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Quasiparticle Molasses: the Giant Force on an Object Moving through a Beam of Thermal Excitations in Superfluid ^{3}He

N.S.Shaw, D.J.Cousins, M.P.Enrico, S.N.Fisher, A.M.Guénault, G.R.Pickett and P.J.Y.Thibault

School of Physics and Chemistry, Lancaster University, Lancaster LA1 4YB, U.K.

Owing to the unusual dispersion curve for excitations in superfluid ^{3}He an object moving through the excitation gas experiences a very much higher drag force than expected for a similar 'conventional' gas. We have made investigations of the force on a body moving through a unidirectional beam of thermal excitations in ^{3}He-B at very low temperatures which shows that owing to the nature of Andreev reflection by the surrounding flow field the moving body (in this case a vibrating wire resonator) experiences a giant drag force *independently* of the relative direction of motion between object and beam.

1. INTRODUCTION

At the very lowest temperatures ($T \leq T_c/4$), where the excitation mean free paths are very long [1, 2], the damping force on an object moving in superfluid ^{3}He arises from normal scattering between the surface of the moving object and incoming quasiparticles (quasiholes) which exchange momentum of order $p_F(-p_F)$. However, the magnitude of the damping force is affected by the condensate superflow as this determines which excitations are able to reach the moving surface. Although in our experiment the moving object is a vibrating wire resonator and a full calculation of the damping is quite complex [3], we can present the mechanism through the following one-dimensional picture which gives a qualitatively similar result [2].

We assume that the wire moves with velocity v. In the rest frame of the wire the local liquid in contact with the surface is stationary, and the excitation dispersion curve has the usual double minimum form, $E = \sqrt{\Delta^2 + (p - p_F)^2 v_F^2}$. The liquid ahead of the wire beyond the region of perturbed flow is approaching at velocity $-v$ and the dispersion curve is skewed by the addition of the extra energy $-v \cdot p$. This means that, in the rest frame of the wire, quasiparticles approaching from the front have a minimum energy of $\Delta + vp_F$. Conversely, quasiparticles approaching the wire from the rear have a lower minimum energy $\Delta - vp_F$. Therefore any quasiparticles with energies less than vp_F above the minimum cannot reach the wire as there are no equivalent quasiparticle states at these energies in the vicinity of the wire. It follows that if the temperature is sufficiently low ($k_B T << vp_F$) then no quasiparticles can reach the wire from the rear. A similar argument shows that under these conditions no quasiholes can reach the wire from the front. These excitations are instead scattered by the condensate flow field via Andreev-like processes. Since the excitation momentum is almost unchanged in such processes, they do not contribute to the damping which consists entirely of the effects due to quasiparticles approaching from the front and quasiholes from the rear. Both these processes oppose the motion of the wire and this asymmetry leads to a very large damping force.

By this argument we can see that a beam of quasiparticle excitations directed parallel to the motion of a object moving in either direction should exert a giant damping force upon the object and this is indeed observed [4]. However, if the beam is directed perpendicular to the motion of the object, then the one-dimensional model presented above predicts no such effect.

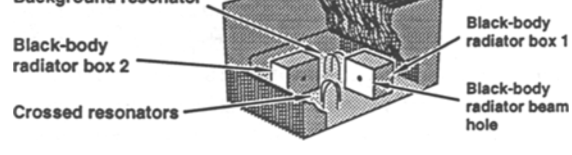

Figure 1: Experimental cell.

2. THE EXPERIMENT

The practical arrangement is shown in figure 1. The experiment is contained in a small void inside a thermally guarded inner cell, otherwise filled with thin Cu refrigerant plates coated in sintered silver powder for thermal contact, the open volume being filled with liquid ^{3}He. The central part of the experiment consists of two vibrating wire resonators arranged to have directions of motion which are mutually perpendicular. A thermal beam of excitations can be generated by either of two quasiparticle black-body radiators [4] also placed so as to produce beams incident on the two crossed resonators in each of the two perpendicular directions. The background gas of thermal excitations is monitored by a further resonator placed outside of either beam.

The experiment is in principle very simple. While the crossed resonators are illuminated by a beam of excitations from one black-body radiator, we monitor their frequency widths which provide a direct measure of the damping. We repeat the experiment with the other beam energised.

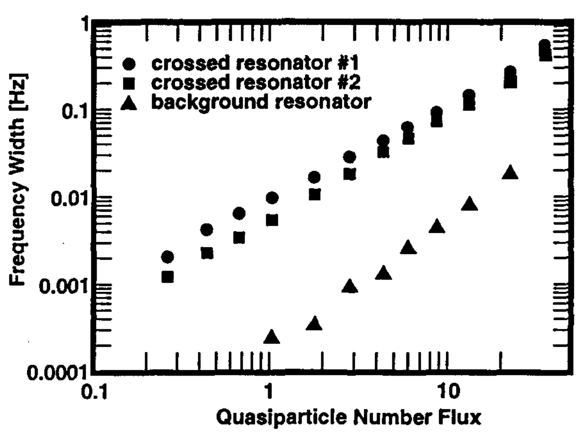

Figure 2: Graph to show comparison of damping on crossed and background resonators.

3. RESULTS

We record the quasiparticle number flux in the beam generated by one of the radiators, and the frequency width of the resonators. In figure 2 we plot the frequency widths of both crossed resonators and that of the resonator monitoring the background incoherent quasiparticle density. It can be seen that the difference between the the damping on each of the two crossed resonators is relatively modest, a factor of about two. However, the damping on the resonator located outside the beam is almost 2 orders of magnitude less. When the experiment is repeated using the other radiator the relative damping effect on the two crossed resonators is inverted. The beams therefore exert an extremely large damping effect, which is only marginally less on a wire moving perpendicular to the beam direction than on a wire moving parallel to the beam direction.

4. DISCUSSION

The model discussed in the introduction assumed our resonators were one dimensional. In fact they are a loop of filamentary wire, with all but one filament removed. A consequence of our resonators being three dimensional objects is that the two crossed resonators observe damping of a similar order of magnitude.

The flow field around a moving three dimensional object provides a filter which allows more quasiparticles to reach the forward surface of the wire and more quasiholes to reach the rearward surface. This has the effect that the sum of the normal scattering processes slows the wire independently of the direction of the incoming beam. A simple argument based on our particular geometry suggests that the damping for parallel motion should be a factor of 2 or so greater than for perpendicular motion, which is comparable with what we see in this experiment.

5. CONCLUSION

We have shown that, when exposed to a thermal beam of quasiparticle and quasihole excitations in superfluid ^{3}He-B, a moving body experiences a very large resistance to motion, independent of its direction of motion. This is a consequence of the very unusual dispersion curve of the excitations.

6. ACKNOWLEDGEMENTS

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