CHANNEL FLOW OF HE II WITH ONE END BLOCKED BY A SUPERLEAK

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Recently we have reported (1) an experimental investigation of a flow of the superfluid phase of ^{4}He – He II – thermally induced by a fountain pump through vertical channels of square cross-section with ends blocked by sintered silver superleaks using the experimental setup shown in Fig. 1. We have confirmed the existence of a weakly temperature dependent critical velocity (2) $v_{\rm cr}^{\rm I}$ of order 1 cm/s, which does not scale with the channel size and is therefore an intrinsic property of the self-sustained vortex tangle of vortex line density L, measured by second sound attenuation. Our principal result was that in addition to the previously reported turbulent A-state (3) characterized by $L^{1/2} = \gamma(T)(v_{\rm s} - v_{\rm cr}^{\rm I})$, where $v_{\rm s}$ is the mean superflow velocity through the channel, we have discovered a new B-state characterized by $L = \beta(v_{\rm s} - v_{\rm cr}^{\rm II})$, where β seems only weakly temperature dependent. We have offered a phenomenological model assuming that in the B-state the coarse-grained superflow profile matches the classical parabolic profile, with a finite, temperature dependent slip velocity $v_{\rm cr}^{\rm II}$ of order few cm/s and that a confined viscous normal fluid flow of toroidal form is induced inside the channel due to the mutual friction force. Besides the linear dependence of L on mean superflow velocity, this model was supported also by our decay measurements. When the fountain pump was switched off, after an initial decay, a confined quasi-viscous exponentially decaying flow of a single-component fluid with an effective kinematic viscosity $\nu_{\rm eff}(T)$ was established. The values of $\nu_{\rm eff}(T)$, calculated using our model from the measured decay times, were in agreement with those deduced from other experiments on decaying He II turbulence.

The existence of the new turbulent B-state strongly suggests that, at higher flow velocities, the quadratic generation mechanism of vortex line density, so well established both experimentally (3; 4) and theoretically (5) in thermal counterflow, ceases to work. It is therefore very important to establish the existence of the B-state as firmly as possible. We decided to get additional information by repeating our steady-state experiment in 6 mm channel, using the same experimental setup (see Fig. 1) and protocol (1), but with the lower superleak removed. In this geometry, the flow of the normal fluid is not any more necessarily confined inside the channel. The normal fluid still cannot pass the remaining upper superleak, but can flow in and out of the channel via its lower end.

Shortly, the experimental procedure is as follows: by adjusting the frequency of a second sound transducer, typically second resonance is found and scanned; the undisturbed amplitude, a_0, and the linewidth, Δ_0, is obtained by fitting it to a Lorentzian. By switching the fountain pump heater on and off, experimental data series such as shown in (1) are recorded, allowing computing the steady–state vortex line density

$$L = \frac{6\pi\Delta_0}{B\kappa}\left(\frac{a_0}{a(t)} - 1\right), \tag{1}$$

where κ denotes the circulation quantum and $a(t)$ is the second sound amplitude reduced due to the presence of quantized vortices. Fig.1 shows the calculated vortex line density versus mean superfluid velocity $v_{\rm s} = \dot{q}/(\rho_{\rm s}ST)$, which is deduced from the known heat input $\dot{Q} = \dot{q}d^2$ that is spent on conversion of a part of incoming superfluid of density $\rho_{\rm s}$ into normal fluid (of density $\rho_{\rm n}$ and entropy S) in such a way that the leaving fountain has the temperature of the bath. We emphasize that the following interpretation of our data is based on this relationship.

Fig. 1 compares the steady-state data obtained with two superleaks with a series of crosses representing the new data measured with the lower superleak removed. Although the experiment and data analysis

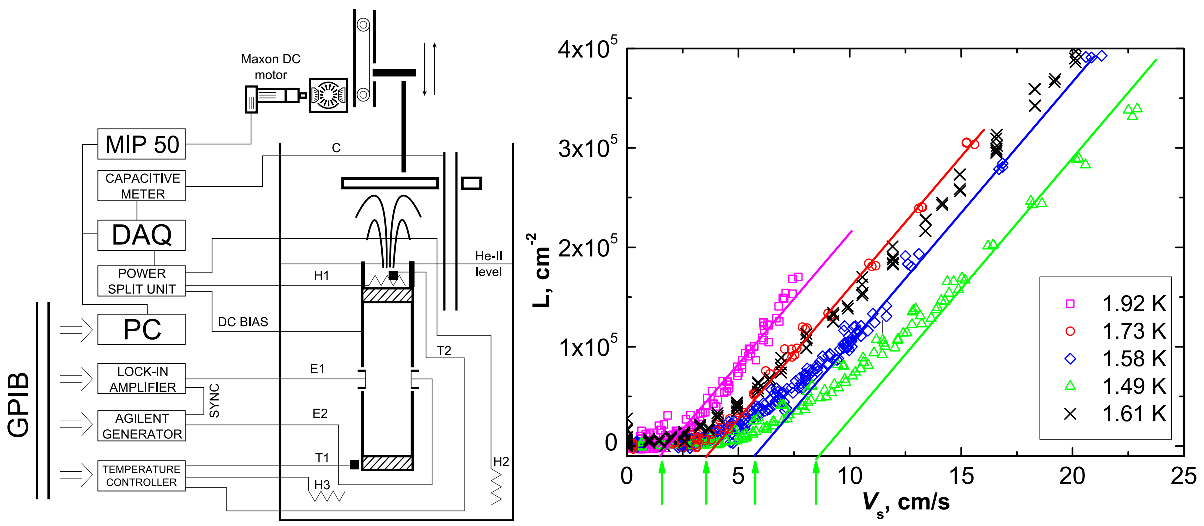

Figure 1: LEFT: The experimental setup used for generating and detecting He II flow in the channel with ends blocked by superleaks. The net superflow is generated thermally, by applying heat from the power splitter via the fountain pump heater H1 (while the total heat delivered via H1 and H2 is kept constant). The temperature difference across the channel is measured by thermometers T1 and T2. The bath temperature is controlled by the temperature controller using additional heater H3. The DC biased second sound transducer is driven by AC signal E2 at one of the standing second sound resonances. The signal E1 from the receiver placed across the channel, the width of which serves as an acoustic resonator, provides information on second sound attenuation and thus serves as a measure of the vortex line density in the channel. The lift system keeps the He II level inside the nozzle constant, using the signal C from the home-made level meter and capacitance bridge. RIGHT: The calculated steady-state vortex line density plotted versus the mean superfluid velocity in the 6 mm channel with both ends blocked by superleaks (open symbols) and with the lower superleak removed (crosses). The arrows from below indicate the fitting parameter – slip velocity v_{cr}^{II}; the solid lines are plots of linear dependencies $L = \beta(v_s - v_{cr}^{II})$.

is still in progress, the main conclusion can already be made - at sufficiently high superfluid velocities $L \propto v_s$ - a clear signature of the B-state. We conclude therefore that the existence of the turbulent B-state in our channel is confirmed experimentally using different boundary conditions with possibly different geometry of flow.

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References

[1] T.V. Chagovets, L. Skrbek, Phys. Rev. Lett. **100**, 215302 (2008); J. Low Temp. Phys. (2008) in print; T.V. Chagovets, *Experimental Investigation of Quantum Turbulence in Superfluid* ^{4}*He*, PhD. Thesis, Charles University, Prague (2008).

[2] M.L. Baehr, L.B. Opatowsky, J.T. Tough, Phys. Rev. Lett. **51**, 2295 (1983).

[3] J.T. Tough, *Superfluid turbulence*, in Prog. in Low Temp. Phys., Vol. VIII, North-Holland Publ. Co., (1982); R.A. Ashton, L.B. Opatowsky, J.T. Tough, Phys. Rev. Lett. **46**, 658 (1981); Physica B **108**, 1127 (1981); L.B. Opatowsky, J.T. Tough, Phys. Rev. B **24**, 5420 (1981).

[4] W.F. Vinen, Proc. Roy. Soc. A **240** 114 (1957); **240**, 128 (1957); **242**, 493 (1957); **243**, 400 (1958).

[5] K.W. Schwarz, Phys. Rev. B **18**, 245 (1978); **31**, **38**, 2398 (1988); Phys. Rev. Lett. **50**, 364 (1983).