Bean Bag Isotopes

Introduction

Studies of radioactivity at the beginning of the 20th century made it possible to investigate the actual structure and mass of atoms. Gradually, evidence began to build that atoms of the same element could have different masses. These atoms were called isotopes. How are isotopes distinguished from one another? What is the average atomic mass of an element that has different isotopes?

Concepts

- Isotope
- Mass number
- Percent abundance
- Atomic mass

Background

Isotopes are defined as atoms that 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 identical—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. Equation 1 shows the atomic mass calculation for the element chlorine.

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

The purpose of this activity is to investigate the mass properties and relative abundance of isotopes for the "bean bag" element (symbol, Bg) and to calculate the atomic mass of this element.

Materials

Balance, centigram (0.01-g precision)

"Bean bag" element, symbol Bg, approximately 50 g

Labeling pen or marker

Weighing dishes or small cups, 3

Safety Precautions

Although the materials used in this activity are considered nonhazardous, please observe all laboratory safety guidelines. The food-grade items that have been brought into the lab are considered laboratory chemicals and are for lab use only. Do not taste or ingest any materials in the chemistry laboratory, and do not remove any food items from the lab after use. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Sort the atoms in the "bean bag" element sample (Bg) into three isotope groups (1, 2, and 3) according to the type of bean. (Assume that each type of bean represents a different isotope and that each bean represents a separate atom.) Place each group into a separate weighing dish or small cup.
2. Count the number of Bg atoms in each isotope group and record the numbers in the data and results table.
3. Measure the total mass of Bg atoms belonging to each isotope group. Record each mass to the nearest 0.01 g in the data and results table. *Note:* Zero (tare) the balance with the empty weighing dish on the balance pan, then add all of the Bg atoms of that type to the weighing dish and record the mass.
4. Determine the average mass of each Bg isotope to two decimal places and record the results in the table.

5. What is the total number of "bean bag" (Bg) atoms in the original sample? Calculate the percent abundance of each isotope: Divide the number of atoms of each isotope by the total number of atoms and multiply the result by 100. Enter the results in the table.

Discussion Questions

1. The atomic mass of the "bean bag" element (Bg) represents a *weighted average* of the mass of each isotope and its relative abundance. Use the following equation to calculate the atomic mass of Bg. *Note:* Divide the percent abundance of each isotope by 100 to obtain its relative abundance.

$$\text{Atomic mass} = (\text{rel. abundance} \times \text{mass})_{\text{isotope 1}} + (\text{rel. abundance} \times \text{mass})_{\text{isotope 2}} + (\text{rel. abundance} \times \text{mass})_{\text{isotope 3}}$$

2. How many Bg atoms in the original sample would be expected to have the same mass as the calculated atomic mass of the element? Explain.
3. Copper (atomic mass 63.5) occurs in nature in the form of two isotopes, Cu-63 and Cu-65.

   a. Use this information to calculate the percent abundance of each copper isotope.

   b. Explain why the atomic mass of copper is not exactly equal to 64, midway between the mass numbers of copper-63 and copper-65.

Data and Results Table

"Bean Bag" Isotope (Bg)	Number of Atoms	Total Mass of Atoms	Average Mass	Percent Abundance
1				
2				
3				

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
MS-PS1 Matter and Its Interactions
PS1.A: Structure and Properties of Matter
Disciplinary Core Ideas: High School
HS-PS1 Matter and Its Interactions
PS1.A: Structure and Properties of Matter

Science and Engineering Practices
Developing and using models
Analyzing and interpreting data
Using mathematics and computational thinking

Crosscutting Concepts
Scale, proportion and quantity
Systems and system models

Tips

- Copy pages 1 and 2 only for student use.
- "Bean bag" isotopes may be mixed in any proportion to prepare samples for analysis. The mixtures analyzed in the *Sample Data* section were prepared by mixing navy beans, pinto beans, and kidney beans in the following proportions: 50 g navy beans, 250 g pinto beans, and 450 g kidney beans. The mixture (750 g total mass) was shaken in a large plastic beaker to mix the "isotopes" and divided into fifteen 50-g samples for student use. (The samples may be placed in zipper lock plastic bags or in weighing dishes.) The samples are obviously not homogeneous—do not expect different student groups to obtain identical results for the percent abundance of each isotope. The percent abundance for the samples analyzed ranged from 13–18% for navy beans, 52–54% for pinto beans, and 30–35% for kidney beans.
- A wide variety of items may be used to simulate atoms in this exercise. Examples include small candies, pre- and post

1982 pennies (average masses 3.0 and 2.5 g, respectively), different shapes of pasta, various sizes of nuts and bolts, etc. The advantages of using beans are they are relatively non-perishable, many varieties are readily available, and students will not be tempted to eat them in the lab.

Sample Data and Results

"Bean Bag" Isotope (Bg)	Number of Atoms	Total Mass of Atoms	Average Mass	Percent Abundance
1	*15*	*2.75 g*	*0.18 g*	*12.3%*
2	*44*	*16.31 g*	*0.37 g*	*36.1%*
3	*63*	*32.21 g*	*0.51 g*	*51.6%*

Answers to Discussion Questions *(Student answers will vary.)*

1. The atomic mass of the "bean bag" element (Bg) represents a *weighted average* of the mass of each isotope and its relative abundance. Use the following equation to calculate the atomic mass of Bg. *Note:* Divide the percent abundance of each isotope by 100 to obtain its relative abundance.

$$\text{Atomic mass} = (\text{rel. abundance} \times \text{mass})_{\text{isotope 1}} + (\text{rel. abundance} \times \text{mass})_{\text{isotope 2}} + (\text{rel. abundance} \times \text{mass})_{\text{isotope 3}}$$

$$\textit{Atomic mass} = (0.123 \times 0.18\ g) + (0.361 \times 0.37\ g) + (0.516 \times 0.51\ g) = 0.42\ g$$

2. How many Bg atoms in the original sample would be expected to have the same mass as the calculated atomic mass of the element? Explain.

None! The atomic mass is a weighted average and does not represent the actual mass of any of the atoms in the sample. ***Note to teachers:*** *This statement is true for the actual samples analyzed in this exercise. Depending on the composition of "bean bag" samples prepared for student use, it is possible for the weighted average to be similar in value to the average mass of one of the types of beans.*

3. Copper (atomic mass 63.5) occurs in nature in the form of two isotopes, Cu-63 and Cu-65. (a) Use this information to calculate the percent abundance of each copper isotope. (b) Explain why the atomic mass of copper is not exactly equal to 64, midway between the mass numbers of copper-63 and copper-65.

There are only two isotopes of copper. Thus, if we set the relative abundance of Cu-63 equal to the unknown variable x, then the relative abundance of Cu-65 is equal to 1 – x. Substitute these variables in the equation for the atomic mass calculation and solve for x.

a. $\textit{Atomic mass (Cu)} = (x)(63.0\ amu) + (1 - x)(65.0\ amu) = 63.5\ amu$

$63.0x + 65 - 65.0x = 63.5$

$-2x = -1.5$

$x = 0.75$

The percent abundance of each isotope is 75.0 % (Cu-63) and 25.0 % (Cu-65).

b. *The atomic mass is "weighted" toward the mass of the more abundant isotope, Cu-63.*

Reference

This activity was adapted from the "Bean Bag Isotopes" experiment in *Atomic and Electron Structure*, Volume 3 in the *Flinn ChemTopic™ Labs* series; Cesa, I., Editor; Flinn Scientific: Batavia, IL (2003).

Materials for *Bean Bag Isotopes* are available from Flinn Scientific, Inc.

Catalog No.	Description
OB2141	Flinn Scientific Electronic Balance, 210 g × 0.01 g
AP1278	Weighing Dishes, Disposable, 31⁄160 × 31⁄160 × 10
AP1279	Weighing Dishes, Disposable, 5½0 × 5½0 × 7⁄80

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

