Published in *Physica B* **280** (2000) 43–44 (2000).

Decay of quantized vorticity in superfluid ^{4}He at mK temperatures

S.I. Davis, P.C. Hendry, P.V.E. McClintock*

Department of Physics, Lancaster University, Lancaster LA1 4YB, UK

Abstract

An experimental investigation of the free decay of quantized turbulence in isotopically pure superfluid ^{4}He at mK temperatures is discussed. Vortices are created by a vibrating grid, and detected by their trapping of negative ions. Preliminary results suggest the existence of a temperature-independent vortex decay mechanism below $T \sim 70$ mK.

Keywords: ^{4}He superfluid; Quantized vortex; Superfluidity; Turbulence; Vortex line

A tangle of quantized vortex lines in He II [1] represents a particularly simple form of turbulence. Above 1 K, it can be maintained by e.g. a pressure or temperature gradient. If the driving force is removed, the tangle decays according to the Vinen equation

$$\frac{dL}{dt} = -\chi_2 \frac{\hbar}{m_4} L^2, \qquad (1)$$

where L is the length of vortex line per unit volume and χ_2 is a (weakly temperature-dependent) dimensionless constant. The physical mechanism driving the decay is believed [2–4] to involve crossings and consequent reconnections of lines. The rapid self-induced motion of the resultant sharp cusps through the normal fluid is dissipative, leading to line shrinkage. The presence of the normal fluid component is thus a key component of the decay mechanism. In the mK range, where the normal fluid density becomes vanishingly small, it is unclear how the tangle will decay. Pioneering numerical investigations are in progress [5]; we are investigating the question experimentally.

The techniques commonly used above 1 K for vortex creation (thermal counterflow) and detection (attenuation of second sound) do not work in the absence of normal fluid component, so new methods have been required. To create vortices we have employed a resonantly excited circular grid [6]. The expectation was that, in the absence of normal fluid, the amplitude of vibration would grow until a critical velocity was attained, after which the energy drawn from the exciting field would be converted to vorticity. To detect the vortices we have observed the attenuation of ion signals caused by trapping of the ions on vortex cores as the ion clouds pass through a vortex tangle in isotopically pure ^{4}He [7] at an average speed slightly beyond the Landau critical velocity v_L [8]. The mechanism by which a rapidly moving ion can get trapped in the effective potential [9] provided by the vortex remains unclear, but may involve e.g. the excitation of vortex waves.

The electrode structure used for the experiment is shown schematically in Fig. 1. The operating procedure was performed in two stages. First, the grid was driven for several seconds, to build up a tangle of vorticity. Secondly, the field-emitter was then pulsed, repeatedly, to create a sequence of ion clouds, which travelled down the cell inducing signals on arrival at the collector. The sequence was then repeated, ensemble-averaging the collector signals to enhance the signal/noise ratio.

Fig. 2 shows a collection of sequentially recorded signals to illustrate their evolution: their growth with time following the grid-driving is attributable to the decay of

* Corresponding author.

E-mail address: p.v.e.mcclintock@lancaster.ac.uk (P.V.E. Mc Clintock)

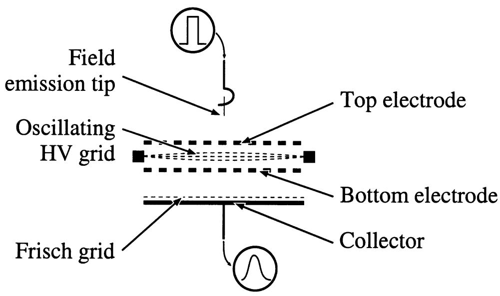

Fig. 1. The experimental arrangement (schematic).

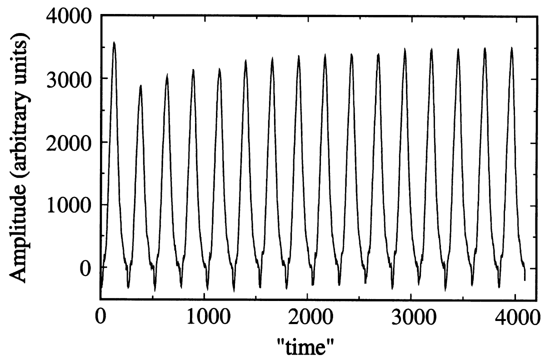

Fig. 2. Signals recorded sequentially before (on the extreme left) and after (other signals) transiently applying the grid driving force. The abscissa axis (arbitrary scale) indicates the times at which the signals were propagated: the signals were of duration ~ 200 μs, and they were separated by 1.3 s intervals.

a vortex tangle. We have found [8] that, for $T < 70$ mK, the decay process is apparently temperature-independent. Remarkably, the data follow quite well the equation obtained by integration of Eq. (1):

$$\left[\ln\left(\frac{S_0}{S}\right)\right]^{-1} = \frac{A}{\kappa d}\left(\chi_2 \frac{\kappa}{2\pi} t + L_i^{-1}\right), \quad (2)$$

where S_0 and S are, respectively, the signal heights in the absence and presence of vortices, A is a constant containing the ion-vortex trapping cross-sections, L_i is the initial vortex line density at $t = 0$, and d is the length of the vorticity-filled region. Plots of $[\ln(S_0/S)]^{-1}$ against t yield straight lines [10]. The absolute density of the vortices, and their distribution within the cell, remain unknown and will be the subject of further research.

Acknowledgements

It is a pleasure to acknowledge helpful discussions with R.J. Donnelly, D.M. Strayer and W.F. Vinen. The work was supported by the Engineering and Physical Sciences Research Council (UK).

References

[1] R.J. Donnelly, Quantized Vortices in He II, Cambridge University Press, Cambridge, 1991.
[2] K.W. Schwarz, Phys. Rev. B 18 (1985) 245.
[3] K.W. Schwarz, Phys. Rev. B 31 (1988) 5782.
[4] K.W. Schwarz, Phys. Rev. B 38 (1988) 2398.
[5] M. Tsubota, T. Araki, S.K. Nemirovskii, Decay of vortex tangle in superfluid ^{4}He at very low temperatures, Physica B, these proceedings.
[6] M.I. Morell, M. Sahraoui-Tahar, P.V.E. McClintock, J. Phys. E 13 (1980) 350.
[7] R.M. Bowley, P.V.E. McClintock, F.E. Moss, P.C.E. Stamp, Phys. Rev. Lett. 44 (1980) 161.
[8] D.R. Allum, P.V.E. McClintock, A. Phillips, R.M. Bowley, Phil. Trans. R. Soc. A 284 (1977) 179.
[9] R.J. Donnelly, P.H. Roberts, Proc. R. Soc. A 312 (1969) 519.
[10] S.I. Davis, P.C. Hendry, P.V.E. McClintock, Decay of quantized vorticity in He II and mK temperatures, in: D. Strayer (Ed.), Proceedings of the Conference on Fundamental Physics and Microgravity, Oxnard, Ca, June 1998, in press.