Phys316 Exploration 3: *Measuring the Curie Point of a Magnet*

<u>Preliminary</u>

Ferromagnetic materials have a permanent macroscopic magnetization at temperatures below their ferromagnetic phase transition temperature, or Curie point. When heated above the Curie point these materials become paramagnetic, and will have no macroscopic magnetization. The Curie temperature (T_C) of iron is about 770 °C, and 358 °C for nickel.

1) Sketch your expected dependence of the magnetization of a ferromagnet as a function of temperature in the space below.

<u>Preliminary 2:</u> Theory

Consider a model system with $N_{\uparrow}$ particles with spin up, and $N_{\downarrow}$ particle with spin down. Let $= N_{\uparrow} + N_{\downarrow}$. Assume that the particles in our ferromagnet are spatially separated on a crystalline lattice.

2) Write down the equation for the partition function of a magnetic particle in a field *B*.

3) Using the semi-classical treatment, generalize the partition function to a system of *N* particles.

4) Derive an equation for the magnetization of the sample in a magnetic field *B.*

5) Plot this function in reduced units for $\langle M \rangle / m_B$ vs. $m_B B / kT$.

Project 1:*Measuring the Curie Point of a Magnet*

Apparatus

The major items used in our setup are:

• Two small (0.8-cm diameter) ferromagnetic cylinders, one iron, one nickel.

• A Type K thermocouple

• A metal heat sheild

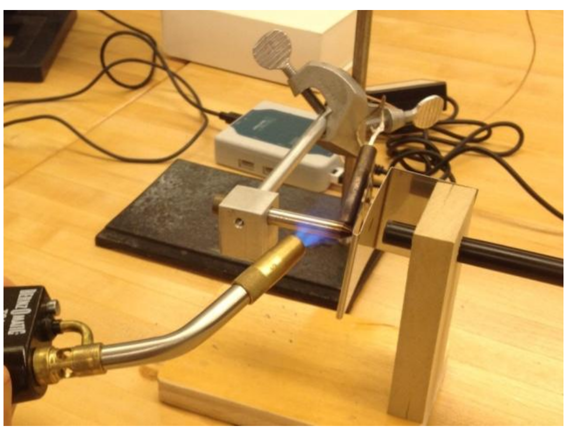
• One neodymium disk magnet

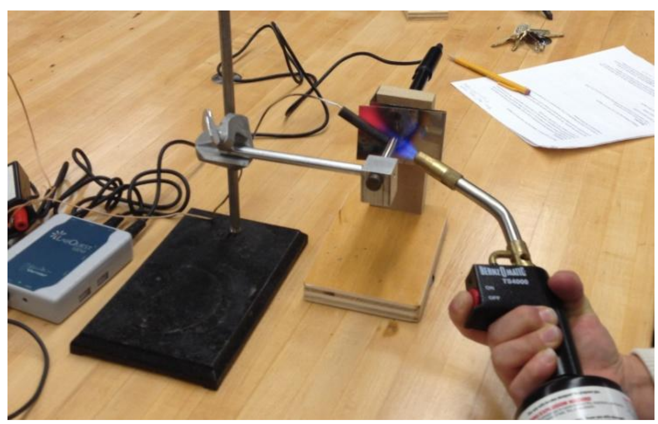
•One Hall Probe

•Vernier display.

The thermocouple is coated with a thin layer of a thermal insulating material so that only the end of the probe is free. This end is inserted into the hole of one of the cylinders, and the cylinder is mounted in a stand to support the apparatus. All of the support pieces and heat shield are non magnetic.

The disk magnet is placed at the end of a cylindrical stainless-steel bar. This provides a constant background magnetic field which helps the systems magnetism recover. The Hall probe is placed ~1/4 inch from the heat shield in order to measure the strength of the magnetic field. The cylinder tip is placed very close to the heat shield. See images below.





Experiment

Read through this entire section before beginning to take data. You will need to designate a person to control the butane torch.

1) Make an estimate of the background magnetic field due to the neodymium disk magnet, by removing the ferromagnet, but maintaining the approximate distance from the permanent magnet to the Hall Probe. Record the value here.

Begin recording the temperature, you may need up to a few hundred seconds in order to reach the appropriate curie temperature (the metal may glow red) and fully cool the system. The heating of the iron will require far more time than the nickel. Heat the cylinder to well above the designated Curie point, so that the material is paramagnetic (~850 °C iron, 450 °C nickel). Heat the cylinder at a distance of about 1 inch from the tip of the cylinder and at a distance of about 1 inch from the exit of the torch. The magnetic field will not reach zero, as the presence of the permanent magnet ensures some residual magnetic field. Therefore heat only until the magnetism seems to level out, or for about 20-30 seconds after the steep decline in magnetic field.

At a temperature above the Curie point, stop heating the cylinder. Allow the temperature to cool continuously while recording the temperature.Please save and export your data as a *.csv or *.txt file to analyze it in excel. If you like you can also save the latest run in order to directly compare both materials by selecting Experiment/Store Latest Run.

2) If you continue to heat, the magnetic field will continue to drop slowly. Why?

Project 2: Data Analysis

Finish acquiring data for one cylinder before continuing on to this section. You may break up into smaller groups for the analysis if you prefer.

3) Plot your data of the recovery of the Magnetic field vs. 1/temperature. You will need to select this data and use Exel. Does your data resemble that of the theoretical prediction you made in problem 5 of the preliminary lab? In what ways does your data differ?

4) What is the apparent T_C of your sample? Why might it differ from the literature value? Check your value of T_C upon cooling, is this significantly different than the value upon heating? Discuss.

5) Correct your data for the heating up to the Curie point for the background magnetic field, that is subtract off the value of the magnetic field for the permanent magnet as estimated from problem 1. Now plot the corrected magnetic field divided by the final corrected magnetic field (M/M_{final}) vs. the temperature divided by the Curie temperature (T/T_C). Sketch your plot on the paper provided.

10) Mean Field theory predicts that the magnetization of a sample as we approach the curie point will follow the functional form

$$M = constant \times \left(\frac{T_C - T}{T_C}\right)^{\beta}$$

where the 3-D Ising model predicts a value of 0.325 for β. A plot of the spontaneous magnetic field for Iron as a function of temperature is shown in Figure 1, along with a theoretical fit from the Ising model. Experimentally β ranges from 0.33 to 0.42. Does your data appear to recover according to this critical exponent behavior?

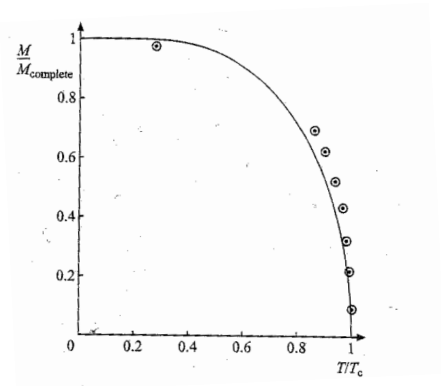


Figure 1 Spontaneous Magnetism vs. Temperature for Iron.

Critical phenomena appear in many systems poised close to their phase transition temperatures. We will discuss some of them next week.

11) Repeat for other material.