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Part S1 - Quantum Fluids and Solids: Liquid Helium

Andreev Reflection from a B-A Interface in Superfluid ^{3}He.

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Superfluid ^{3}He-B has an isotropic energy gap. However, when a magnetic field is applied this gap becomes distorted and at a critical field a transition to the A-phase occurs. In the B-phase a quasiparticle entering a region of increasing field may find that it carries too little energy to continue and is Andreev reflected back along its trajectory. We use a miniature superconducting solenoid to generate a field in a small region. We direct a beam from a Quasiparticle Black Body Radiator into the bore of the solenoid. The Andreev-reflected quasiparticle flux increases the temperature within the radiator. From this we can calculate the maximum gap within the solenoid.

1. INTRODUCTION

In a region of superfluid where the gap is changing a quasiparticle excitation approaching a region of increasing gap may reach a point where it has insufficient energy to propagate further and is converted to a quasihole. This 'Andreev reflection' process involves a minimal change in momentum, but reverses the excitation group velocity. The returning quasihole rather accurately retraces the incident quasiparticle trajectory.

The energy gap in ^{3}He-B is distorted by a magnetic field. With increasing field the gap parallel to the field decreases whilst the perpendicular gap increases. The minimum of the quasiparticle dispersion curve is also split in the direction of the field depending on the excitation spin. When the field is sufficiently large, A-phase is stabilised which has a gap profile with two polar nodes and a maximum gap slightly larger than that of the undistorted B-phase. At zero bar the transition occurs at 339mT[1] at low temperatures.

2. EXPERIMENT

The experiment is placed in a cavity in the sinter stack of a nuclear demagnetisation chamber, giving temperatures down to $0.1T_c$. We use a small superconducting solenoid to generate a localised field. The coil is 1.2mm long with a 1 mm diameter bore and can produce fields up to 440mT, sufficient to stabilise the A-phase at low pressure.

The coil is placed around the orifice of a quasiparticle black-body radiator[2] with its excitation beam directed into the bore of the solenoid as shown in figure 1. The radiator is a box with a small hole in one wall. Inside are two Vibrating Wire Resonators(VWRs), one used as a heater and the second as a thermometer. When heat is applied, the excess excitations escape through the radiator hole as a quasiparticle beam. Any Andreev reflection from the distorted gap within the solenoid can be thought of as increasing the "hole impedance" and leads to an increase in the temperature within the radiator box.

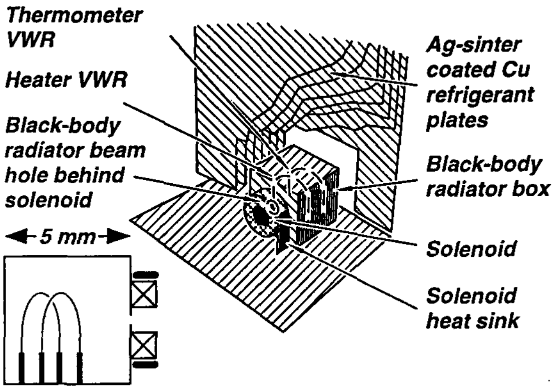

Figure 1: The experimental arrangement.

The VWR thermometer measures the temperature T inside the box while a known amount of power is supplied by the VWR heater. In steady state, this equals the power leaving the radiator in the beam $\dot{Q}$. In low magnetic fields, the beam power can be calculated as $Q = AT(\Delta_0 + k_B T)e^{-\Delta_0/k_B T}$, where A is a collection of terms including the area of the radiator hole.

3. DISCUSSION

When the solenoid is magnetized the B-phase is distorted. The maximum energy gap for down spin excitations $\Delta_\downarrow$ moving along the field axis is increased, while the gap for up spins decreases. Down spin excitations with energies less than $\Delta_\downarrow$ are therefore Andreev reflected, while the up spins escape freely. So, considering a collimated beam along the solenoid axis, the beam power can be calculated as

$$\dot{Q} = AT(\Delta_\downarrow + k_B T)e^{-\Delta_\downarrow/k_B T}/2 \\ +AT(\Delta_0 + k_B T)e^{-\Delta_0/k_B T}/2 \qquad (1)$$

When A-phase is present, up spins also face an energy barrier Δ_A and may be Andreev reflected. Since $\Delta_\downarrow > \Delta_A$ the down spins are unaffected by the A-phase plug. Thus the corresponding equation with an A-phase 'plug' is

$$\dot{Q} = AT(\Delta_\downarrow + k_B T)e^{-\Delta_\downarrow/k_B T}/2 \\ +AT(\Delta_A + k_B T)e^{-\Delta_A/k_B T}/2 \qquad (2)$$

Expressions (1) and (2) allow the values of $\Delta_\downarrow$ and Δ_A to be inferred from the measurements of $Q(T)$ for a given magnetic field. Unfortunately the solenoid distorts the B-phase inside the radiator near the orifice and we have to make a correction for the power lost by the leakage of excitations in this region which have energies below Δ_0. This leads to an extra unknown parameter which is chosen to give the expected value for $\Delta_\downarrow$ just below the A-B transition at zero bar.

In figure 2 we plot the maximum gap both for B-phase only (open circles) and assuming A-phase is also present (filled circles). At low fields the B-phase assumption gives values of the maximum gap which are close to those expected[3] while those calculated on the assumption of A-phase present give trivial results. However, at 340mT for 0bar we see that values given by the B-phase assumption go suddenly to infinity whilst those calculated on the assumption of A-phase present suddenly increase near the theoretical expectation for Δ_A. This is the clear signature of A-phase forming in the solenoid where the 'impedance' of the radiator orifice suddenly jumps as excitations of both spin species are affected by the A-phase gap whereas only down-spin excitations are reflected by the distorted B-phase. The field at which we see the transition to the A-phase increases with pressure in agreement with expected values[1].

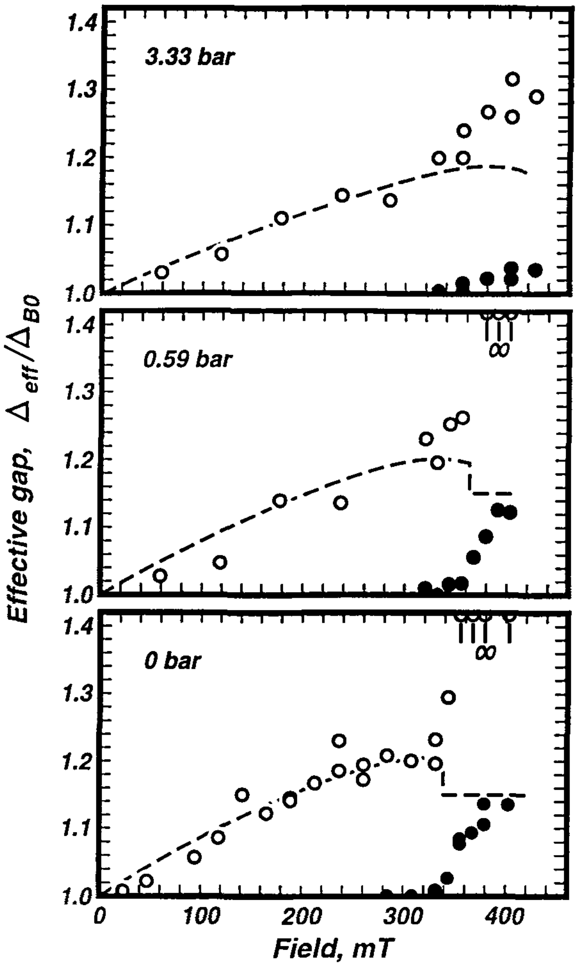

Figure 2: Results from the models, B-Phase(open symbols), A-Phase(closed symbols) and theoretical prediction(dashed line).

REFERENCES

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