MASTER

MICRO-MAGNETIC SUSCEPTOMETER FOR THE ACTINIDES*

S. E. Naves and Paul G. Huary

Department of Physics, University of Tennessee, Knoxville, TN 37916, and
Transuranium Research Laboratory, Oak Ridge National Laboratory, Oak Ridge,
TN 37830.

A D.C. magnetic susceptometer incorporating a SQUID as a magnetic flux sensor has been constructed with sensitivity to measure the magnetic susceptibility of submicrogram actinide samples as a function of temperature. For a two microgram actinide sample the minimum measurable dimensionless susceptibility is $\sim 10^{-7}$ CGS in a 2000 gauss field. The sensitivity has been determined in a series of calibration experiments using samples of lead spheres at 4.2°K. Pick-up coils insensitive to changes in spatially uniform fields and fields with a constant first derivative were used to reduce noise. The field was trapped in a niobium cylinder to produce a uniform stable applied field. The flux produced by the sample in the pick-up coils is proportional to the magnetic susceptibility of the sample and is a function of the sample position.

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INTRODUCTION

With the development of the Superconducting Quantum Interference Device (SQUID) a high sensitivity magnetic susceptometer has become available for use in determining the magnetic properties of limited sample quantities. We have constructed an apparatus based on these electronics which emphasizes a large sample to pick-up coil flux transfer ratio. At the same time we have retained the versatility of variable sample temperature between 4.2 K and room temperature, and an externally applied magnetic field, up to 2000 gauss.

APPARATUS DESCRIPTION

A cross-sectional diagram of the low-temperature part of this apparatus is shown in Fig. 1. The crosshatched parts of the apparatus remain immersed in a liquid helium dewar. The pick-up coils are located in the geometric center of a superconducting magnet (not shown). Trim coils above and below this magnet provide a null field in the neighborhood of the SQUID and maintain a below critical field for the shield tubing and lead wires. A thermally activated niobium cylinder (Fig. 1) is rigidly attached about the pick-up coils to shield them from external electromagnetic noise and to trap the uniform applied magnetic field. The pick-up coils are wound with a 1.5 mm inside diameter in a "second derivative" fashion so that they do not respond significantly to changes in a spatially invariant magnetic field nor to changes in a field with constant first derivative. This geometry, shown in Fig. 2, reduces the effect of external noise, and ideally gives a persistent response only when a sample is displaced relative to the coils in the presence of an applied field. The design achieves a maximum fractional coupling of 0.0029 of the sample flux to the SQUID element.

The samples are held by G.E. 7031 varnish in a 0.2 mm cavity drilled in the side of a uniform .5 mm diameter gold wire. The wire is enclosed

inside a quartz tube for positioning and insulation. The gold wire is held by a copper chuck which contacts a thermal ballast (Fig. 1). The ballast contains heaters and a variety of thermometers. The chuck, gold wire, and sample may be removed through a vacuum interlock for sample exchange. The entire chuck and ballast may also be driven up or down by a motor at a rate of 15 $\mu\text{m}/\text{sec}$. This displacement moves the sample through the pick-up coils and is detected by a linear potentiometer.

A series of experiments were conducted to calibrate the apparatus. In one a 60-microgram sphere of lead was used to define the sample susceptibility as $\chi = -1/4\pi$ due to its perfect diamagnetism at 4.2 K. A plot of the theoretical magnetic flux per unit dipole moment of the sample, $\frac{\Phi}{\mu}$, versus position in our pick-up coils is illustrated in Fig. 2. Points taken from an experimental measurement, Φ_{signal} , versus position of the sample in our pick-up coils is also given for comparison in Fig. 2. For a sphere the sample moment is $\mu = \frac{3}{2} \frac{\chi m}{\rho} H$, where m is the sample mass, ρ is its density, and H is the applied field. Thus, $\Phi_{\text{signal}} = \left(\frac{-3Hm}{8\pi\rho} \right) \left(\frac{\Phi}{\mu} \right) f$. f (the flux transfer ratio) is the fraction of the sample flux coupled to the SQUID and depends on the various coil geometries through their inductances. The value of f obtained by using the response when the sample is in the geometric center of the coils is 0.0029.

For the 8.3 gauss measurement shown in Fig. 2, a maximum signal of $163 \Phi_0$ was obtained. $\Phi_0 = 2.07 \times 10^{-7}$ gauss-cm². Since $\Phi_{\text{signal}} \propto \chi H m$ it may be seen that a 0.1-microgram sample of ²⁴⁹Cf metal (which has $\chi = 10^{-3}$ at 50 K) is expected to give a signal of $0.6 \Phi_0$ in a field of 2000 gauss. This measurement is accessible with our system noise level of $10^{-3} \Phi_0$. For a two microgram actinide sample in a 2000 gauss field our minimum measurable dimensionless susceptibility is thus $\Delta\chi \sim 10^{-7}$ CGS (or $\Delta\chi_g \sim 10^{-6} \frac{\text{cm}^3}{\text{gm}}$).

With these sensitivity levels measurements should be of sufficient accuracy so as to be limited by other uncertainties such as sample geometry, bulk and surface contamination, and reproducibility of weighing. A computer program designed to compensate for a distribution of magnetic moments has been written to deconvolute the flux vs. position data. With this program we may to first order account for geometrical sample or coil irregularities.

FIGURE CAPTIONS

Fig. 1. Cross section of the low temperature part of the micro-magnetic susceptibility apparatus.

Fig. 2. A plot of the theoretical magnetic flux divided by the sample moment $\frac{\Phi}{\mu}$ (in cm^{-1}) coupled to the persistent pick-up coils (also indicated) as a function of the position (in mm) of a spherical sample. Points taken from an experimental measurement, Φ_{signal} , are also indicated for a 60 μg lead sphere in a uniform 8.3 gauss field.

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