Refrigerator Magnet Analogy for Scanning Probe Microscopy

Solving The Structure of the Atom

FLINN SCIENTIFIC CHEM FAX!

Introduction

Cut thin vertical and horizontal sections from a refrigerator magnet and then run these strips across the surface of the magnet. The strips act as probes that can be used to infer the arrangement of the magnetic poles on the magnet. The observations provide a simple analogy for the basic principle of scanning probe microscopy, which has allowed scientists to take “pictures” of atoms.

Concepts

- Atomic structure
- Scanning tunneling microscopy
- Nanotechnology

Background

All magnets have two opposite-polarity poles, a north pole and a south pole. No matter how small a bar magnet is broken up, each piece will always have a north pole and a south pole. When two magnets are placed side-by-side, the interaction between them will depend on the relative arrangement of the poles on the two magnets. Magnets will physically repel each other if two identical poles of the magnets are facing each other (either N/N or S/S)—the magnets do not want to touch. When the north pole of one magnet is brought close to the south pole of the second magnet, however, the magnets will attract each other and come together.

Materials

Refrigerator magnet, large

Scissors

Safety Precautions

Although this activity is considered nonhazardous, please follow all normal classroom or laboratory safety guidelines.

Procedure

1. A typical refrigerator magnet consists of multiple magnets. Discuss the nature of a permanent magnet, specifically, that there must be two opposite poles, and have students brainstorm the possible arrangements of the north and south poles on a refrigerator magnet. Some possible orientations are shown below.

Some possible magnetic pole arrangements for a refrigerator magnet.

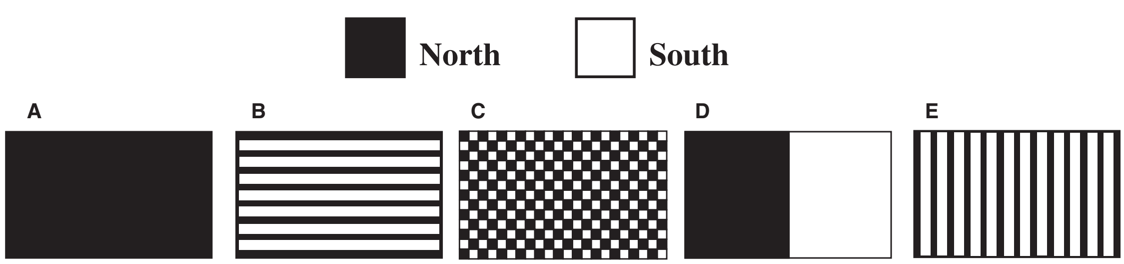

Figure 1. Possible orientations of magnetic poles for a refrigerator magnet.

2. Cut thin horizontal and vertical strips from the top and side of the magnet, respectively (see Figure 2).

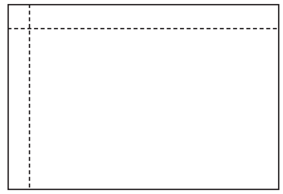

Figure 2. Cut thin sections of the refrigerator magnet to use as probes.

3. Run the horizontal strip or probe across the back of the refrigerator magnet in all directions (up and down, side to side, etc.) Note any interaction(s). Does the probe slide or flow smoothly across the back of the magnet? Does the probe stick to the magnet? Does the probe alternately skip and slide over the surface?
4. Run the vertical strip or probe across the back of the refrigerator magnet in all directions (up and down, side to side, etc.) Note any interaction(s). Does the probe slide or flow smoothly across the back of the magnet? Does the probe stick to the magnet? Does the probe alternately skip and slide over the surface?
5. The interactions between the probe(s) and the surface of the magnet provide *indirect evidence* for the arrangement of the magnetic poles making up the refrigerator magnet. What is the most likely orientation of the multiple magnets making up the refrigerator magnet? Explain.

Disposal

None required—save all materials for future use.

Tips

- The results of this activity will depend on how the design is laid out on the refrigerator magnet. Some appear to be horizontally “striped,” whereas others have vertical “stripes” (see the *Discussion* section).
- This activity may be incorporated into an activity stations lab on atomic structure. Other suitable activities include shooting marbles at a hidden target to determine the shape of the target (see “Atomic Target Practice” in this Flinn Scientific eLearning Video) and determining the interaction of transition metal salts with a strong magnet (see “Paramagnetic Transition Metal Ions” in *Electron Configuration*, part of the Flinn Scientific eLearning Video Series).
- This activity has a fundamental application in terms of understanding the nature of evidence and the scientific method. Many school science experiments rightfully focus on the importance of observations and measurements—direct evidence that can be seen, heard, manipulated, etc. Direct evidence works well on the macroscopic scale. When the scale that we want to study shifts, however, to either the very, very small (submicroscopic) or very, very large (astronomical), the type of evidence that scientists have to work with is often indirect. Indirect evidence is evaluated based on possible models for the subject or object being examined. In this activity, the possible models are the suggested arrangements of the north and south poles of the magnets. We predict that the magnetic strips or probes will interact differently with the magnet depending on the actual orientation of the magnetic poles. The observations are interpreted as being consistent with only one model.
- Visit the official Web site of the Nobel Foundation at http://nobelprize.org/educational_games/physics/microscopes/scanning/gallery/index.html to learn more about and view an impressive gallery of “atomic” photos obtained with the scanning tunneling microscope.
- Have students research other topics where indirect evidence has been interpreted to postulate basic scientific principles. Examples include evolution, the “big bang” theory for the formation of the universe, the plate tectonics model in geology, and genetic recombination.

Discussion

The 20th century was known as the atomic age based on the discoveries of the nuclear and electronic structure of the atom, which revolutionized not only science but history as well. The atomic age was ushered in by the discoveries of the electron, proton, and the nucleus of the atom near the beginning of the 20th century. Most of these discoveries were based on indirect evidence, because atoms of course could not be seen or measured directly. It is fitting, therefore, that near the end of the 20th century scientists had invented new and sophisticated instruments that allowed them for the first time to actually "see" atoms.

Scanning tunneling microscopy (STM) is the most important tool for studying the size, shape, and surface of materials at or near the atomic level. Using this non-optical, scanning probe microscope, scientists are able to "see" individual atoms and molecules at a resolution of 0.2 nm, which is equal to 2×10^{-10} m. (By way of comparison, the diameter of a typical metal atom, such as copper or silver, is about 0.3 nm.) A tiny electrical probe or stylus is moved across a surface, producing a weak electrical current between the tip and the surface. The locations of atoms on the surface are visualized as regions of high electron density due to changes in the magnitude of the current or the position of the stylus. Heinrich Rohrer and Gerd Binnig of the IBM Research Laboratory in Zurich, Switzerland, received the Nobel Prize in Physics in 1986 for their invention of the STM.

In this activity, magnetic strips cut from a refrigerator magnet act as probes to try to understand the relative arrangement of the magnetic poles on the multiple magnets making up a refrigerator magnet. A horizontal strip cut from the top of the magnet alternately sticks and slides when it is swept from side to side over the back of the magnet—the probe appears to be alternately attracted to and repelled by the magnet. The same horizontal strip slides smoothly over the surface, however, when it is swept from top to bottom over the back of the magnet. Taken together, the indirect evidence suggests an alternating vertical or striped orientation of the north and south poles of the multiple magnets making up the refrigerator magnet (see Figure 3).

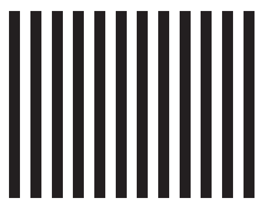

Figure 3. Arrangement of magnetic poles in a refrigerator magnet.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
- Systems, order, and organization
- Evidence, models, and explanation

Content Standards: Grades 9–12
- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science, structure of atoms, interactions of energy and matter
- Content Standard E: Science and Technology
- Content Standard G: History and Nature of Science, nature of scientific knowledge

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Refrigerator Magnet Analogy for Scanning Probe Microscopy* activity, presented by Annis Hapkiewicz, is available in *Solving The Structure of the Atom*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.