Isotopes

Author: Hening Lin, Jane Earle, and Lauren Downing
Date Created: July 2007
Subject: Chemistry
Level: High School
Standards: *New York State- Chemistry* *(www.emsc.nysed.gov/ciai/)*
Standard 1- Analysis, Inquiry and Design
Standard 4- Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.
Standard 7- Interdisciplinary Problem Solving
Schedule: One 60-minute Class Period

Objectives:

Students will learn what an isotope is and how their real-world applications make them useful to scientists.

Students will:

- See the difference between isotopes of the same element.
- Play a game to better understand isotopes and their properties.
- Learn about real-world applications of isotopes.

Vocabulary:

Isotope
Atomic Mass
Atomic Number

Materials:

For Each Group:
Isotope Game:
- Isotope Cards
- Periodic Table Mat
- Recording Sheet

For Each Student:
Activity Sheet 1: *Isotopes*

Teacher Should Provide:
- Protons/Neutrons (marbles, counters, etc.)
- 2 Dice (symbols and numbers)
- Atomic Bowl

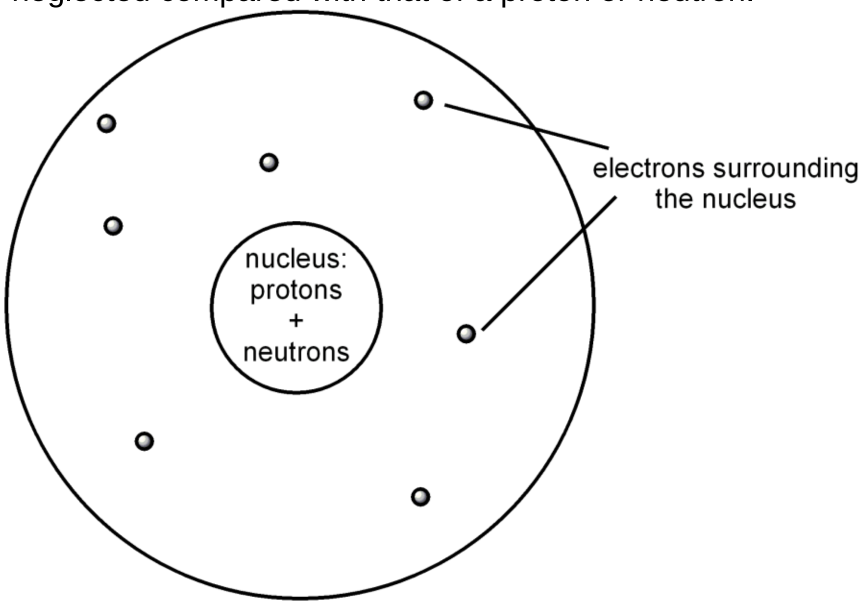
Safety:

There are no safety concerns associated with this activity.

Science Content for the Teacher:

The components of an atom.

An atom consists of a nucleus and electrons surrounding the nucleus. The nucleus is made of protons and neutrons. A proton carries one positive charge, an electron carries one negative charge, while a neutron is neutral. A proton and a neutron each have a mass unit of 1, while the mass of an electron can be neglected compared with that of a proton or neutron.



The number of protons in the nucleus determines the identity of the atom. For example, atoms that contain 1 proton in their nucleus are hydrogen atoms, while atoms that contain 6 protons in their nucleus are carbon atoms.

In a neutral atom that carries zero negative charge, the number of electrons surrounding the nucleus is equal to the number of protons in the nucleus. Thus a neutral carbon atom has 6 electrons.

Definition of isotope.

Atoms with the same number of protons in the nucleus can have different numbers of neutrons. Atoms with the same number of protons but different number of neutrons are isotopes of the same element. Typically, the number of protons and neutrons are equal, but this is not always the case. For example, the most common isotope of carbon is ^{12}C, which has six protons and six neutrons. However, ^{238}U is the most common isotope of uranium, which clearly has many more neutrons than protons.

Another difference among isotopes is the mass. Since neutrons have one mass unit, different isotopes of the same element have different masses. This difference, although it cannot change the nature of chemical reactions, could influence the rate of reactions. For reactions that involve hydrogen atoms, this effect could be significant because the three different hydrogen isotopes have very different masses (the mass of ^{2}H is twice of that of ^{1}H). Biochemists often utilize this effect to study the mechanism of enzymatic reactions

When speaking of different isotopes, a special kind of notation is used:

$$^{14}_{6}C$$

Here, the superscript number is the mass number, or the total number of neutrons and protons present in the atom. The subscript number is the atomic number, or the number of protons in the nucleus. Other ways to write this same isotope include:

^{14}C Carbon - 14

Properties and practical uses of isotopes.

Isotopes of the same elements tend to behave the same in chemical reactions, which only involve the electrons surrounding the nucleus. However, there are several differences in isotopes that make them very useful in many applications.

Different isotopes can differ dramatically in stability. Some isotopes are very stable, while others are unstable and decay spontaneously and emit radiation (energy) when the decay happens. Thus the unstable isotopes are called radioactive isotopes. For example, ^{31}P is a stable isotope of phosphorus, while ^{32}P is a radioactive isotope. Because radioactivity can be easily detected, radioactive isotopes are very useful in labeling and tracing chemical species in biochemistry or medical applications, for example to track the spread of a drug in the body .

The rate at which the radioactive isotope decays is given by its *half-life*, the interval after which half of the material breaks down. Half-life varies between a fraction of a second and thousands of years. ^{14}C, with a half-life of roughly 5700 years, has been used to determine the approximate age of an artifact or fossil. Isotopes with very short half-life cannot be used for this because after thousand of years, all the radioactive isotope would have been decayed and there would be no difference in samples from different ages.

Radio isotope decay can also be accelerated by supplying external energy, such as neutrons. Because some radio isotopes generate more neutrons when they decay, this could generate a “nuclear chain reaction” and produce massive energy. This is how the most famous isotope ^{235}U, is used in nuclear power plants and weaponry.

Different isotopes sometimes also differ in spin numbers which determine whether they have a signal in nuclear magnetic resonance (NMR). For example, ^{12}C, the most abundant carbon isotope, is NMR silence, while ^{13}C has a NMR signal. The most abundant nitrogen isotope ^{14}N is NMR silence, while ^{15}N has an NMR signal. Thus, ^{13}C and ^{15}N have been routinely used to label chemical species in NMR studies to obtain structural information.

Preparation:

- Prepare printed materials for students (Activity Sheet 1).
- Make games accessible to students.

Classroom Procedure:

Engage (Time: 10 mins)

Give students a very brief introduction to isotopes by reviewing the meaning of mass number, atomic number, and chemical notation. Do not give them the definition of an isotope, they will be writing their own later.

Explore (Time: 40 mins)

Have students play Isotope Rummy (see Appendix A for additional copy of rules, others are included with the game). Move about the class and answer questions about isotopes as they arise.

Explain (Time: 20 mins)

Have the students complete Activity Sheet 1: *Isotopes* in their groups from the game. Have students present their answers and discuss them with the class.

Assessment:

The following rubric can be used to assess students during each part of the activity. The term “expectations” here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

1= exceeds expectations
2= meets expectations consistently
3= meets expectations occasionally
4= not meeting expectations

	Engage	Explore	Explain
1	Shows leadership in the discussion and a good understanding of isotopes.	Plays game fairly; seeks further understanding of isotopes through information on cards and the game rules.	Provides and in depth explanation of findings. Makes excellent and thoughtful comparisons to everyday life. Fills out worksheet clearly.
2	Participates in the discussion and shows an understanding of isotopes.	Plays game, seeks some further knowledge of isotopes.	Provides clear explanation of findings. Notes good correlations to everyday life. Fills out worksheet clearly.
3	Contributes to the discussion, but shows little understanding of isotopes.	Make some mistakes with the game, seeks some further knowledge of isotopes.	Provides a limited explanation of findings. Struggles to make comparisons to everyday life. Fills out some of the worksheet.
4	Does not participate in discussion. Shows no understanding of isotopes.	Has trouble playing fairly, does not seek to further understand isotopes.	Is not clear in explanation of findings. Does not fill out worksheet.

Acknowledgments:

<http://www.wisegeek.com/what-is-an-isotope.htm>

Extension Activities:

See Appendix B, Carbon-14 dating.

Appendix A: Game Rules

Materials:
Isotope Cards
Periodic Table Mat
2 Dice (symbols and numbers)
Atomic Bowl
Protons/Neutrons (marbles, counters, etc.)
Tally Sheet

Setup:
Arrange the Isotope Cards by element on the Periodic Table Mat. Place protons and neutrons next to the atomic bowl (assign one color to represent protons, the other for neutrons). Pick a random element or isotope to start with and place the correct number of protons and neutrons in the atomic bowl.

Rules:
The person who will next celebrate their birthday goes first.

On each turn, choose and say out loud whether you are going to change the number of protons or neutrons in the atomic bowl. Roll both dice to determine the number of particles you will be adding or subtracting. Add or subtract this many protons or neutrons from the atomic bowl. Attempt to identify the isotope represented by the marbles in the atomic bowl (example: Carbon-14). Then, if correct, pick up the card for that isotope. Note: if the isotope does not exist, nothing happens and the play passes to the next student.

The first time playing, try to collect three isotopes of a single element. The first player to do so wins.

Next, each player should get a Point Sheet to keep track of their points. Each card is awarded points based on the information on it. A regular card is worth 5 points, a stable isotope is worth 10 points, an isotope with a common use or property listed on the card is worth 15 points, and an isotope that is both stable and has a listed property is worth 20 points. Cards can be played in sets of two or three as follows: To turn your cards into points, a student must collect one of the following combinations: three isotopes of one element, three stable isotopes of either the same or different elements, two cards with properties, or two isotopes that are both stable and have properties. When you collect one of these combinations, record the combination type, isotope notation (the chemical abbreviation and numbers on card), and the points for that card on your score sheet. Make a pile of discarded isotopes and add your cards to this once you have tallied your points.

The game is over when the first player reaches 50 points and wins the game. (This number can be increased to lengthen the game.)

Objectives:
Be the first player to reach 50 points. Remember, you can purposefully change the number of protons or neutrons in the bowl to make this more difficult for other players.

Appendix B: Carbon Dating

Archaeologists use the exponential, radioactive decay of carbon 14 to estimate the age of fossils. The half-life of a radioactive isotope describes the amount of time that it takes half of the isotope in a sample to decay. For example, if you had 2 kg of carbon 14, it would take 5,730 years for that sample to decay, and you would be left with 1 kg of carbon 14. (Therefore the half life of carbon 14 is 5730 years.)

This relation is summarized in the following formula:

$$-t = \left[\frac{\ln(\frac{N}{\mathrm{N}_0})}{\ln(2)} \right] \times t_{1/2}$$

In this formula, $t_{1/2}$ is the half-life of the isotope, N/N_o is the percentage of carbon 14 still remaining in the sample, ln(2) is the rate of decay of carbon 14, and t is the age of the fossil. $t_{1/2}$

1. You have just discovered a fossil and tested it to discover it contains 35% of the original carbon 14, about how old is it?

2. If you know a sample is 2715 years old, what percent of carbon 14 would you expect to find in the fossil?

3. Now assume you have an isotope whose half-life is only 234 years. If you begin with 8 kg, how many years will it take the sample to decay to .5 kg?

4. If a sample of the isotope in #3 is 1744 years old, what percent of the isotope would you expect to find in the fossil?