Modeling Radioactive and Stable Atoms

With the Modeling Radioactive and Stable Atoms activity, students gain a better understanding of the differences between radioactive atoms and stable atoms. Students gain a better understanding of protons, neutrons, and electrons. Students are able to visualize what is meant by proton, neutron, and electron particles. By extension, this experiment is a useful analogy to radioactive decay. This experiment is best used by students working in groups.

A zip-close plastic bag represents the nucleus of an atom. If the atom is stable, zip the bag closed. If atom is radioactive, bag is left open to emit ionizing radiation (alpha particles, beta particles and/or gamma rays).

Grade Level

5-9

Disciplinary Core Ideas (DCI)

5-ESS3-1, 3-5 ETS1-1, MS-PS3-2, HS-PS1-8, HS-PS3-2, HS-PS4-1, HS-PS4-4, HS-PS4-5

Time for Teacher Preparation

30-60 minutes – To gather materials and set-up

Activity Time:

30-60 minutes (1 Class Period)

Materials

- Pen, Marker, or Pencil
- Student Data Collection Sheets
- Water, 1 cup
- Food coloring, 1/2 to 1 bottle
  - Pink and yellow
- Toothpicks, round, undyed
- Zipper-type plastic bags
- Marshmallows Large and Mini- air-dried (sticky-free), as many as you need
- Styrofoam tray
- Glue
- Flashlight
- Pipe cleaners

Safety

- Students should not eat marshmallows
- Students should not throw marshmallows at fellow students
- Students should use care when handling toothpicks

Science and Engineering Practices (NGSS)

- Ask questions and define problems
- Plan and carry out investigation
- Analyze and interpret data
- Use mathematics and computational thinking
- Construct explanations
- Argue from evidence
- Obtain, evaluate and communicate information

Cross Cutting Concepts (NGSS)

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change of Systems

Objectives

- Define Atomic Number
- Define Atomic Mass
- Define Radiation
- Define Radioactive Decay
- Discuss the differences between radioactive and stable atoms

Background

An **atom** is made up of three subatomic particles -- **protons**, **neutrons** and **electrons**. The center of an atom, called the **nucleus**, is composed of protons and neutrons. Protons are positively charged, neutrons have no charge at all and electrons are negatively charged. The proton-to-electron ratio is generally one to one, so the atom as a whole has a neutral charge. For example, a carbon atom has six protons and six electrons. Generally, if the proton to neutron ratio is larger than 1 to 1.5, the nuclear binding energy cannot hold the nucleus together and the nucleus will emit radiation and decay.

It's not that simple though. An atom's properties can change considerably based upon how many of each subatomic particles it has. If you change the number of protons, you wind up with a different element altogether. If you alter the number of neutrons in an atom, you wind up with an **isotope**. For example, carbon has three isotopes:

- carbon-12 (six protons + six neutrons), a stable and commonly occurring form of the element,
- carbon-13 (six protons + seven neutrons), which is stable but rare, and

- carbon-14 (six protons + eight neutrons), which is rare and unstable (or radioactive).

As we see with carbon, some atomic nuclei are stable and some are unstable. Unstable nuclei spontaneously emit particles and waves that scientists refer to as radiation. A nucleus that emits radiation is, of course, radioactive, and the process of emitting radiation is known as radioactive decay. Three types of radioactive decay will be studied:

- **Alpha decay**: A nucleus ejects two protons and two neutrons bound together, known as an **alpha particle**. **The atomic number will decrease by 2, and the mass will decrease by 4**.
- **Beta decay**: A neutron becomes a proton, an electron and an antineutrino. The ejected electron is a beta particle and it is accompanied by the antineutrino (a massless, chargeless particle). **The atomic number will increase by 1, and the mass will remain the same.**
- **Spontaneous fission:** A nucleus splits into two pieces. In the process, it can eject neutrons, which can become neutron rays.

In all three types of decay, the nucleus can also emit a burst of electromagnetic energy known as a gamma ray. Gamma rays are the only type of nuclear radiation that is wave energy instead of a fast-moving particle.

Teacher Lesson Plan:

Traditional

Demonstration:

Preparation for Student activity:

1. Remove the marshmallows from the packaging and let them "air" for a day.
2. Mix the water and food coloring in a cup.
3. Insert a toothpick into a marshmallow.
4. Dip the marshmallow "fondue style" into the colored water for about 2-3 seconds.

One suggestion - make the protons PINK and make neutrons YELLOW. There should be 7 protons and 7 neutrons and 1 mini-marshmallow electron per group.

5. Remove from colored water and stick in a Styrofoam tray to dry.
6. Let dry for several days or until not sticky to the touch.
7. Use marker to indicate protons with a "+" (plus sign).
8. Put in plastic bags, i.e., 7 neutrons (yellow) and 7 protons (pink) and 1 mini-marshmallow.

NOTE: If you keep the marshmallows in a cool, dry place your "particles" will last for several years.

9. Mark 7 large (pink) marshmallows with a positive (+) sign. They represent protons.
10. Select 7 unmarked large (yellow) marshmallows to represent neutrons.

11 From the group above, select 2 "protons" and 2 "neutrons"; use toothpicks and glue to join these into a group of four. This represents an alpha particle.

12. Mark the sides of 1 mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, 1 toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of 1 "proton" (so the positive sign is partially covered). This now represents a neutron.
13. Put the alpha particle from step #3 into an empty zip-close bag. Add 4 "protons" (pink) and 4 unmarked neutrons (yellow). Zip bag closed. The closed bag represents the nucleus of a stable atom. If the binding energy can contain all the protons and neutrons within the nucleus, the atom is stable.
14. Open the bag. Add one "neutron" (yellow) and one "neutron" that was made in step #4. Leave the bag unzipped; excess neutrons have now made it unstable because the proton-neutron ratio is greater than 1:1.5.
15. To become stable, the nucleus will emit a beta particle. Find the "neutron" you made in step #4. Pull off the mini-marshmallow (now it is a beta particle) and toss it about 1-2 feet from you. Leave the remaining proton in the bag and zip it closed. The atom's nucleus has changed and is stable again.

To show a different radioactive atom that emits an alpha particle to become stable, place an alpha particle in an empty zip bag.

Radiation Types

Add 2 protons and 2 neutrons. This represents the nucleus of Beryllium-8. The atom "emits" an alpha particle, which will pick up two electrons to become a stable atom of Helium-4. The result is two atoms of Helium-4.

Represent a gamma ray emission by shining a flashlight through the bag and shaking the contents, showing nuclear re-arrangement. Although gamma rays are really not visible, you can use this to model the fact that gamma rays are not particles; they are a form of electromagnetic radiation.

If desired, you can add pipe cleaners around the bag to represent the orbits or shells where electrons would be present; mini-marshmallows with a negative (-) sign on them can be attached to the pipe cleaners to represent orbital electrons.

NGSS Guided Inquiry

Split students into small groups and give each student marshmallows. Have students design an experiment to model the differences between radioactive and stable atoms.

Student Procedure

1. Mark 7 large (pink) marshmallows with a positive (+) sign. They represent protons.
2. Select 7 unmarked large (yellow) marshmallows to represent neutrons.
3. From the group above, select 2 "protons" and 2 "neutrons"; use toothpicks and glue to join these into a group of four. This represents an alpha particle.
4. Mark the sides of 1 mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, 1 toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of 1 "proton" (so the positive sign is partially covered). This now represents a neutron.
5. Put the alpha particle from step #3 into an empty zip-close bag. Add 4 "protons" (pink) and 4 unmarked neutrons (yellow). Zip bag closed. The closed bag represents the nucleus of a stable atom. If the binding energy can contain all the protons and neutrons within the nucleus, the atom is stable.
6. Open the bag. Add one "neutron" (yellow) and one "neutron" that was made in step #4. Leave the bag unzipped; excess neutrons have now made it unstable because the proton-neutron ratio is greater than 1:1.5.
7. To become stable, the nucleus will emit a beta particle. Find the "neutron" you made in step #4. Pull off the mini-marshmallow (now it is a beta particle) and toss it about 1-2 feet from you. Leave the remaining proton in the bag and zip it closed. The atom's nucleus has changed and is stable again.
8. Draw your atoms on the Student Data Collection Sheet

Data Collection

Attached Student Data Collection Sheets

Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

Questions

After Step 5:

1. How many positively charged marshmallows (protons) are in the bag? (Do not count the one whose positive sign is partially covered by the mini-marshmallow!) This is the atomic number of the atom.
2. What element is represented by this model?
3. How many neutral particles are in the bag? (You **do count** the particle where positive and negative charges cancel each other out!)
4. What is the atomic mass of this atom? (Each large marshmallow equals 1 atomic mass unit, regardless of charge.)

Assessment Ideas

- Have students discuss the differences between radioactive and stable atoms
- Have the students discuss the difference between radiation and radioactive decay

Differentiated Learning/Enrichment

- Have students discuss how the different arrangements of protons, neutrons, or electrons affect the radioactivity of an atom

Enrichment Questions

1. What is the atomic number of the atom at the end of the experiment?
2. What element does the atomic model represent at the end of the experiment?
3. What is the atomic mass of the atom at the end of the experiment?

Further Resources

ANS Center for Nuclear Science and Technology Information
http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

Modeling Radioactive and Stable Atoms

Student Data Collection ANSWER Sheet

Objectives

- Define Atomic Number
- Define Atomic Mass
- Define Radiation
- Define Radioactive Decay
- Discuss the differences between radioactive and stable atoms

Procedure

1. Mark 7 large (pink) marshmallows with a positive (+) sign. They represent protons.
2. Select 7 unmarked large (yellow) marshmallows to represent neutrons.
3. From the group above, select 2 “protons” and 2 “neutrons”; use toothpicks and glue to join these into a group of four. This represents an alpha particle.
4. Mark the sides of 1 mini-marshmallow with a negative (-) sign; it represents an electron. Stick, but do not glue, 1 toothpick into this mini-marshmallow. Glue the other end of the toothpick into the side of 1 “proton” (so the positive sign is partially covered). This now represents a neutron.
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6. Open the bag. Add one “neutron” (yellow) and one “neutron” that was made in step #4. Leave the bag unzipped; excess neutrons have now made it unstable because the proton-neutron ratio is greater than 1:1.5.
7. To become stable, the nucleus will emit a beta particle. Find the “neutron” you made in step #4. Pull off the mini-marshmallow (now it is a beta particle) and toss it about 1-2 feet from you. Leave the remaining proton in the bag and zip it closed. The atom’s nucleus has changed and is stable again.
8. Draw your atoms below.

Modeling Radioactive and Stable Atoms

Student Data Collection ANSWER Sheet

Questions

1. How many positively charged marshmallows (protons) are in the bag? (Do not count the one whose positive sign is partially covered by the mini-marshmallow!) This is the atomic number of the atom.

   There are 6 protons in the bag (2 in the alpha particle and the 4 that were added).

2. What element is represented by this model?

   Carbon-12

3. How many neutral particles are in the bag? (You do count the particle where positive and negative charges cancel each other out!)

   There are 6 neutrons in the bag (2 in the alpha particle and the 4 that were added: 3 neutrons and a proton-electron pair).

4. What is the atomic mass of this atom? (Each large marshmallow equals 1 atomic mass unit, regardless of charge.)

   The atomic mass is 12.

Enrichment Questions

1. What is the atomic number of the atom at the end of the experiment?

   The atomic number is 7, because the neutron decayed to a proton and electron which added 1 to the atomic number.

2. What element does the atomic model represent at the end of the experiment?

   It is nitrogen-14.

3. What is the atomic mass of the atom at the end of the experiment?

   The atomic mass is 14.

Radiation Types

Modeling Radioactive and Stable Atoms

Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

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- Define Atomic Number
- Define Atomic Mass
- Define Radiation
- Define Radioactive Decay
- Discuss the differences between radioactive and stable atoms

Procedure

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3. From the group above, select 2 "protons" and 2 "neutrons"; use toothpicks and glue to join these into a group of four. This represents an alpha particle.
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7. To become stable, the nucleus will emit a beta particle. Find the "neutron" you made in step #4. Pull off the mini-marshmallow (now it is a beta particle) and toss it about 1-2 feet from you. Leave the remaining proton in the bag and zip it closed. The atom's nucleus has changed and is stable again.
8. Draw your atoms below.

Radiation Types – Modeling Radioactive and Stable Atoms
Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

Questions

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2. What element is represented by this model?

3. How many neutral particles are in the bag? (You do count the particle where positive and negative charges cancel each other out!)

4. What is the atomic mass of this atom? (Each large marshmallow equals 1 atomic mass unit, regardless of charge.)

Enrichment Questions

1. What is the atomic number of the atom at the end of the experiment?

2. What element does the atomic model represent at the end of the experiment?

3. What is the atomic mass of the atom at the end of the experiment?