# Ultrasensitive Micromachined Si Magnetometers for Magnetization Measurements at Very Low Temperatures and Very High Magnetic Fields

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## Introduction

Magnetization, which is a thermodynamic variable of state, i.e., the derivative of the free energy respect to the magnetic field, provides crucial information about the magnetic state, magnetic and electronic phase transitions, their corresponding critical behavior (for a second order phase transition) as well as the actual valence of ions in a variety of compounds. In metals it is a function of the density of states at the Fermi level. It is thus one of the most important physical parameters characterizing a material. Most of the techniques currently available to measure magnetization in magnetic or weakly magnetic materials require samples with a mass in the order of several tenths of milligrams. However, one is frequently confronted with the fact that highly valuable single crystals of new materials, usually grown by the self-flux method, may weigh a milligram or even a fraction of it. Other techniques, such as AC-susceptibility that can be optimized to measure small samples, are difficult to adapt to sub-kelvin or millikelvin temperatures particularly when coupled to extremely high magnetic fields. Here we show that one can measure samples with masses as small as 1 microgram using micromachined Si magnetometers, by picking up the natural force produced in a magnetic single crystal under the natural gradient of a resistive magnet.

## Experimental

A special probe was built to measure four samples in respectively four magnetometers per Si chip down to $^3$He temperatures. The sample mass were determined from the shift in the natural resonance frequency of each device, after determining the mass of the glue by the same method. The actual design, allows a relatively important torque signal for relatively large samples when the device is placed at the field center. To subtract the torque component the device is placed respectively above and below field center (typically 1 cm above/below field center in a 33 T class magnet) with the subtraction of both curves leading to the removal of the torque signal. Magnetization measurements as a function of field and temperature were performed in the first single crystals of the spin-dimer compound $Ba_3Cr_2O_8$ [1] whose overall behavior is consistent the existence of a Bose-Einstein condensation of spin-triplet excitations. The mass of this crystal is ~1.3 μgrams.

## Results and Discussion

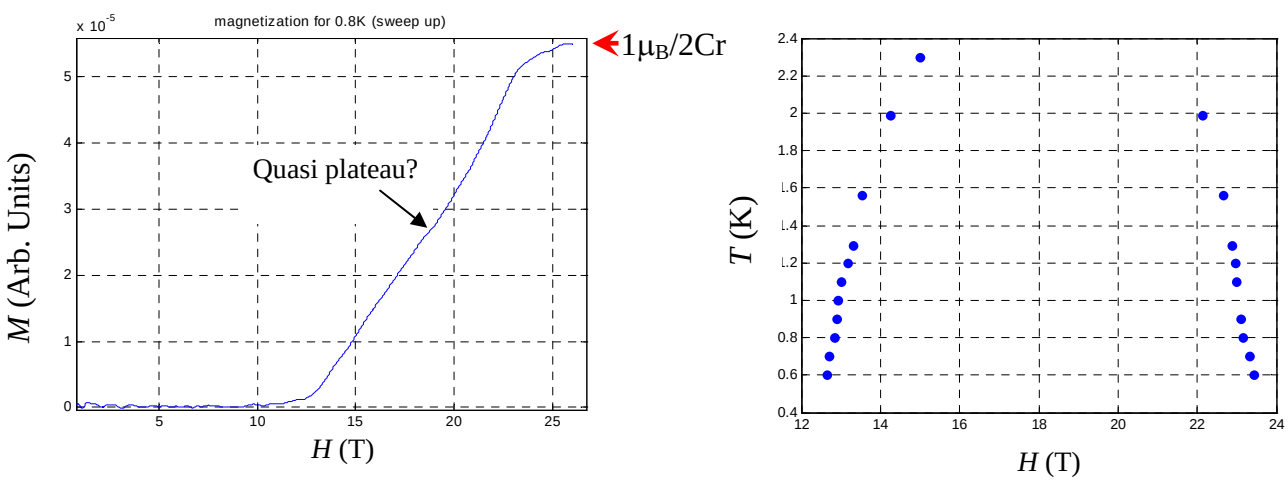


Fig. 1 Left panel: Typical trace of the magnetization for a $Ba_3Cr_2O_8$ single crystal as a function of field at 0.8 K. Evidence for the development of a quasi-plateau in the magnetization is seen at ~ 18 T. Right panel: The preliminary phase diagram obtained with our technique revealing anisotropy.

## Conclusions

The technique is easy to couple to high magnetic fields and is easily extendable to millikelvin temperatures. As for $Ba_3Cr_2O_8$, the quasi-plateau at first glance seems consistent with the prediction of a possible spin super-solid phase [2].

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## References

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[2] P. Sengupta and C. D. Batista, Phys. Rev. Lett. **98**, 227201 (2007)