

BACKGROUND SIGNALS IN SQUID MAGNETOMETERS*

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ABSTRACT

Since a SQUID magnetometer is an extremely sensitive device capable of detecting minute magnetic flux changes in a sample, it will also detect unwanted signals from materials near the magnetometer. The presence of temperature dependent "background signals" limits the accuracy of measurements of the temperature variation of the magnetization of a sample. Measurements of the magnetization from 1K down to 0.01K of materials used in the construction of the magnetometer described here show that these materials are responsible for the background signals. From these data, magnetometers can be designed so that the background contribution introduces an uncertainty of less than one flux quantum for a temperature change from 1K down to 0.01K in a field of 100 Oe.

INTRODUCTION

One of the most important applications of SQUID magnetometers is in investigations of electronic^{1,2} and nuclear magnetism in solids³ at low temperatures and in small magnetic fields. An important problem, quite often not realized, is that since this device is so sensitive, it will easily detect unwanted signals (known as background signals) from materials used in the construction of the magnetometer. These background signals vary with temperature. This causes difficulties when studying the temperature dependence of the magnetization of very weakly magnetic systems such as nuclear spins³ at very low temperatures and it is a limitation on the use of the full sensitivity of the magnetometer. One source of background signals had previously been traced to the enamel insulation⁴ on the niobium wire used in the flux transformer for coupling the flux from the sample to the SQUID. In the magnetometer to be described here, the flux transformer was wound with heavy Formvar insulated niobium wire. There was still a temperature dependent background signal and this has stimulated an investigation of the magnetic behavior of the materials used in the construction of the magnetometer.

APPARATUS

The apparatus was designed for studies of the magnetization of dilute magnetic alloys or of nuclear paramagnets from approximately 2K down to 0.01K using a ³He-⁴He dilution refrigerator and a SQUID magnetometer. The sample is placed inside the mixing chamber in direct contact with the dilute ³He-⁴He solution. To measure the magnetization of the sample, its magnetic flux is coupled by means of a superconducting flux transformer to the SQUID sensor anchored at 4K. The steady field that establishes the magnetization is achieved by trapping an externally applied field in a superconducting niobium tube around the sample. This tube is 2.5cm long, 5.0x10⁻¹cm i.d. and 5.7x10⁻¹ o.d. Figure 1 shows the details of the very low temperature part of the magnetometer.

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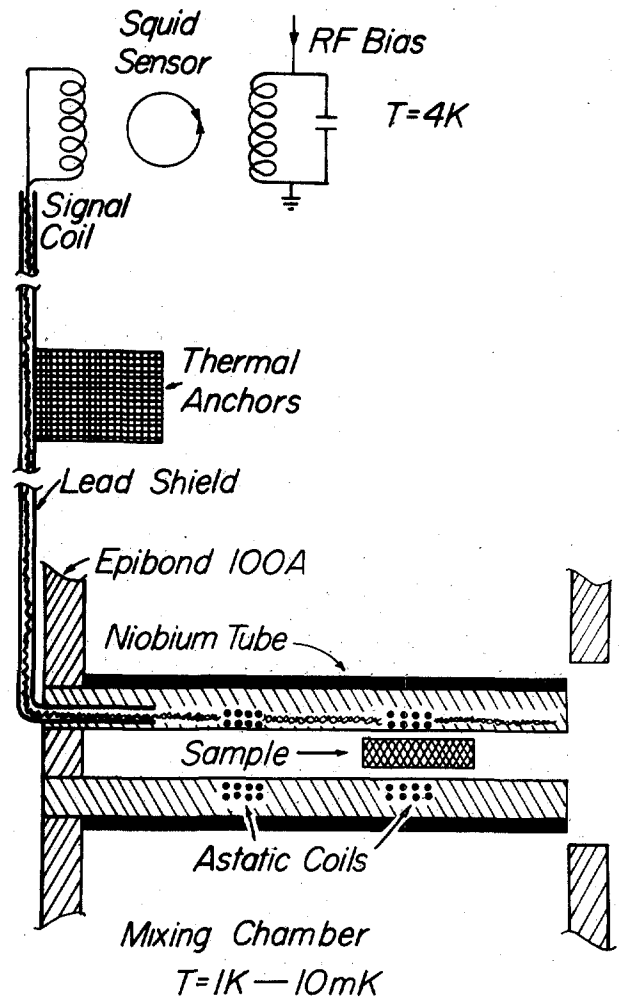


Fig. 1 Low temperature SQUID magnetometer.

The flux sensor consists of an astatic pair of coils, the sample being in one of them; each coil consists of 24 turns of 7.6x10⁻³cm diameter Formvar insulated niobium wire. Such a differential arrangement minimizes outside contributions to the signal. The asymmetry of the astatic pair is estimated to be 1%. The very low temperature part of the magnetometer forms a rigid unit that is not susceptible to vibration; this is achieved by embedding the sensing coils in epoxy resin, Epibond 100A,⁶ and gluing this unit with Epibond 121 (with Hardener 946) to the niobium tube. The twisted leads going from the astatic pair to the signal coil in the SQUID sensor are magnetically shielded with lead foil. The signal coil at the SQUID sensor has 86 turns of the same niobium wire as used in the flux sensor coil.

For determining the temperature, a CMN thermometer is located inside the mixing chamber and its magnetization is determined with another SQUID magnetometer. Such an arrangement allows the magnetization of a sample to be measured as a function of temperature.

RESULTS

To investigate the possible contributions to the background signal, samples of Epibond 100A, Epibond 121, heavy Formvar insulated niobium wire, lead foil, and niobium, were investigated since they were used in the construction of the magnetometer. This would indicate which materials could cause significant contributions to the background signal. The magnetization of these samples was measured in a field of 100 Oe from 1K down to 0.01K. An external field is applied at high T to the niobium tube surrounding the sample, and this field becomes trapped within the tube when the latter is cooled below its transition temperature. In order to ensure that there is no trapped flux in the lead foil or induced currents in the flux transformer as a result of this procedure, both the lead shield and the transformer are then heated until they become normal; they are then subsequently cooled. Table I shows the flux at the SQUID sensor due to the materials investigated in a field of 100 Oe and for the temperature range 1K to 0.1K; this flux is normalized to the flux quantum ϕ_0 .

Table I

Signals due to Various Materials Used in Magnetometer. The temperature range is 1K-0.1K, the field is 100 Oe.

Material	Shape	Signal ϕ_s/ϕ_0
Epibond 100A	solid cylinder, 6.4mm long, 2.4mm diameter	0.40/T
Epibond 121 (+ Hardener 946)	solid cylinder 6.4mm long, 2.4mm diameter	2.93/T
Nb wire, with heavy Formvar, 7.6×10^{-3} cm dia. 0.6 cm long	bundle of 32 wires	0.82/T
Empty magnetometer		0.40/T
Compensated empty magnetometer		0.07/T
Aluminum	solid cylinder 6.4mm long, 2.4mm diameter	0.62/T

Actually the flux ϕ_s at the SQUID sensor is related to the flux ϕ produced by the sample by

$$\phi_s = f \phi \quad (1)$$

where f is the flux transfer factor and is approximately equal to $(M/2L)N$. M is the mutual inductance between signal coil and SQUID sensor, L is the inductance of the signal coil, (for optimum flux transfer, the inductance of the signal coil should be equal to that of the astatic pair⁷) and N is the number of turns in the coil around the sample. The flux transfer factor f for the magnetometer used here is 0.034.

For comparison, the background signal (without any sample) is also given in Table I. This background signal was subtracted from the measurements of all the samples listed in Table I. The magnitude of this background signal is such that it is comparable to the signal from nuclear spins in aluminum (Table I). A piece of lead foil and a piece of niobium sheet (used in the field trapping tube) were rolled in the form of a tube ~1mm diameter and their magnetization was measured as well. The signal in an applied field of

100 Oe for the lead was $\phi_s/\phi_0 = 0.5/T$ and $0.4/T$ for the niobium. Calculations show that these signals cannot be attributed to impurities within the penetration depth of the lead and the niobium. These signals are most likely due to the change of inductance of one of the astatic coils (caused by a superconducting loop formed by the lead and niobium samples), thus emphasizing the background signal. Below 0.1K the magnetization signals showed departures from Curie-Weiss behavior due to saturation or due to lack of equilibrium as in the case of Epibond 100A. At the lowest temperatures, equilibrium times for the Epibond 100A were very long (more than 4 hours); this is not unexpected as part of the signal was due to the protons which would likely have a long relaxation time in such a material.

It is instructive to examine Table I to determine which is the most likely source of background signals in our magnetometer. The Epibond 121 (with Hardener 946) has a large signal; when this resin was mixed it had some color which is indicative of paramagnetic ions. This material was used mainly as a vacuum-tight glue for the Epibond 100A and for attaching the astatic pair of coils firmly to the niobium tube. The epoxy resin was not distributed symmetrically around the astatic coils, hence contributing to the signal. Therefore in designing the very low temperature part of the magnetometer it is important to minimize the amount of epoxy-resin because of its magnetic behavior and the long relaxation times which can cause spurious signals.

Special precautions were taken to maintain the symmetry of the very low temperature part of the magnetometer; also all nylon sleeving was removed from around the flux transformer leads in the region of the magnetic field as it also contributed to the background signal. The signals observed here compare well with previously quoted values at higher temperatures.⁸

Instead of redesigning and rebuilding the magnetometer, it was convenient to compensate the background signal. This was achieved by placing a small amount of Epibond 121 on one side of the sample holder (a thin Epibond 100A tube with the top half cut away). The result was a background signal in 100 Oe of $\phi_s/\phi_0 = 0.07/T$ at the SQUID sensor. This is reproducible to 10%, which means that the background signal can be subtracted from the sample signal to within $\phi_s/\phi_0 = 7 \times 10^{-3}/T$. Such accuracy is adequate for many measurements. It is interesting to note that although the root-mean-square equivalent flux noise for a typical SQUID⁷ is $10^{-4} \phi_0$ for a bandwidth of 1 Hz, background signals presently limit the accuracy of temperature dependent magnetization measurements.

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REFERENCES

1. E. C. Hirschhoff, O. G. Symko and J. C. Wheatley, *J. Low Temp. Phys.* **5**, 155 (1971).
2. J. C. Doran and O. G. Symko, to be published in *Solid State Communications*.
3. E. C. Hirschhoff, O. G. Symko, L. L. Vant-Hull and J. C. Wheatley, *J. Low Temp. Phys.* **2**, 653 (1970).
4. E. C. Hirschhoff, O. G. Symko and J. C. Wheatley, *J. Low Temp. Phys.* **4**, 111 (1971).

5. Available from SHE Mfg. Corp., San Diego, Calif.
6. Available from Furane Plastics Inc., Los Angeles Calif.
7. R. P. Giffard, R. A. Webb, and J. C. Wheatley, J. Low Temp. Phys. 6, 533 (1972).
8. G. L. Salinger and J. C. Wheatley, Rev. of Sci. Instruments 32, 872 (1961).