The CMP Magnetic-Susceptibility Experiment

The magnetic response of nominally non-magnetic materials is a non-destructive view into the spin content of materials. TeachSpin already offers a Foundational Magnetic Susceptibility experiment to make possible the room-temperature, and absolute, measurement of the magnetic susceptibility χ. Now we are announcing the Magnetic Susceptibility experiment that is part of our Dewar-based CMP system. It uses an a.c. technique to measure the relative χ of solid and powdered materials in the temperature range 80 ï 400 K.

In response to an experimentally-controlled magnetic field *H*, samples develop an internal magnetization (magnetic moment per unit volume) *M*. Para- and dia-magnetic materials are characterized by **susceptibility** χ , defined via the relation $M = \chi H$. The value, and especially the temperature dependence, of χ for materials is direct evidence for the kind of magnetic response they undergo. Many materials display diamagnetic response with χ negative and temperature-independent, while the simplest (Curie-Law) paramagnetic materials exhibit a χ that is positive, and inversely proportional to absolute temperature.

For use in our Dewar system, we have built an a.c.-susceptibility measurement system based on a specialized ódifferential transformerô called a **Hartshorn coil**. A primary coil of solenoidal form, excited by an audio-frequency a.c. waveform, creates a field *H* of size up to 1600 A/m (20 Oe). This field also exists inside our samples, which approximate long thin cylinders. Then the differential emf induced in two secondary coils is a direct measure of the a.c. magnetization $M(t)$ developed in the sample. We depend on a lock-in technique to measure the amplitude and phase of that audio-frequency emf.

Our **samples** all have the same form, of epoxy-bonded cylinders of 6 mm diameter and 25 mm long. Typically about 0.5 g of powdered material suffices to form a sample. Our experiment comes with a dozen prepared samples, and with all thatôs needed for users to prepare dozens more. The experiment is easily sensitive enough to detect the (diamagnetic) response of an all-epoxy óblankô sample, and the contribution from the epoxy in a general sample can be accurately subtracted. The smallest detectable magnetic moments arising are $\approx 10^{-9}$ A·m^2 ($\approx 10^{-6}$ emu).

We have devised a way to position the samples inside our Hartshorn coil, in a 1-atmosphere pressure of nitrogen gas. The presence of the gas, together with the **all-alumina** construction of our Hartshorn-coil form, give good thermal contact between the sample and its temperature-controlled environment.

Our equipment includes the sample-holding probes needed for use in the Dewar, and a special probe equipped with a temperature transducer that can simulate a sample, and which gives a transferable standard for temperature measurement inside the Hartshorn coil. We also have prepared samples to help students learn the use of **phase-sensitive** lock-in detection to distinguish between the magnetic-susceptibility, and the electrical-conductivity, response of a sample.