Rolling Spheres Down an Inclined Plane

Mass Spectrometry

Introduction

Build a simple model to demonstrate the fundamental principle of mass spectrometry—the separation of charged atoms based on their masses. Use this demonstration to promote inquiry, inspire wonder, and engage students in the process of scientific discovery. In this activity, science is not a noun, it is a verb—an active verb!

Concepts

- Scientific method
- Guided inquiry
- Mass spectrometry
- Isotopes

Materials

Mass Spectrometer Kit—each kit contains the following components:
  Adhesive tape, two-sided
  Billiard ball
  Inclined plane "launching ramp" with a nail positioned in the ramp
  Magnet, strong, mounted between two pieces of wood (2 × 4s)
  Spheres, set of metal (steel) of different sizes
  Ice cube trays or empty egg cartons to serve as collection boxes
  Plexiglas® or transparent plastic sheet, approximately 15″ × 15″
  Scale or balance (optional)
  Wooden 2 × 4s, 2–4″ long, 4 pieces

Safety Precautions

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

Preparation

1. Assemble the mass spectrometer model according to the kit instructions, as shown in Figure 1.
2. Mount the Plexiglas or other transparent plastic sheet on four pieces of 2 × 4s.
3. Place the sheet on top of the magnet mounted between two wooden blocks (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.
4. Attach the inclined plane to the Plexiglas sheet using two-sided adhesive tape. Note the position of the "launching ramp" above the magnet.
5. The inclined plane has a nail in place in order to be certain that all the spheres have the same velocity when they roll down the ramp. The position of the nail on the launch ramp can be altered, if necessary, to allow the metal spheres to roll by the magnet faster or slower.

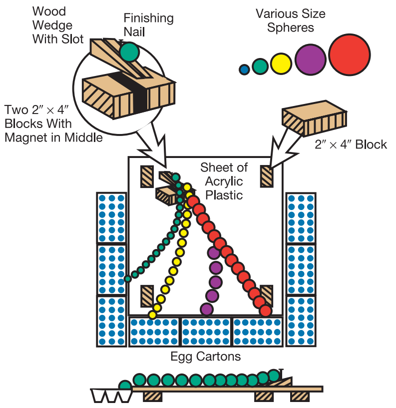

Figure 1.

6. The steel spheres 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.

Overview of the Activity

The purpose of this activity is to use a guided-inquiry method to teach students about the separation of charged atoms or molecular ions using a mass spectrometer. The steel spheres represent charged atoms or molecules in this analogy, and their different diameters correspond to different masses. The model can be used to explain the discovery of the isotopes as well as the forensic applications of modern mass spectrometry for the identification and analysis of drugs and other compounds. It is also possible to use the experiment to construct a model of how magnets affect the path of moving metallic spheres.

1. 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.)*
2. Bounce the metallic spheres one at a time on the hard surface to demonstrate that they are metallic.
3. 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 a curved path across the plastic top. The extent of the "deflection" depends on the diameter or mass of the sphere.)*
4. 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.

Guided-Inquiry Narrative

The following narrative is provided as a possible guide for engaging students in the process of scientific discovery. The objective is to have students observing, asking questions, identifying patterns, making predictions, and proposing explanations. One of the hardest things teachers must do in this activity is avoid the temptation to answer the students' questions before they have had a chance to observe all of the results and identify any patterns or trends. The other challenge is to "force" students to actually make predictions. Students must vote!

TEACHER	Class, for this experiment I would like you to observe quietly. Please do not discuss any of your observations or thoughts with anyone else. Please respond only to my questions and comments.
TEACHER	Bounce a non-magnetic sphere on the table so that the students can "see" it does not appear to be metallic.
TEACHER	Without any comment, hold the sphere against the nail, and allow it to roll down the ramp and and come to rest in one of the collection trays (egg cartons or ice cube trays). You will do the same thing with the other spheres as the experiment proceeds.
TEACHER	Select the largest of the steel spheres. Tell the students that it is steel, and have them compare the masses of the first (non-metallic) sphere and the steel sphere on a scale or balance. The steel sphere will have a mass of approximately 8 times that of the non-metallic sphere. Bouncing the sphere before using it in the experiment will remove any temporary magnetism that may have developed in the sphere during storage in a box with magnets.
TEACHER	Class, I am going to roll this sphere down the ramp in the same way as the first one was allowed to roll. Please predict where you think the sphere will end up
STUDENTS	Students will predict (or you can tell them) that the sphere will take one of three different paths….the same path as that taken by the first sphere, or to the left or to the right of the first sphere. All students are then asked to vote. Everyone must vote by show of hands.
STUDENTS	Students will predict that the sphere will take one of three different paths….the same path as that taken by the first sphere, or to the left or to the right of the first sphere. Since the students have no other evidence, they vote just by guessing. Some students will vote for each of the different possibilities.
TEACHER	Select the next smaller steel sphere, bounce it on the table top, allow students to compare the masses of the two steel spheres, and the first non-metallic sphere. It is readily apparent that this smaller steel sphere is lighter than the first (larger) steel sphere, but heavier than the non-metallic sphere. Ask the students to predict where this sphere will end up when it is rolled down the ramp. There are five possibilities. • To the left of the non-metallic sphere. • Same path as the non-metallic sphere.

- Between the non-metallic and the metallic sphere.
- Same path as the metallic sphere.
- To the right of the metallic sphere.

STUDENTS Most students will predict that this sphere will end up between the non-metallic sphere, and the larger steel sphere. This is really the only logical prediction that they can make, at this point.

TEACHER How do you know? Note that at this point the students do not have very much evidence. They do not know for sure that the object beneath the Plexiglas sheet is a magnet.

STUDENTS The sphere is between the first two in mass, therefore it will end up between them.

TEACHER Roll the sphere down the ramp. Allow the students to observe. Do not ask any questions yet, and do not allow the students to ask any questions either.

TEACHER Select the next smaller sphere; ask the students to predict its path. Do not ask for explanations. Repeat this process with a number of spheres. Some of the students will, after a few trials suspect that the object beneath the Plexiglas must be a magnet.

TEACHER After a number of incorrect predictions, roll a very small sphere down the ramp. The sphere will "stick" to the magnet!

Disposal

Save all materials for future use.

Tips

- In this exercise we used, rather than discussed, the scientific method.
- All of the spheres have the same velocity when they pass through the magnetic field. The position of the nail can be com pared to the charges on the ions in a mass spectrometer.
- The position of the nail can be altered to change the particle velocity and simulate different electrical fields.
- Modern mass spectrometers are workhorse instruments in chemical analysis, including forensics. (The popularity of CSI-type television shows makes it likely that all of your students have seen and heard about mass spectroscopy on TV.) Have students look up mass spectrometry on the Internet and briefly describe two applications of this technology in forensic analysis. *Examples:* Mass spectrometry is used in toxicology studies to detect and analyze drugs that might have been used in a crime. The technique is also used in arson investigations to detect the presence of accelerants that might have been used to set a fire.

Discussion

The following background information explains the first experiments in the history of mass spectrometry and the discovery of isotopes.

Two lines of evidence in the early 20th century suggested the possible existence of isotopes. The first came from work by J. J. Thomson with "positive rays," positively charged streams of atoms generated in gas discharge tubes. When these positive rays 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.

The second line of evidence suggesting the existence of isotopes came from studies of radioactivity. One of the products of the radioactive decay of uranium is lead. When the atomic mass of lead deposits in radioactive uranium minerals was analyzed, it was found to be significantly different from the atomic mass of lead in lead ore. The actual composition of the lead atoms seemed to be different, depending on their origin.

In 1913, Frederick Soddy, professor of chemistry at the University of Glasgow, coined the term *isotope* to define atoms of the same element that have the same chemical properties but different atomic masses. The word isotope was derived from Greek words meaning "same place" to denote the fact that isotopes occupy the same place in the periodic table (they are the same element) even though they have different masses. Soddy received the Nobel Prize in Chemistry in 1921 for his investigations into the nature and origin of isotopes.

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. 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 modern definition of isotopes is based on knowledge of the subatomic particle structure of atoms. Isotopes have the same number of protons but different numbers of neutrons. Since the identity of an element depends only on the number of protons (the atomic number), isotopes have the same chemical properties. Isotopes are thus chemically indistinguishable from one another—they form the same compounds, undergo the same reactions, etc. Isotopes are distinguished from one another based on their mass number, defined as the sum of the number of protons and neutrons in the nucleus of the atom.

Chlorine, for example, occurs naturally in the form of two isotopes, chlorine-35 and chlorine-37, where 35 and 37 represent the mass numbers of the isotopes. Each isotope of chlorine has a characteristic *percent abundance* in nature. Thus, whether it is analyzed from underground salt deposits or from seawater, the element chlorine always contains 75.8% chlorine-35 atoms and 24.2% chlorine-37 atoms. The atomic mass of an element represents the *weighted average* of the masses of the isotopes in a naturally occurring sample of the element. Equation 1 shows the atomic mass calculation for the element chlorine.

$$\text{Atomic mass (chlorine)} = (0.758)(35.0\text{ amu}) + (0.242)(37.0\text{ amu}) = 35.5\text{ amu} \qquad \textit{Equation 1}$$

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
- 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 *Rolling Spheres Down an Inclined Plane* activity, presented by Irwin Talesnick, is available in *Mass Spectrometry* and in *Using Demonstrations to Promote Inquiry*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Rolling Spheres Down an Inclined Plane* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Mass Spectrometer Model Kit* available from Flinn Scientific.

Catalog No.	Description
AP8717	Mass Spectrometer Model Kit

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