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The characteristic response curve, I(ΔP), of a ^{3}He weak link

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We report measurements of the mass current as a function of pressure difference, I(ΔP), for superfluid ^{3}He flowing through an aperture whose dimensions are on the order of the temperature dependent coherence length. The goal of the experiment is to see to what extent this weak link behaves like a simple Josephson junction. A model has been developed which predicts I(ΔP) for the case where the weak link is analyzed as a series connection of resistance, inductance and ideal Josephson junction. This model is found to be inadequate to explain the central feature of the data, i.e. the current increases monotonically with ΔP.

1. INTRODUCTION

This experiment is motivated by the desire to understand properties of flow of superfluid ^{3}He through micro-apertures which have at least two dimensions of the order of the coherence length, $\xi(T) = \xi_0(1-T/Tc)^{-1/2}$ (where ξ_0=65 nm at zero pressure). Measurements on a superfluid ^{3}He Helmholtz resonator, containing a micro-aperture in parallel with a much larger tube, indicate that the micro-aperture can be modelled as a Josephson junction in series with a inductance[1-3]. This model was first proposed for superconducting weak links by Deaver and Pierce [4]. A model with these elements can be used to predict the mass current versus pressure characteristic for flow through a single micro-aperture. We have measured the I(ΔP) characteristic for a 7.8 μm x 0.27 μm aperture in a 0.1 μm thick silicon nitride window.

2. MODEL

The model circuit consists of a resistance R, inductance L and Josephson junction with critical current I_0, all in series. The results of calculations to find the average mass current for a given pressure across this circuit are shown in Figure 1. These calculations will be reported in detail elsewhere[5].

When the applied pressure is less than I_0R, there is no pressure across the Josephson junction and thus no alternating currents at the Josephson frequency flow through it. When the pressure is larger than I_0R these ac currents are not symmetric in time and thus a average dc current flows through the junction. In this range the average current is an monotonically *decreasing* function of pressure difference. Such results have also been reported for calculations on electronic Josephson junctions in similar circuits[6].

3. EXPERIMENT

The experimental cell containing superfluid ^{3}He, is divided in two by a wall containing a flexible plastic diaphragm and a Si chip containing the micro-aperture. Mass current is driven through the aperture by the motion of the diaphragm under the application of electrostatic forces, and is measured by an inductive position sensor whose sensitivity is 3×10^{-13} m/√Hz.

The pressure difference across the aperture is calculated from the spring constant of the

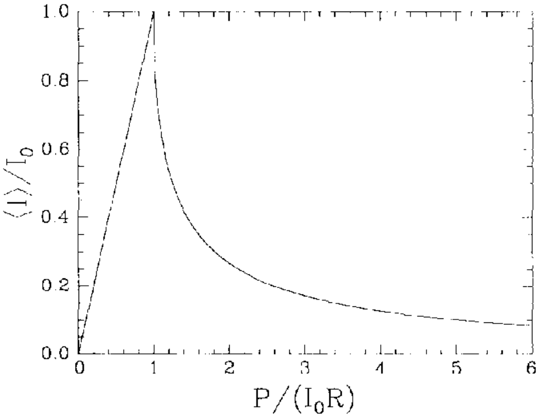

Fig.1 Calculated average current versus pressure.

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diaphragm and the measurement of its displacement. Pulsed NMR on two ^{195}Pt samples (one on each side of the diaphragm) provides thermometry. The micro-aperture is made by e-beam lithography in 0.1 μm thick, free standing, silicon nitride window supported on a Si chip[6]. The cell is attached to a nuclear demagnetization cryostat. Measurements are made between 0.375 mK and 0.929 mK, and at zero ambient pressure.

The principle of the experiment is as follows. A voltage applied between the metalized surface of the diaphragm and a nearby capacitor plate produces a pressure difference across the micro-aperture. The diaphragm moves in the direction to relieve the pressure and in doing so forces fluid through the micro-aperture. The current I, and pressure difference ΔP, are calculated from the diaphragm position as a function of time. At temperatures just above Tc the same pressure produces flows of order 10^{-6} times smaller.

3. RESULTS

The I(ΔP) characteristic is shown at several different temperatures in Figure 2. In no part of the pressure range is a current monotonically decreasing in pressure observed. At very low pressures, ($\Delta P < 10^{-3}$ Pa) a zero pressure branch is observed whose critical current is typically ~30% of the maximum current we can force through the aperture.

When the current exceeds this lower critical current it then rises approximately linearly with the log of applied pressure. Results of this form have now been measured in at least 3 other apertures, ranging from 0.25 μm X 0.27 μm to 10 μm X 0.27 μm in size.

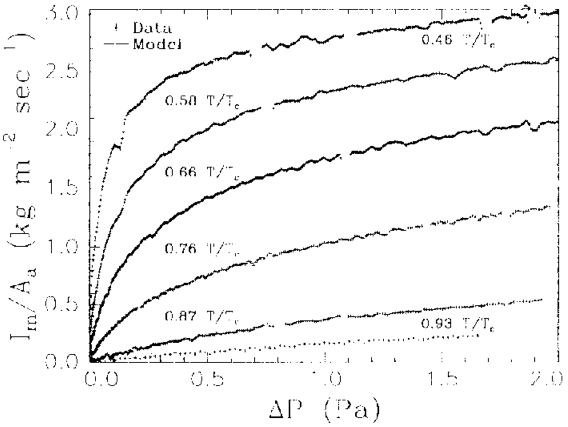

Fig. 2 Measured current density as a function of the applied pressure difference.

4. CONCLUSIONS AND FUTURE

The Deaver and Pierce model[4] is not sufficient to characterize the I(ΔP) characteristics observed in superfluid ^{3}He weak links. When fluctuations, either thermal or quantum, are added to this model it is possible to explain the positive slope of I(ΔP). Perhaps an extension of the more complete model and calculations of Soininen, Kopnin and Salomaa [8,9] can explain these obeservations. In that picture the aperture behaves as a Josephson junction at low currents and as a vortex mill at higher currents (which are still less than the pair breaking current).

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REFERENCES

1. O. Avenel and E. Varoquaux, Jpn. J. Appl. Phys. **26**, 26 (1987).
2. O. Avenel and E. Varoquaux, Phys. Rev. Lett. **60**, 416 (1988).
3. E. Varoquaux, O. Avenel, G. Ihas, R. Salmelin, Physica B **178**,309 (1992).
4. B.S. Deaver and J.M. Pierce, Phys. Lett **38A**,81 (1972).
5. J. Steinhauer and R.E. Packard to be published.
6. Yu. M. Ivanchenko, L.A. Zil'berman, JETP **28**, 1272 (1969).
7. A. Amar, Y. Sasaki, R.L. Lozes, J.C. Davis and R.E Packard, to be published J. of Vacuum Science and Technology, April 1993.
8. N.B. Kopnin and M.M.Salomaa, Phys. Rev. B **41**, 2601 (1990).
9. P.J Soininen, N.B Kopnin, M.M Salomaa, Europhys. Lett. **14**, 49 (1991).