T_\lambda/T_\lambda = (Q/Q_0)x$ where $x=0.74$, and $Q_0 = 13000$ W/cm\textsuperscript{2}. Most recently, the renormalization group theory calculation of Haussmann and Dohm\textsuperscript{2} predicted a similar shift with a slightly smaller $Q_0$.

Several experiments have already studied the transition under heat flow. Leiderer and Pobell\textsuperscript{3} and later Bhagat and Lasken\textsuperscript{4} have measured the temperature in the fluid under heat flow condition. As $T_\lambda$ is approached, a sudden temperature change was interpreted by Bhagat and Lasken as the location of $T_\lambda$ under a counter flow current. Recently, Duncan, Ahlers and Steinberg\textsuperscript{5} (DAS) have extended these measurements to a reduced temperature of $10^{-8}$ with the use of a high resolution thermometer. As shown in Fig. 1, there are significant differences between experiments and theories.

![Figure 1](image)

**Figure 1.** The apparent shift in $T_\lambda$ under a heat flux or an equivalent $v_s$. The data are: A - Clew and Reppy, A - Leiderer and Pobell, O - Bhagat and Lasken, @ - Duncan, Ahlers and Steinberg. The solid lines labeled RG and O are the predictions of Haussmann and Dohm, and that of Onuki respectively. The dashed line is a best fit to the data.

It was suggested that the shift in $T_\lambda$ is caused by the depression of the superfluid density $\rho_s$ under superfluid flow condition.

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The depression of \( \rho_8 \) is based on sound theoretical arguments that the extra degree of freedom of counterflow in the two-fluid model, must be reflected as a dependence of the intrinsic properties of helium on the counterflow velocity. Hess\(^6\) has already observed this effect far away from \( T_\lambda \). The question is whether there is any independent evidence that \( \rho_8 \) is depressed near what DAS considered to be \( T_\lambda \). Some information to the answer of this question are contained in the experiment of Clew and Reppy\(^7\), where the angular momentum of a superfluid gyroscope is measured near \( T_\lambda \). Due to macroscopic quantization, the superfluid velocity \( v_s \) is constant as the temperature is varied. Thus as \( T_\lambda \) is approached, the angular momentum is proportional to \( \rho_8 \), until a critical point is reached where \( v_s \) spontaneously decays to a lower value, and the angular momentum decreases abruptly. This point was interpreted as the temperature where the intrinsic critical velocity was exceeded. The Langer and Fisher theory\(^8\) attributes this effect to the creation of vortex rings through thermal activation. Subsequent observation of the decay characteristics of \( v_s \) by Kukich, Henkel and Reppy\(^9\) confirmed the thermal activation origin of the process. Based on these data, there is no observable depression in \( \rho_8 \) up to the point where the intrinsic critical velocity \( V \) is exceeded. To compare this experiment with the experiment using counter flow, we have converted \( v_s \) to an equivalent heat flux \( Q_5 \), using the two fluid model \( Q_5 = s T_\rho s v_y c \). The data are shown by the solid triangle in Figure 1. The data coincide with those of Bhagat and Lasken, and Leiderer and Pobell, suggesting that their observations are obtained at a point where \( \rho_8 \) is finite, and thus are better explained by the intrinsic critical velocity rather than the depression of \( \rho_8 \). The data of DAS are obtained with a much smaller heat flux, where measurement of \( \rho_8 \) does not yet exist. The proposed experiment is to measure the heat capacity under both heat flux condition and persistent current condition. The use of high resolution thermometer\(^10\) with a resolution of 3x0-10 K/V/Hz would allow the heat capacity to be measured to 0.2% in the temperature range covered by DAS, with a limitation set by gravity. Any deviation of the heat capacity under superfluid flow would support the idea of \( \rho_8 \) depression. A space bound experiment would then be designed to fully map out the heat capacity as a function of temperature and \( v_s \). Such data would provide a valuable test of the renormalization group theory which is currently being developed to cover this experimental situation.

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11. V. Dohm, private communication.