Mass Spectrometry

Introduction

Mass spectrometers are workhorse instruments for modern chemical analysis, including forensics, toxicology, and even space exploration. This activity consists of two demonstrations to illustrate the basic working principle of mass spectrometry, the deflection or "bending" of charged particles in a magnetic field. In Part A, dropping a magnet through a metal tube demonstrates the formation of eddy currents and provides evidence for the interrelationship of electric and magnetic fields. Thus, a moving charge creates a magnetic field, and a moving magnet or changing magnetic field also induces an electric current. In Part B, a model mass spectrometer simulation, steel spheres representing charged particles follow a curved path when they roll past a magnet.

Concepts

- Spectroscopy
- Cathode ray tube
- Mass spectrometer
- Electricity and magnetism

Materials

Eddy current demonstration kit or materials*	Plexiglas® or transparent plastic sheet, approx. 15″ square
Mass spectrometer demonstration kit or materials†	Support stand (optional)
Paperclips or bar magnet	Towel (optional)

**Eddy Current Demonstration Kit available from Flinn Scientific (Catalog No. AP4698) consists of 2-ft long aluminum tube and two cylinders, one magnetic, the other nonmagnetic. The cylinders are sheathed in identical black shrink tube wrapping.*

†Mass Spectrometer Model Kit available from Flinn Scientific (Catalog No. AP8717) consists of magnet mounted between two pieces of wood, set of steel spheres of different sizes, billiard ball, two-sided adhesive tape, and an inclined plane "launching ramp" to roll the spheres past the magnet.

Safety Precautions

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

Procedure

Part A. Eddy Current Demonstration

1. Obtain an Eddy Current Demonstration Kit, or gather the following items: aluminum or copper metal tube, approximately two feet long, and two spheres or cylinders, one magnetic and one nonmagnetic. Suitable materials include a bar or disk magnet for the magnetic object and an aluminum cylinder or sphere for the nonmagnetic object.
2. Determine which sphere or cylinder is magnetic and which is nonmagnetic using steel paperclips or another magnet. To easily distinguish the objects during the course of the demonstration, hold both spheres or cylinders in your hand along with the paper clip.
3. Hold the metal demonstration tube vertically with one hand or clamp the tube to a support stand.
4. Drop the nonmagnetic cylinder through the metal tube. Have a student catch the cylinder or let it land on a soft towel. Observe the speed at which the nonmagnetic cylinder falls due to gravity.
5. Drop the magnetic cylinder through the tube. Have a student ready to catch the cylinder. Observe that the cylinder takes a very long time to fall through the aluminum tube.
6. Repeat step 5 as many times as necessary, allowing students to view the magnetic cylinder while it travels through the tube. The cylinder appears to be suspended in mid-air.

Part B. Mass Spectrometer Demonstration

1. Assemble the mass spectrometer model according to the kit instructions, or gather the following items: strong magnet, steel spheres of different sizes, billiard ball, small wooden wedge or inclined plane, wooden blocks to mount the

magnet, tape. See Figure 1.

2. Mount a Plexiglas or transparent plastic sheet on wooden blocks on top of the magnet. See Figure 1. The clear plastic allows students to see that the object underneath it is a magnet—do not tell the students it is a magnet, however.
3. Attach the inclined plane to the Plexiglas sheet using two-sided adhesive tape. Note the position of the "launching ramp" above the magnet.
4. Steel spheres will become magnetized when they are stored or placed near the magnet. Bounce the spheres a few times before rolling them down the launching ramp. This will remove any temporary magnetism.
5. Bounce the billiard (non-metallic) ball on a hard surface. Roll the billiard ball down the inclined plane and observe where it goes. *(The non-magnetic ball should roll in a straight line across the clear plastic top of the model mass spectrometer.)*
6. Bounce the metallic spheres one at a time on the hard surface.
7. Starting with the metallic sphere that is most similar in diameter to the billiard ball, roll the spheres one at a time down the inclined plane. Before rolling each sphere, ask students to predict where the spheres will land. Observe the path taken by each sphere and where they land. *(The metal spheres follow curved paths across the plastic top. The extent of the "deflection" depends on the diameter or mass of the sphere.)*

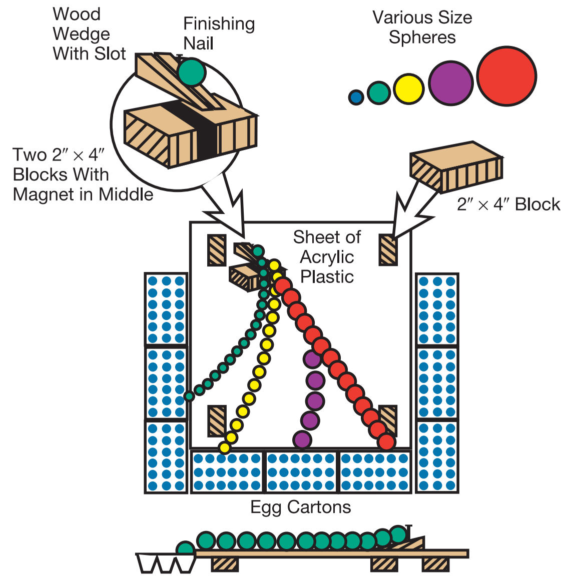

Figure 1. Model Mass Spectrometer

8. Ask student to examine the results. Is there a relationship between where the metallic spheres land and the size or diameter of the sphere? Identify any pattern or trend in this relationship.

Disposal

None required—save all materials for future use.

Tips

- In Part A, have students look through the tube from the top to observe the magnetic cylinder as it falls. The cylinder falls slowly down the tube and reaches a terminal velocity (a constant speed) as it tumbles. The terminal speed is achieved when the accelerating force of gravity is balanced by the dampening force of the eddy currents, resulting in zero acceleration. The cylinder is not slowed because of friction with the wall of the tube.
- Students may believe that the eddy current demonstration tube itself must be magnetic. Show them the metal tube is not magnetic by bringing a magnet near the tube—there is no attraction.
- The different size steel spheres used in Part B represent charged particles having different masses.

Discussion

Electricity and magnetism are closely related. Thus, it is known that an electric current in a wire creates a magnetic field around the wire, and also that a changing magnetic field can generate or induce an electric current in a wire. A moving charged particle, in turn, creates a magnetic field, and can thus be bent from its path by passing through an external magnetic field. The amount of bending is directly proportional to the charge on the particle and inversely proportional to the mass of the particle.

In the eddy current demonstration, a cylindrical magnet is dropped through a metal conducting tube. The tube may be envisioned as consisting of a linear series of thin, closed conducting loops. As the magnet approaches one of these loops, it induces eddy currents in the loop which in turn produce a magnetic field in the opposite direction as the magnetic field of the magnet (to maintain the original magnetic flux, which was zero). The opposing magnetic fields create an upward force on the magnet as it falls through the tube, "pushing" the magnet away from the loop. Once the magnet passes through the loop and the magnetic field begins decreasing in this loop, a current is induced in the closed loop that travels in the opposite direction to when the magnet was approaching the loop. This current then produces a magnetic field that is oriented in the same direction as the falling magnet, resulting in an attractive force pulling upward on the magnet as it travels away from the loop, so that the magnet is "pulled" back toward the loop. The upward forces dampen the speed at which the magnet falls. The force of gravity and the upward forces will eventually become balanced and the magnet will reach a constant velocity inside the tube.

Mass spectrometry is a method of chemical analysis in which atoms and molecules are separated based on their masses. The substance to be analyzed is heated in a vacuum and the resulting vapor stream is ionized either by electron impact or chemical ionization. The ions are accelerated through an electric field and then passed through a magnetic field. The paths of the ions through the magnetic field are curved or "bent," with the amount of deflection depending on the mass to charge ratio of the ions. Since most of the ions produced in a mass spectrometer have a +1 charge, in effect the amount of separation that occurs depends only on the relative masses of the ions. The basic components of a mass spectrometer are shown in Figure 2. Ion currents can be measured with a sensitive electrical detector such as an electron multiplier.

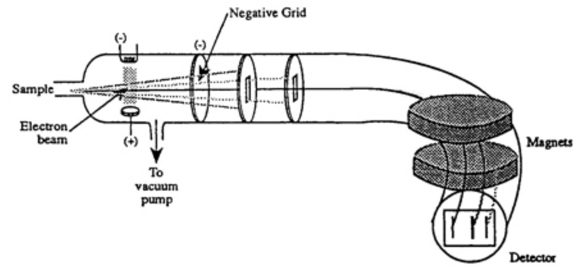

Figure 2. Basic Design of a Mass Spectrometer.

The origin of the basic principle of mass spectrometry dates back to J.J. Thomson's discovery of the electron in 1897 and to his work with "positive rays," positively charged streams of atoms generated in gas discharge tubes. When these positive ions were bent or deflected in the presence of electric and magnetic fields and then allowed to strike a photographic film, they left curved "spots" on the film at an angle that depended on the mass and charge of the atoms. In 1912, Thomson found that when the gas in the tube was neon, he obtained two curves or spots. The major spot corresponded to neon atoms with a mass of about 20 atomic mass units (amu). There was also a much fainter spot, however, corresponding to atoms with a mass of 22 amu. Although these results were consistent with the existence of two types of neon atoms having different masses, they were not precise or accurate enough to be conclusive.

Conclusive proof for the existence of isotopes came from the work of Francis W. Aston at Cambridge University. Aston built a modified, more accurate version of the "positive ray" apparatus that Thomson had earlier used to study ions. This was essentially the first mass spectrometer. In 1919, Aston obtained precise measurements of the major and minor isotopes of neon, corresponding to 20 and 22 atomic mass units, respectively. Aston received the Nobel Prize in Chemistry in 1922 for his discovery of isotopes.

The first commercial mass spectrometers were produced in the 1940s. They were used primarily in the oil industry for gas analysis. In 1942 there was only one university laboratory where precise analysis of uranium isotopes could be carried out. A large number of scientists and engineers was introduced to mass spectrometry during World War II, and when the war ended these individuals returned to peace-time research pursuits convinced of the usefulness of mass spectrometry. The demand for more powerful and more precise commercial mass spectrometers increased substantially.

Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement

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

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Mass Spectrometry* activity, presented by Annis Hapkiewicz, is available in *Mass Spectrometry*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Mass Spectrometry* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP4698	Eddy Current Demonstration Kit
AP8717	Mass Spectrometer Model Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.