Apparatus for Teaching Physics

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Determining the Curie Temperature of Iron and Nickel

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The phenomenon of ferromagnetism is well-known to high school and undergraduate students, and its physical basis is explained in most general physics textbooks.[1-2] There are some elegant undergraduate experiments that investigate the ferromagnetic-paramagnetic phase transition by means of the analysis of the magnetic properties and the electrical resistance of the material above and below the transition point.[3-6] However, most of the simple classroom demonstrations of this phenomenon are designed essentially for demonstrating the existence of the Curie point. In this paper we describe a rather simple demonstration experiment for determining quantitatively the Curie temperature of a ferromagnetic material.

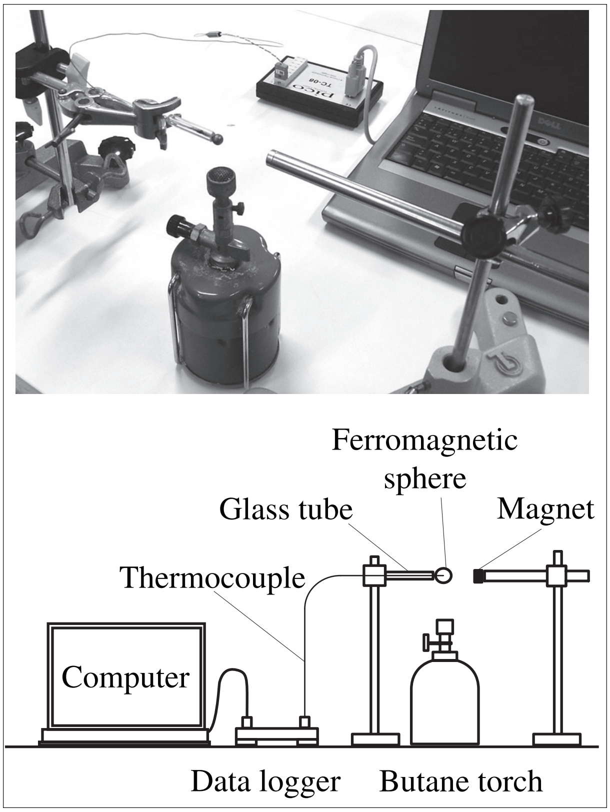

Fig. 1. Photo and schematic of the experimental setup used to determine the Curie temperature of iron and nickel. The end of a type K thermocouple is inserted into a small hole in the sphere, the temperature of which is recorded by means of a data logger connected to a PC.

At room temperature materials such as iron and nickel are ferromagnetic, and so they are attracted to a permanent magnet. When these materials are heated above a certain characteristic temperature, they become paramagnetic and are no longer attracted to the magnet. This characteristic temperature is named the Curie temperature (T_C) in honor of the French physicist Pierre Curie, who supposedly[7] discovered it in 1892. The Curie temperature is about 770ºC (1043 K) for soft iron and about 358°C (631 K) for nickel.[8]

A simple way to demonstrate the existence of the Curie temperature is with the so-called Curie-point pendulum.[9-13] In this experiment, a little piece of a ferromagnetic material (rod, nail, coin) is attached to the end of a thin wire, which is hung vertically. A nearby magnet attracts the piece of material, which is then heated with a Bunsen burner

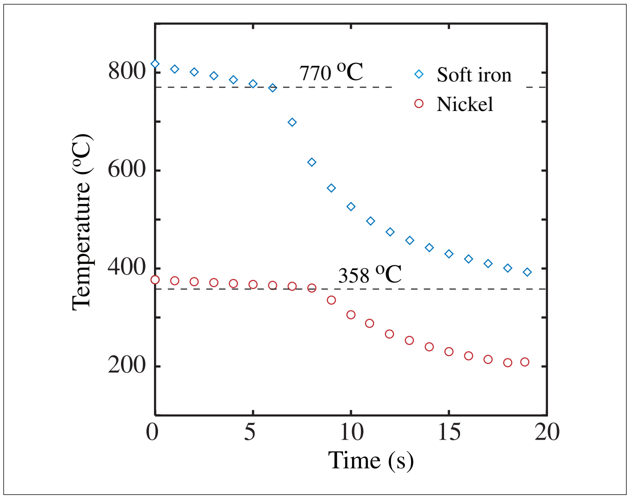

Fig. 2. Cooling curves for the iron and nickel spheres. The change in the slope occurs when the sphere jumps off the thermocouple and onto the magnet, indicating the corresponding Curie temperature (horizontal lines).

flame. When the temperature of the material exceeds its Curie value, it becomes paramagnetic and falls away from the magnet. After cooling, the material recovers its ferromagnetic character and is again attracted to the magnet. Another simple demonstration employs a small magnet attached to a horizontal ferromagnetic wire.[14] The wire is heated by passing an electric current through it. When it reaches its Curie temperature the magnet drops from the wire. Such demonstrations normally do not allow for a quantitative determination of the Curie temperature. However, Kizowski et al.[15] have shown how to modify the magnet/heated wire method to allow such determinations to be made. Their method requires a number of assumptions, measurements, and calculations that are not needed in our experiment.

Apparatus

The major items used in our setup are:

- Two small (0.8-cm-diameter) ferromagnetic spheres, one iron, one nickel. The spheres have radial holes 0.125 cm in diameter and 0.47 cm deep drilled into them.
- A Type K thermocouple (-270°C to 137°C with 0.1-cm diameter stainless steel probe).
- A cylindrical glass tube, 0.8 cm o.d., 0.15 cm i.d.
- One neodymium disk magnet, 1.2 cm diameter, 0.5 cm thick.
- Data logger 16 and PC.

The thermocouple is coated with a thin layer of a thermal insulating tape and passed through the glass tube so that only the end of the probe (0.47 cm) is free. This end is inserted into the hole of one of the spheres, and this assembly is positioned horizontally with the help of a clamp (See Fig. 1). The disk magnet is placed at the end of a cylindrical stainless-steel bar. To ensure that the system works properly, with everything at room temperature, the magnet is slowly brought close to the sphere (the axes of the magnet and thermocouple probe should be kept aligned). When the magnet is close enough (~2.5 cm), the sphere must slide off the thermocouple probe without any impediment and jump over to the magnet. Then the magnet is moved back to its original position and the sphere is again placed on the end of the thermocouple.

Experiment

The sphere is heated with the flame of the butane torch and raised above the metal's Curie temperature (~810°C for iron and ~400°C for nickel). The glass bar acts as a shield and thermal insulation for the thermocouple. The torch is turned off, and the magnet is quickly moved close to the sphere (~2 cm). The data logger/PC[16] system now records the thermocouple temperature once every second. While the temperature of the material is above its Curie temperature, the sphere remains in contact with the thermocouple. When the slowly falling temperature reaches T_C, the sphere recovers its ferromagnetic character and jumps to the magnet.[17] The end of the thermocouple is then free, and it cools very quickly due to the surrounding air, resulting in an abrupt change in the slope of the recorded cooling curve. This change makes it easy to identify the Curie temperature. Figure 2 shows the cooling curves for our iron and nickel spheres and the corresponding Curie temperatures, 770°C for iron and 358°C for nickel. If the magnet is situated very close to the sphere, the temperature indicating the jump can be slightly larger than the Curie temperature. This is because the cooling of the sphere is not uniform—its surface cools more quickly than the inside. The total time for the experiment (measurements for both spheres) is about 10 minutes—very reasonable for a classroom demonstration.

Acknowledgments

We are grateful for the financial support by the Ministerio de Educación y Ciencia of Spain under Grants BFM 2003-07106 FEDER and FIS2005-05081, and by Junta de CyL-FSE of Spain under Grants SA080/04 and SA092/04.

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14. See Ref. 9, E-104, p. 292.
15. Czeslaw Kizowski, Sylwia Budzik, and Józef Cebulski, "Finding the Curie temperature for ferromagnetic materials," *Phys. Teach.* **45**, 31–33 (Jan. 2007).
16. We have used the TC-08 temperature logger produced by Pico Technology Ltd.
17. At this point we immerse the sphere and magnet in a container of water in order to avoid excessive heating of the magnet.

PACS codes 01.50.Pa, 05.00.00

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Women in Physics: New Book Tells the Story for the First Time

Out of the Shadows: Contributions of Twentieth-Century Women to Physics, edited by Nina Byers and Gary Williams, is an important contribution to the history of science.[1] It is 40 stories of women who made major contributions to 20th century physics, written by distinguished scientists who are themselves actively engaged in the areas of physics about which they write... It cannot be read without a sense of regret at what the world lost by not having greater involvement of women in science. Even today, my freshman physics class averages only 10% women."[2]

[1] *Out of the Shadows: Contributions of Twentieth Century Women to Physics*, edited by Nina Byers and Gary Williams (Cambridge University Press, UK, Sept. 2006).

[2] Robert L. Park, *What's New,* Friday, 13 Oct 2006, http://www.bobpark.org/index.html.