Determining the Curie Temperature of Minerals with Ferromagnetic Properties Using Hysteresis

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In today's society materials that possess ferromagnetic properties prove to be extremely useful. They have a wide range of applications, from the construction of audio speakers and motors to computer hard disks and videotapes [1]. To better understand these materials, we study the minerals that make them up.

Ferromagnetic minerals are minerals in which the neighbouring dipoles align themselves parallel to each other in the presence of a magnetic field and remain magnetized even in the absence of this external magnetic field [2]. Not all minerals that display ferromagnetic properties, ability to remain magnetized when removed from an external field, are necessary ferromagnets. Ferrimagnetic minerals display ferromagnetic properties but instead of parallel alignment of the dipoles, they have anti-parallel alignment of unequal spins[3].

When these minerals are subjected to increasing temperatures, there is an increase in thermal agitation. This increase in agitation means that there is a decrease in the effectiveness in the dipole alignment. When the temperature is great enough to completely break up the dipole alignment, the mineral becomes paramagnetic. This temperature is referred to as the Curie temperature [4]. Determining this temperature can be crucial because it allows us to know at what temperature the ferromagnetic properties will be lost. This means it creates an upper temperature limit and that we must take this into consideration when constructing something that depends on a material's ferromagnetic properties.

To determine the Curie temperature, we will plot the mineral's hysteresis curve. Hysteresis is the delayed effect in a material's magnetization when the external magnetic field is changed. This curve allows us to determine the saturation point of the mineral, which is the point at which the mineral can no longer be magnetized. Above the saturation point, the ferromagnetic material becomes paramagnetic [5]. A paramagnetic material is one in which the atoms only react with each other when a magnetic field is present. These materials are weakly attracted to magnets and are commonly considered as non-magnetic because their magnetism is extremely weak in comparison to that of a ferromagnetic material [6]. This means that any point above this temperature will diverge from the hysteresis curve and that this saturation temperature is the Curie temperature. By plotting a mineral's hysteresis curve, we can determine its Curie temperature by determining the curve's saturation point and where it diverges from the curve. This transition from ferromagnetic to paramagnetic at the saturation point is not gradual therefore it should be easily measureable[7].

To ensure the accuracy of our results, determination of the Curie temperature, we will plot the mineral's magnetization as a function of its temperature. The temperature where the mineral's magnetization experiences a sharp decrease, because it is paramagnetic and not ferromagnetic, will be the Curie temperature.

To make the measurements that will allow us to determine the Curie temperature, we will use the ballistic method. This requires us to crush the sample into grains and pack them tightly into a cylindrical vessel. To ensure we do not destroy the mineral, the crushed grains should be of a diameter of approximately 0.5 mm [8]. The apparatus to be used to help us determine the Curie temperature can be seen in Figure 1.

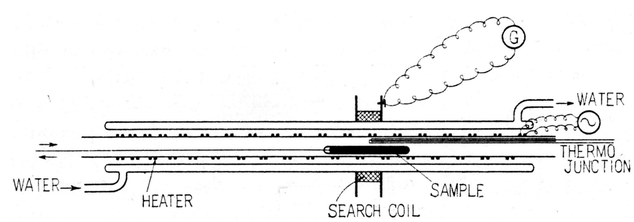

Figure 1: "Schematic view the device for measurement of magnetisation of rocks at high temperatures" [9].

The diameter of the coil should be as small as possible and its length small compared to that of the sample. The bobbin of the heating coil should be made of fused silica or porcelain as to ensure that the electric furnace remains non-inductive and non-magnetic. Following the same reasoning, the heating coil should be either platinum or pure nichrom wire. For the field coil that produces a magnetic field around the test sample, a Helmholtz coil is best. To be able to generate a hysteresis curve, our field coil must be able to produce a magnetic field equal to or greater than 0.2 T. This value can be obtained with the use of an electromagnet. The electromagnet is to be at the poles of the search coil as seen in Figure 2 [10].

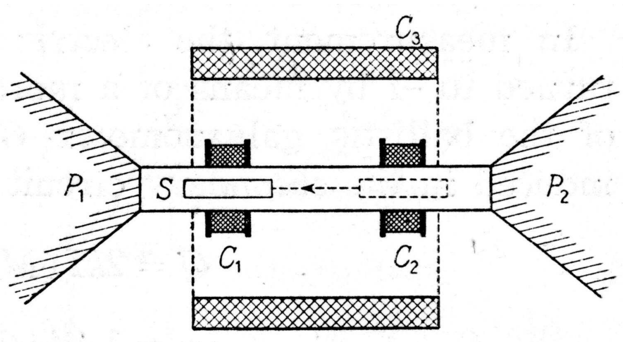

Figure 2: "The search-coil system for measuring the magnetisation of rocks in a strong magnetic field. S, sample; C_1, C_2, seach-coils; C_3, compensating coil; P_1, P_2, pole-pieces of Weiss elecromagnet" [11].

This induced EMF can be measured by the galvanometer. With the adjustment to the apparatus seen in Figure 1, we will be able to plot the hysteresis curve and the relationship of the magnetization vs. temperature. This allows us two separate methods of determining the Curie temperature.

The minerals we have chosen to study are magnetite, hematite, and pyrrhotite. Magnetitie (Fe_3O_4) is one of the most important magnetic minerals. It is a ferrimagnetic mineral that displays strong magnetism [12]. The importance of this mineral is that it is a major iron ore which is used by the oil industry [13]. Hematite (Fe_2O_3) is another iron ore and proves to be the most important ore for steel manufacturing. It is also used in pigments, red ochre, polishing powder, and can be cut as gems [14]. Finally, pyrrhotite ($Fe_{(1-x)}S$) takes advantage of the magnetic properties of Fe and S. It is a ferrimagnetic mineral that displays magnetism, weaker than magnetite [15]. Its uses include being a source of sulphur and an iron ore [16]. By being able to determine the Curie temperature of these minerals, we can better understand and utilize them.

References

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A Material List

- Samples of hematite, magnetite, and pyrrhotite
- Rock crusher
- Multimetre
- Helmholtz coil
- The heating coil's bobbin that is made of fused silica or porcelain
- Heating Coil made of platinum or pure nichrom
- Electromagnet (Weiss - type electromagnet)
- Water
- Cylindrical vessel to house sample
- Large cylinder to house moving sample
- AC source
- Heater that can be fitted around the large cylinder
- Two cylinders that can be fitted on either side of the large cylinder to house water
- Loud speaker to propel sample a few centimetres

B Timeline

Week 1 :

- Assemble Apparatus
- Crush Minerals
- Write program to read in necessary data for the creation of the hysteresis and temperature vs. magnetization curves

Week 2 :

- Data retrieval and analysis for Magnetite sample

Week 3 :

- Data and analysis for Hematite
- Start data retrieval for Pyrrhotite

Week 4 :

- Finish data retrieval and analysis for Pyrrhotite
- Final analysis and report