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Part S1 - Quantum Fluids and Solids: Helium films

Superfluid flow and Kapitza resistance of very thin ^{4}He films

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The thermal-counterflow experiment in the film-vapour system is used to investigate the superflow of very thin ^{4}He films at temperatures between 1.0 K and 2.1 K. We measure the filmflow resistance on both sides of the Kosterlitz-Thouless 2-D phase transition. On the superfluid side we observe the predicted (AHNS) powerlaw behaviour over a range of 3 decades in the flow resistance, the exponent being 2 at the KT-point and rising with increasing film thickness. On the non-superfluid side the powerlaw still rather well describes the massflux dependence of the flow resistance, the exponent being smaller than 2. The influence of the substrate material is studied by comparing the weak binding solids H_2 and Ne with glass. The second phase transition on H_2, reported by *Mochel et. al.*, is not observed. Secondly we check our previous observation of a gradual increase of the Kapitza resistance with decreasing film thickness in a new device with a well-localized heat exchanger.

1. INTRODUCTION

In thermal-counterflow experiments in the film-vapour system, a steady circulation of helium is induced between a heater and a cold spot [1]. By measuring the temperature distribution along the return path through the film, we investigate the flow resistance and the Kapitza resistance of the film as a function of the heater power $\dot{Q}$, the temperature T, the film thickness δ and the substrate material.

2. MEASURING DEVICE

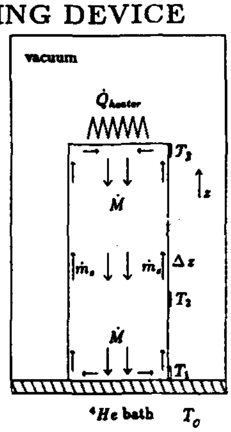

Figure 1: Schematic drawing of the device

The film covers the inside of an axially symmetric body, which is surrounded by vacuum, see Fig.1. The heater is mounted at the top and the heat exchanger at the bottom of the device, in order to avoid spontaneous convection of heat by the vapour. The tube is given a low thermal conductance and a small gas flow resistance in order to optimize the film contribution. The heat is transfered to the bath in a well-localized heat exchanger of 15 cm^2 highly conducting silver, so that its Kapitza resistances dominate.

3. RESULTS

3.1. Flow resistance

We investigate the flow resistance with several tube lengths and diameters. Up to large values of δ we observe the predicted (AHNS) powerlaw behaviour, $\frac{dT}{dz} = c\dot{Q}^{\gamma}$, over a range of 3 decades in the temperature gradient.

The temperature gradient is obtained by measuring $\Delta T = T_3 - T_1$ or $T_2 - T_1$. For $\Delta T > 1$ mK we observe that ΔT becomes larger than $c_0\dot{Q}^{\gamma_0}\Delta z$. We can account for this enhancement by numerical integration of the powerlaw over Δz. By using different separations Δz we extend the range of accessible temperature gradients.

On the non-superfluid side of the Kosterlitz-Thouless transition the powerlaw still applies, thereby going beyond the AHNS prediction. Now the exponent $\gamma < 3$ and decreases rapidly to 1.

The dependences on T and δ of γ and $\dot{Q}_{1\mathrm{mK}}$, the heater power needed to obtain $\Delta T = 1$ mK, can very well be described by one parameter $x = \frac{\delta - \delta_s}{\xi_\perp}$, up to $x \approx 2.7$. The bulk transverse correlation length $\xi_\perp = \frac{m_4^2 k_B T}{\hbar^2 \rho_{s,b}(T)}$. The value of δ is derived from the vapour pressure using the standard FHH procedure. For the results on glass of Fig.2 and Fig.3., obtained with $\Delta z = 30$ mm and tube radius 2.5 mm, we use a vanderWaals constant of 27 K a.l.[3] and $\delta_s = 0.43$ a.l. Note the continuous slope of $\dot{Q}_{1mK}$ in Fig.2 at the KT-transition where $\gamma(\delta) = 3$ and strongly curved.

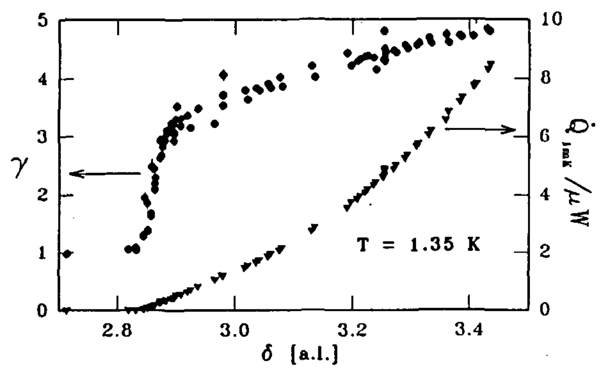

Figure 2: $\gamma(\delta)$ and $\dot{Q}_{1mK}(\delta)$ at $T = 1.35$ K

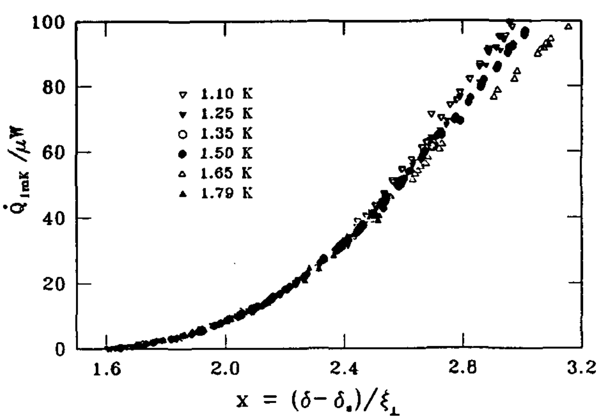

Figure 3: The scaling of $\dot{Q}_{1mK}$ with x

3.2. Substrate

The influence of the substrate material is studied by plating the glass tube with the weak binding solids H_2 and Ne. Although their vanderWaals constants are known to be much smaller than the one of glass, we observe very little difference between the flow characteristics measured at the same vapour pressure, see e.g. Fig.4. Moreover, the second phase transition on H_2, first reported by *Mochel and Chen* is not observed [2] [3]. Although several precautions were taken to achieve uniform plating, the quality of the resulting layers is not fully guaranteed.

3.3. Kapitza resistance

The possible variation of the Kapitza resistance with δ is studied by measuring $\Delta T = T_1 - T_0$ as function of $\dot{Q}$. Results for various values of p/p_{sat} and $T = 1.06$ K, are presented in Fig.5. They show that when $\dot{Q}$ is small enough, ΔT is proportional to $\dot{Q}$ and practically independent of δ. This finding demonstrates that down to the thinnest film investigated ($\approx 1.3\delta_{onset}$ in Fig.5) the Kapitza resistance between film and silver substrate does not change significantly [4]. The steep rise of the curves at large $\dot{Q}$ signifies the increase of the filmflow resistance, hindering the accessibility of the heat exchanger.

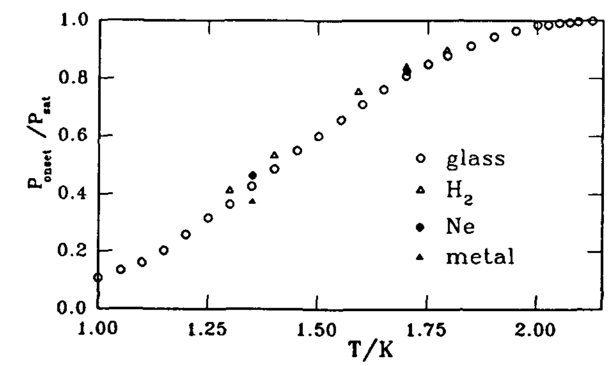

Figure 4: The vapour pressure at onset of superfluidity for glass, H_2, Ne and metal substrates

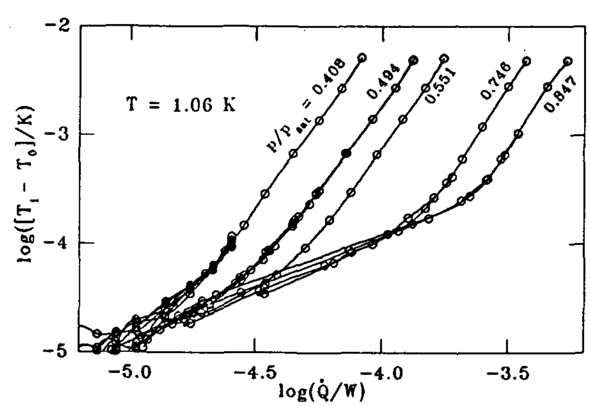

Figure 5: $T_1 - T_0$ across the heat exchanger

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