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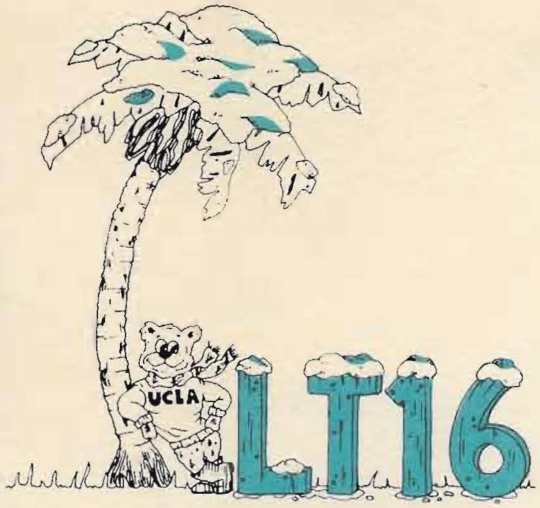

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MANOMETRIC MEASUREMENT OF MAGNETIC SUSCEPTIBILITY OF ^{4}He AND ^{3}He LIQUIDS IN HIGH MAGNETIC FIELDS

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A method has been developed for measuring the magnetic susceptibility of liquids in high magnetic fields at low temperature. The method has been tested with liquid ^{4}He and liquid ^{3}He. The sensitivity is adequate for an accurate measurement of the nuclear paramagnetism of liquid ^{3}He at 1 K and below.

INTRODUCTION

We have adapted the classical method[1,2] of measuring the magnetic susceptibility of liquids to low temperature measurements on ^{4}He and ^{3}He liquids. In essence, the susceptibility is determined from the liquid level difference in two arms of a manometer in different magnetic fields. The high sensitivity is obtained because of the high precision of capacitance measurements and the use of high magnetic fields.

EXPERIMENTAL METHOD

The apparatus is shown in Fig. 1. Two sheets of glass 0.5 cm x 4.0 cm and 0.015 cm thick are separated at the edges by mylar spacers about 25 μm thick. The inner faces of the glass are coated with evaporated indium-tin alloy films and have a capacitance when empty of about 70 pF. The glass plates are held in a veritcal position in a metal container into which He gas can be introduced through a capillary tube. The coaxially shielded leads to the capacitance bridge enter the container through epoxy seals. Because of the small separation of the capacitor plates, the capillary rise in height of liquid ^{4}He is about 1.45 cm at 1 K and for ^{3}He about 1.1 cm at 0.45 K. The capacitor plates fit closely in a slot in a short soft-iron cylinder, which is secured to the container wall. When a uniform magnetic field is applied to the region of the container, the soft-iron cylinder decreases the field inside the slot. If the liquid levels for H = 0 are as shown in Fig. 1 (deeply shaded), then in a high field the level in the capacitor will rise for a diamagnetic liquid such as ^{4}He. The liquid level in the container will decrease only slightly because of its much greater surface area. The change in height of the liquid in the capacitor, except for some small corrections, is

$$\Delta h = \chi(H_1^2 - H_2^2)/2\rho g. \qquad (1)$$

Here χ is the volume susceptibility of the liquid and ρ is its density. H_1 is the magnetic field at the liquid surface in the container and H_2 is the field at the liquid surface inside the capacitor. For a diamagnetic liquid, χ is negative and Δh is a positive quantity. In the present apparatus the decrease of the magnetic field in the center of the iron cylinder is about 0.9 T at fields above the saturation field of the iron, which is about 2.2 T. The field on the surface in the outer container is slightly greater than the applied field. Well above the saturation field for the iron, $H_1 - H_2 = \Delta H$ is nearly constant and the rise in height is given rather accurately by

$$\Delta h = \chi\,[2H_2\,H - (\Delta H)^2]/2\rho g. \qquad (2)$$

At very high fields Δh is nearly proportional to the applied magnetic field.

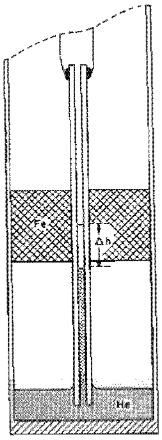

Figure 1 : Liquid He manometer showing liquid levels for H = 0 (darkly shaded) and the change in level Δh in a high magnetic field.

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MEASUREMENTS

Figure 2 shows the measured rise in height in the capacitor as a function of applied field for ^{4}He at 1.2 K. Δh is nearly proportional to H over much of the field range. The initial bump near 0.1 T is probably associated with the alignment of domains in the iron. The region up to about 1.2 T appears quadratic in H as one might expect before the iron is saturated. The downward curvature near the highest field reflects the fact that the liquid level has moved to very near the position of greatest shielding in the center of the iron. The measured value of H at 7.8 T agrees with the calculated value using Eq. (2) and the known value of χ.

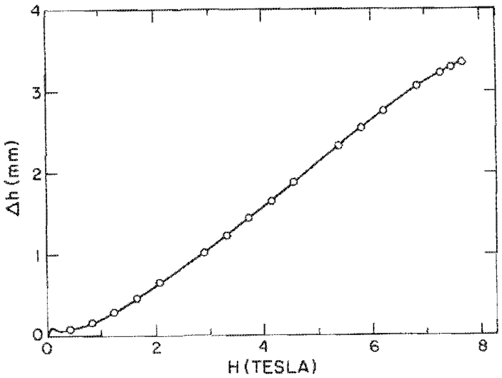

Figure 2 : Increase in liquid level within the capacitor for ^{4}He at 1.2 K as a function of magnetic field for the H = 0 level shown in Fig. 1.

DISCUSSION

The least detectable rise in height in the present measurements was about 2 μm. This sensitivity allows $\chi(^4He)$ to be measured to 1 part in 2000 provided we accurately know the amount of magnetic shielding. In practice we use ^{4}He to calibrate the equipment for use with ^{3}He. At 1 K the nuclear paramagnetic susceptibility of ^{3}He is about 7% of the atomic diamagnetic term and varies as 1/T. In high fields at 1 K it should be possible to measure the nuclear term to about 1% and with increasing accuracy at lower temperatures. Preliminary measurements on ^{3}He agree with this analysis.

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