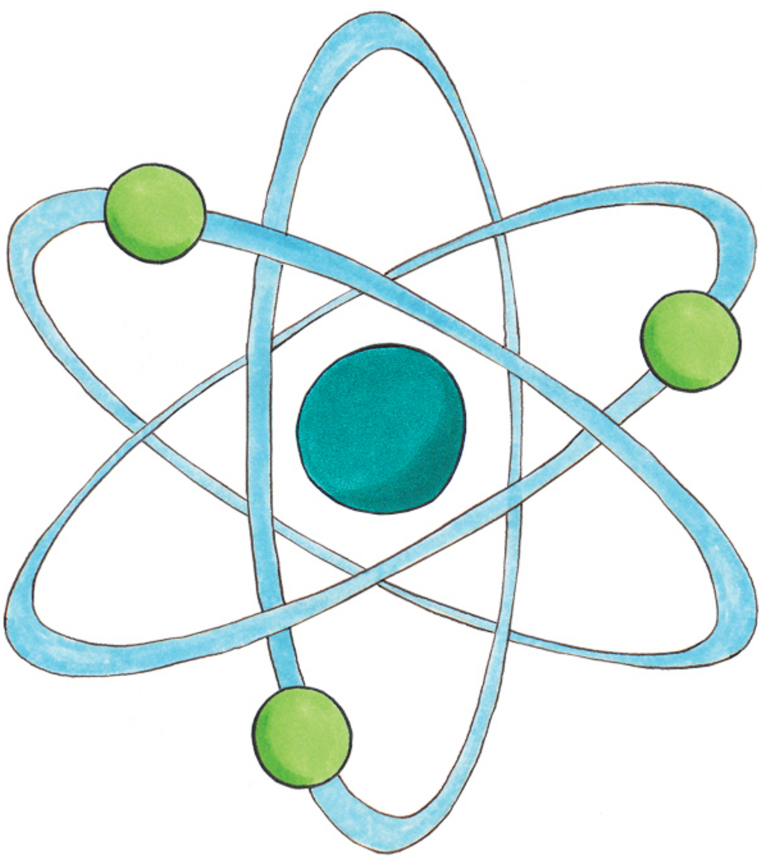
U.S. EPA Radiation Education Activities:

Evolution of a Radioactive Atom



United States Environmental Protection Agency

U.S. EPA Radiation Education Activities: **Evolution of a Radioactive Atom**

Atoms are the basic building blocks of all matter. Ionizing radiation can come from unstable (radioactive) atoms or it can be produced by machines. As unstable atoms decay and attempt to become stable, the nuclei release energy in the form of ionizing radiation (alpha particles, beta particles and gamma rays). The energy released is called ionizing radiation because it has enough energy to knock tightly bound electrons from an atom's orbit. This causes the atom to become a charged ion.

Target Audience and Activity Topics

The Evolution of a Radioactive Atom activities are designed to help middle and high school students identify the structure of an atom and describe the structural changes that occur in unstable (radioactive) atoms as they decay. Students will learn about the Rutherford-Bohr Theory of Atomic Structure and use the periodic table to determine an element's atomic structure. Students will also learn about the process of radioactive decay and the types of ionizing radiation emitted from radioactive atoms as they decay. Additionally, students will learn about commonly encountered radioactive elements, fission and fusion.

NOTE: The term "radiation" used in the activities generally refers to ionizing radiation unless otherwise indicated.

Activity Times

All U.S. Environmental Protection Agency (EPA) Radiation Education Activities can be used individually or modified and combined to create multiple lessons. Activity options allow you to customize the activities to fit the time you have available (e.g., 1–2 class periods) and meet the needs and interests of your students.

The time needed to complete activities is between 45-60 minutes, not including optional activities or extensions.

Next Generation Science Standards

The concepts within these activity sets can be used to support the following science standards:

- PS1. Structures and Properties of Matter
- PS2. Forces and Interactions

Common Core State Standards (CCSS)

The concepts in the Vocabulary Activities align with the following CCSS English Language Arts Standards for Literacy in History/Social Studies, Science, & Technical Subjects:

- Key Ideas and Details: CCSS.ELA-LITERACY.RST.6-12.2
- Craft and Structure: CCSS.ELA-LITERACY.RST.6-12.4
- Vocabulary Acquisition and Use: CCSS.ELA-LITERACY.L.6-12.6

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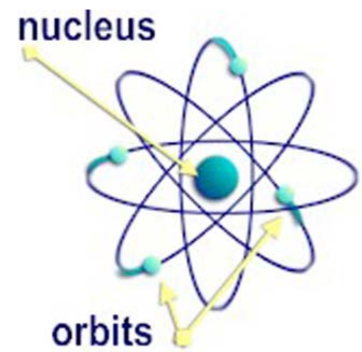
Evolution of a Radioactive Atom: Teacher Background Information

In the early 20th century, New Zealand scientist Ernest Rutherford conducted an experiment where he shot relatively large, electrically charged particles (alpha particles) at thin gold foil. He found that most of the particles passed directly through the foil, but some came off at odd angles as though they had been deflected. Rutherford concluded that atoms were mostly empty space, but that each contained a dense region — a central mass that alpha particles could not pass through. He determined that this central mass must have a positive charge to deflect the positively charged alpha particles. This is because like charges or magnetic fields (positive to positive or negative to negative) repel, as demonstrated when trying to place like poles of magnets together (north to north or south to south).

Rutherford-Bohr Theory of Atomic Structure



Rutherford and Danish scientist Niels Bohr developed a way of thinking about the structure of an atom in which an atom looks like our solar system. At the center of every atom is a nucleus, which is comparable to the sun. Electrons move around the nucleus in orbits similar to the way planets move around the sun.

Scientists' understanding about atomic structure has continued to evolve. Yet, we credit the Rutherford-Bohr Theory of Atomic Structure for providing us with a basis for understanding atomic structure. Atoms consist of protons, neutrons and electrons. The nucleus contains protons and neutrons; together these are called nucleons. Protons are positively (+) charged particles. Neutrons are electrically neutral and have no electrical (0) charge. Protons and neutrons are about 1800 times as heavy as an electron, which orbits the nucleus as a cloud. Electrons are negatively (–) charged and balance the positive electrical charge of the protons in the nucleus.

Determining the Structure of a Neutral Atom

Neutral atoms have the same number of protons (+) and electrons (-). We can use the periodic table, specifically the atomic number and atomic mass for each element, to determine the structure of neutral atoms. The atomic number, which is unique for each element, indicates the number of protons in an atom. For example, all hydrogen atoms have 1 proton, all carbon atoms have 6 protons and all oxygen atoms have 8 protons. Neutral atoms have the same number of protons and electrons. Therefore, hydrogen atoms have 1 proton and 1 electron, carbon atoms have 6 protons and 6 electrons and oxygen atoms have 8 protons and 8 electrons.

Atoms are so small that it does not make sense to calculate their mass using the same units we use every day, like ounces or grams. Early radiation scientists developed the Atomic Mass Unit (AMU) for calculating atomic mass. The atomic mass indicates the number of nucleons (protons and neutrons). To calculate the number of neutrons in an atom, we round the atomic mass to the nearest whole number and subtract the atomic number or number of protons from the atomic mass. For example:

- Carbon: 12 (atomic mass) - 6 (atomic number) = 6. The result indicates a carbon atom has 6 neutrons, 6 protons and 6 electrons.

What Holds the Parts of an Atom Together?

Opposite electrical charges of the protons and electrons hold the electrons in orbit around the nucleus of an atom. Within the nucleus, electromagnetic forces tend to shove the positively charged protons (and as a result the entire nucleus) apart. However, the nucleus is held together by an attractive, so-called strong nuclear force between nucleons: proton-to-proton, neutron-to-neutron and proton-to-neutron. This strong nuclear force is extremely powerful and only extends a very short distance — about the diameter of a proton or neutron. The strong nuclear force is helped by the presence of neutrons (to help counter the competing or repelling forces of protons) or the exchange of a particle, called a meson.

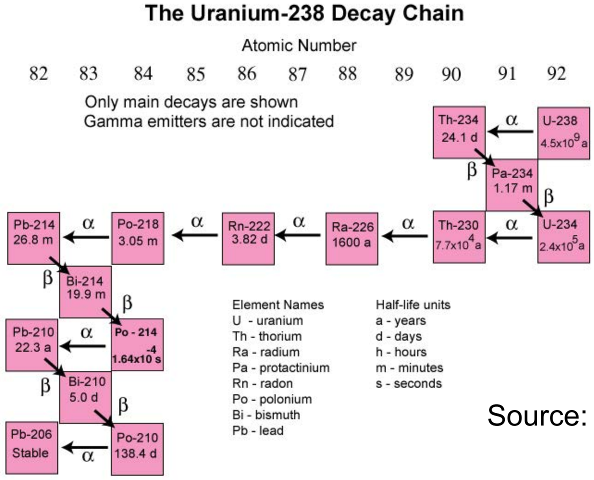
Why Are Some Atoms Radioactive?

The delicate balance of forces among particles keeps the nucleus stable. Any change in the number, the arrangement, or the energy of the nucleons can upset this balance and cause the nucleus to become unstable and create a radioactive atom. Disruption of electrons close to the nucleus can also cause an atom to emit radiation.

Can Unstable Atoms Become Stable?

As the unstable nucleus attempts to become stable, it emits radiation and changes into a different element as the number of protons changes. This process is called radioactive decay and it continues until the forces in the nucleus are balanced and stable. Another force, so-called weak nuclear force is responsible for radioactive decay. An example of weak nuclear force is the nuclear fusion reactions that power our sun and provide energy to sustain life on Earth. Unstable atoms will attempt to become stable by changing into a new isotope or element, and energy is released in the form of ionizing radiation until the forces in the nucleus are balanced and stable. The series of changes that a given radioactive element undergoes is called a decay chain. The following is an example of a decay chain for uranium-238.

The Uranium-238 Decay Chain



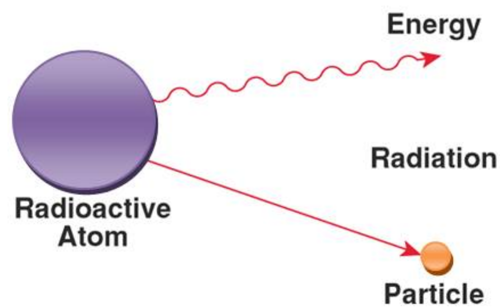
Source: U.S. Geological Survey (USGS)

Each radioactive element decays at a unique rate. This rate is known as a half-life; the amount of time it takes for approximately half of the radioactive atoms in a sample to decay into a more stable form. The image above indicates that radium-226 has a half-life of 1,602 years. So every 1,602 years approximately half of the radium-226 atoms in a sample decay and change to radon-222 (the next element in the decay chain). Note that uranium, radium and lead are metals, while radon is an inert gas under normal conditions. It is possible that as radioactive elements decay, their form (metal, gas, liquid, etc.) may change.

The half-life of slow decaying elements like uranium-238 and carbon-14 can be used to determine the age of organic matter. Radiographers also use half-life information to adjust film exposure times for x-rays and scans using other forms of ionizing radiation.

Is All Ionizing Radiation the Same?

When radioactive atoms decay, they release energy in the form of ionizing radiation (alpha particles, beta particles and gamma rays). The energy is called ionizing radiation because it has enough energy to knock tightly bound electrons from an atom's orbit. This causes the atom to become a charged ion.



Alpha Particles

When the ratio of neutrons to protons in the nucleus is too low, certain atoms restore the balance by emitting alpha particles. An alpha particle is a positively charged (+2) particle made up of two neutrons and two protons. They are relatively heavy, high-energy particles that cannot penetrate most matter. Rutherford's experiment (described on Page 4) involved extremely thin gold foils that were penetrated by alpha particles. A piece of paper or the dead outer layers of skin is sufficient to stop alpha particles. Radioactive material that emits alpha particles (alpha emitters) can be very harmful when inhaled, swallowed or absorbed into the blood stream because internal organs are more directly exposed without a protective layer of skin cells.

Beta Particles

Beta particle emission occurs when the ratio of neutrons to protons in the nucleus is too high. In this case, an excess neutron transforms into a proton and an electron. The proton stays in the nucleus and the electron (-1) is ejected energetically. This process decreases the number of neutrons by one and increases the number of protons by one. Since the number of protons in the nucleus of an atom determines the element, the conversion of a neutron to a proton actually changes the radioactive element (radionuclide) to a different element.

The speed of individual beta particles depends on how much energy they have, and varies widely. Beta particles can be stopped by a layer or two of clothing or by a few millimeters of a substance such as aluminum. They are capable of penetrating the skin and causing radiation damage, such as skin burns. As with alpha emitters, beta emitters are most hazardous when they are inhaled or ingested.

Gamma Rays

Gamma radiation is very high-energy ionizing radiation. Gamma rays have no mass and no electrical charge — they are pure electromagnetic energy. Gamma rays travel at the speed of light and can cover hundreds to thousands of meters through the air before expending their energy. They can easily penetrate barriers such as skin and clothing. Gamma rays have so much penetrating power that several inches of a dense material like lead or several feet of concrete may be required to stop them. Gamma rays can easily pass completely through the human body; as they pass through, it's possible for them to damage tissue and DNA.

While gamma rays and x-rays pose the same kind of hazard, they differ in their origin. Gamma rays originate in the nucleus. X-rays originate in the electron fields surrounding the nucleus or are machine produced.

Additional Resources:

- RadTown USA: www3.epa.gov/radtown
- Radiation Basics: http://www2.epa.gov/radiation/radiation-basics
- Radiation: Facts, Risks and Realities: http://www2.epa.gov/sites/production/files/2015-05/documents/402-k-10-008.pdf

Evolution of a Radioactive Atom Vocabulary Activities

The concepts surrounding radiation can be complex. By conducting a vocabulary activity before beginning an activity or series of activities, students will have a shared base knowledge.

Materials and Resources

- *Vocabulary Materials* document.
- Materials noted in activity suggestions.

Common Core State Standards (CCSS)

The concepts in this activity align with the following CCSS English Language Arts Standards for Literacy in History/Social Studies, Science, & Technical Subjects:

- Key Ideas and Details: CCSS.ELA-LITERACY.RST.6-12.2
- Craft and Structure: CCSS.ELA-LITERACY.RST.6-12.4
- Vocabulary Acquisition and Use: CCSS.ELA-LITERACY.L.6-12.6

Vocabulary by Activity

Activity 1: Atomic Discoveries	• Alpha particle • Atom • Electron	• Neutron • Nucleus • Proton
Activity 2: Atomic Math and Shorthand	• Atom • Electron • Isotope	• Neutron • Nucleus • Proton
Activity 3: Strong Nuclear Forces	• Atom • Electron • Ionizing radiation • Meson • Neutron	• Nucleus • Proton • Radioactive atom • Strong nuclear force
Activity 4: Atomic Stability	• Alpha particles • Atom • Beta particles • Electron • Ionizing radiation • Neutron	• Nucleus • Proton • Radiation • Radioactive atom • Radioactive decay
Activity 5: Half-Life Data Sheet	• Atom • Decay chain • Half-life • Ionizing radiation	• Radiation • Radioactive atom • Radioactive decay
Activity 6: Radioactive Decay Chain	• Atom • Alpha particles • Beta particles • Decay chain • Gamma rays	• Half-life • Ionizing radiation • Radiation • Radioactive atom • Radioactive decay

Activity Suggestions

- **Identifying images.**
  - Print the applicable images from the *Vocabulary Materials* document.
  - Display the images around the room or spread them out in an open area on the floor.
  - Pronounce the vocabulary words one at a time. NOTE: You can provide the definition of the given word at this time or after students have identified the words.
  - Have students take turns identifying the words in an active manner. Suggestions include having students move to and identify the correct image, use a flashlight to point to the correct image (being careful to avoid light in another person's eyes), drive a remote control car to the correct image or throw a bean bag to land on the correct image.
- **Matching words and images.**
  - Print the applicable words and images from the *Vocabulary Materials* document.
  - Give each student a vocabulary word or image. Options: Fold or ball up the copies and let each student select one. Have students trade their copy with another student once or twice. NOTE: You may need to participate to have an even number of participants.
  - Direct students to find the person with the matching word or image.
  - Review the matches to confirm they are correct.
  - Pronounce each word and provide a definition.
- **Spelling the words.**
  - Print the applicable words and images from the *Vocabulary Materials* document.
  - Display the words and images at the front of the classroom.
  - Pronounce each word and provide a definition.
  - Conduct a spelling activity:
    - Have students create a word scramble or word find activity; trade papers and complete the activity.
    - Play spelling basketball. Divide the class into two teams. Pronounce a vocabulary word. Have a student (alternating between teams) spell or write the word on the board. Students that spell the word correctly are given an opportunity to shoot a basket (use a trash can) with a ball of paper (ball) from a designated distance (or varying distances for a different number of points). The team that scores the most points wins. You can have students provide a definition for extra points.
- **Creating definitions.**
  - Print the applicable words and images from the *Vocabulary Materials* document.
  - Display the words and images at the front of the classroom.
  - Pronounce the vocabulary words.
  - Have students work in pairs or small groups to hypothesize and create a definition for each vocabulary word.
  - Options: Direct one student from each pair/group to rotate and join another pair/group or have two pairs/groups join together. Direct the newly formed groups to compare their definitions and modify them if desired.
  - Review each pair/group's definitions, have students discuss what they agree/disagree with and confirm the accurate definition.

Activity 1: Atomic Discoveries

Objectives

Students will:

- Simulate Ernest Rutherford's Gold Foil Experiment.
- Explain how the Rutherford-Bohr Theory of Atomic Structure helps provide us with a basic understanding of atomic structure.

NOTE: This activity serves as an introduction to atomic structure and does not address radiation or radioactive elements.

Next Generation Science Standards

The concepts in this activity can be used to support the following science standard:

- PS1. Structure and Properties of Matter.

Materials and Resources

- *Evolution of a Radioactive Atom: Teacher Background Information.*
- *Vocabulary Materials.*
- *The Smallest Matter Worksheet* (one per student, pair or group) and *The Smallest Matter Teacher Answer Key*.
- Objects to simulate the gold foil experiment (enough for a class or group demonstrations).
    - Solid object to represent the detecting screen (e.g., thin metal sheet, cardboard or books).
    - Small solid objects to represent the protons within the nucleus of gold atoms (e.g., small gravels or rocks that have a flat bottom to keep them in place).
    - Marbles, ping pong balls or other small balls to represent alpha particles being shot through the gold foil.
    - Online video of the gold foil experiment (optional). Sources may include TeacherTube or other allowed Internet sources.

Time

45-60 minutes, not including optional activities or extensions.

Vocabulary

- Alpha particle
- Atom
- Electron
- Neutron
- Nucleus
- Proton

Directions

1. Start with a vocabulary activity if students are not familiar with radiation and the terms used in this activity, or provide students with the terms and definitions.

2. Ask students to explain or hypothesize:
   - How we know about the existence of atoms and their structure. **Ancient Greeks were the first to believe that all matter in the universe must be made of tiny building blocks — or atoms. Early scientists started forming theories about, and conducting experiments to confirm, the existence and structure of atoms.**
   - Whether we know everything about atoms. **Beginning with early science scholars throughout history and into this century, scientists strive to learn more about the atom and how to control it. For example, scientists are exploring how to use nuclear fusion — the joining of lighter nuclei to create a larger one — to generate power.**

3. Provide students with a copy of *The Smallest Matter Worksheet*. Explain that Ernest Rutherford and Niels Bohr were among those early scientists who wanted to know more about atoms. They formed their model after Rutherford conducted a gold foil experiment (described in the *Evolution of a Radioactive Atom: Teacher Background Information*).

4. Have students work in pairs or small groups to simulate Rutherford's gold foil experiment and to answer the questions on *The Smallest Matter Worksheet*. You can also search online and show students an image, simulation or video of Rutherford's gold foil experiment when conducting this activity. NOTE: You may want have students answer question 1 on *The Smallest Matter Worksheet* first.

5. Conclude by asking students how the Rutherford-Bohr Theory of Atomic Structure Model helps us understand atomic structure today. **The theory provides us with the understanding that an atom has a dense, positively-charged nucleus and that electrons orbit around the nucleus.**

6. Optional activity or extension: Direct students to:
   - Examine other historical atomic models, compare them with our current understanding of atomic structure and analyze how our understanding of atomic structure has evolved over time.
   - Explore or diagram the atomic structure of different elements.
   - Examine Rutherford and Bohr's other discoveries related to atomic theory and radioactivity.

The Smallest Matter Worksheet

Name: ______________________________ Date: ________________

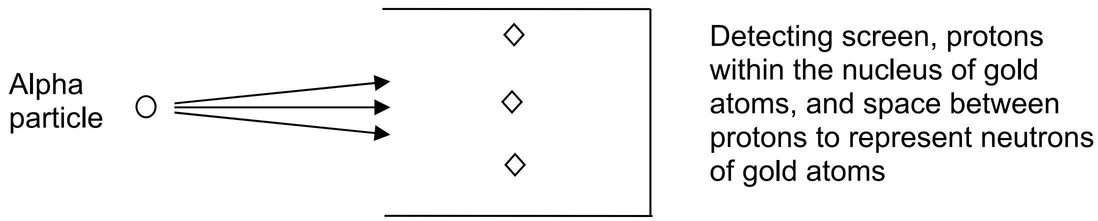
During the early 20th century, New Zealand scientist Ernest Rutherford conducted an experiment. He shot electrically charged alpha particles at thin gold foil. This experiment helped Rutherford and Danish scientist Niels Bohr develop a way of thinking about the structure of an atom.

Follow the directions to simulate Rutherford's Gold Foil Experiment.

Equipment:

- Solid object to represent the detecting screen.
- Small solid objects to represent the protons in the nucleus of gold atoms.
- Round object to represent alpha particles (positively charged particles made up of two neutrons and two protons).

Directions:
Select a flat surface. Set up the detecting screen in a U or circular shape, leaving an opening for the alpha particle. Place the small objects that represent the protons of a gold atom in the center of the area within the detecting screen. The space between the protons represents neutrons.



1. Observe the experiment setup and hypothesize what will happen when you roll alpha particles at the gold foil and why.

   ____
   ____
   ____

2. Roll the round object representing alpha particles toward the gold foil. Observe and record your observations for each roll.
   Roll 1: ______________________________
   Roll 2: ______________________________
   Roll 3: ______________________________
   Roll 4: ______________________________
   Roll 5: ______________________________
   Roll 6: ______________________________
   Roll 7: ______________________________
   Roll 8: ______________________________
   Roll 9: ______________________________
   Roll 10: ______________________________

3. Share your conclusions.

   a. What conclusions did you form about the structure of an atom based on the experiment and your observations?

   ____

   ____

   ____

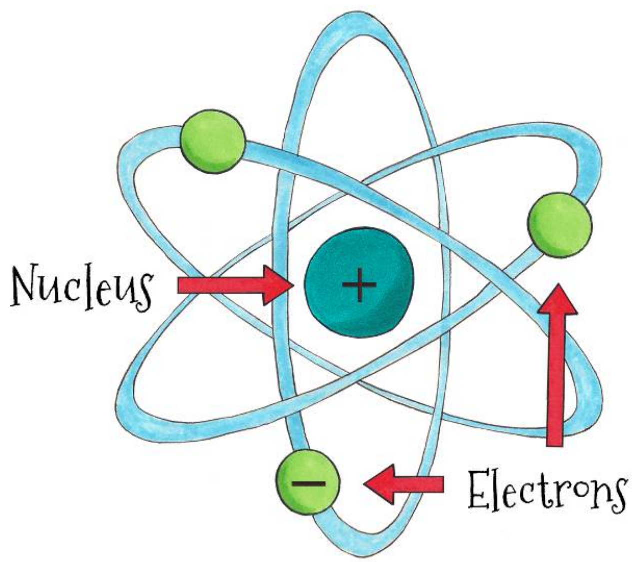
   b. From the gold foil experiment, Rutherford and Bohr concluded that each atom was mostly empty space, but also contained a central mass that the alpha particles could not pass through. Rutherford concluded that the central mass must have a positive charge. Why did he think that?

   ____

   ____

   ____

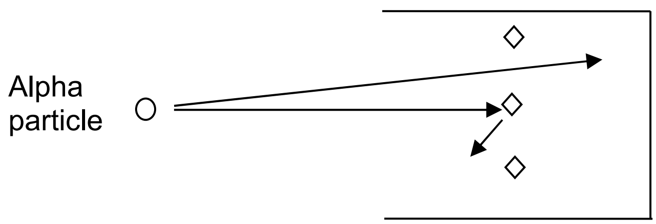
The Rutherford-Bohr Theory of Atomic Structure



The Smallest Matter Teacher Answer Key

1. Observe the experiment setup and hypothesize what will happen when you roll alpha particles at the gold foil and why.
   Answers will vary.

2. Roll the round object representing alpha particles toward the gold foil. Observe and record your observations for each roll.
   Answers will vary. Students should observe the alpha particles (marbles, ping pong balls, etc.) passing straight through at times and striking the protons and deflecting in different directions at times.



3. Share your conclusions.

   a. What conclusions did you form about the structure of an atom based on the experiment and your observations?
   Answers will vary.

   b. From the gold foil experiment, Rutherford and Bohr concluded that each atom was mostly empty space, but also contained a central mass that the alpha particles could not pass through. Rutherford concluded that the central mass must have a positive charge. Why did he think that?
   Because the positively charged alpha particles were deflected by the positively charged nucleus. This is based on the principles of electromagnetic force and the repulsion of like charges.

Activity 2: Atomic Math and Shorthand

Objectives

Students will use information from the periodic table to calculate the number of protons, neutrons and electrons in a neutral atom.

NOTE: Students should be familiar atomic structure and particles. The atomic shorthand information may serve as an introduction to *Activity 6: Radioactive Decay Chain*.

Next Generation Science Standards

The concepts in this activity can be used to support the following science standard:

- PS1. Structure and Properties of Matter.

Materials and Resources

- *Evolution of a Radioactive Atom: Teacher Background Information.*
- *Vocabulary Materials.*
- Several objects that represent or are made of different elements (e.g., gold ring, copper twine or pipe or lead from a pencil).
- *Periodic Table of Elements* (one per student, pair or group).
- *Atomic Calculations Worksheet* (one per student, pair or group) and *Atomic Calculations Teacher Answer Key*.
- *Radiation Baseball* game sheet (re-create on the board; print and use; or print, laminate and use with a dry erase marker).

Time

45-60 minutes, not including optional activities or extensions.

Vocabulary

- Atom
- Electron
- Isotope
- Neutron
- Nucleus
- Proton

Directions

1. Start with a vocabulary activity if students are not familiar with radiation and the terms used in this activity, or provide students with the terms and definitions.

2. Explain that all matter is made up of elements, some of which we can see (e.g., metals) and others we cannot (e.g., colorless gases). The smallest form of elements and all matter is atoms. Display two or more objects representing different elements (e.g., gold ring, copper twine or pipe or lead from a pencil) for students to identify.

3. Ask students how the atoms of these elements are similar and how they differ. **All atoms are made up of the same particles: protons, neutrons and electrons. The atoms of each element have a unique number of protons, neutrons and electrons.**

4. Provide students with the *Periodic Table of Elements.*

5. Ask students what data on the periodic table can be used to determine the atomic structure of an atom. **The atomic number indicates the number of protons and the number of electrons in an atom. Each element has a unique atomic number. The atomic mass is used to calculate the number of neutrons by subtracting the atomic mass from the atomic number.**

6. Select an element or use the objects you showed at the beginning of the activity. Work through an example of how to use the periodic table to determine the atomic structure of the element. Reference the *Determining the Structure of a Neutral Atom* section of the *Evolution of a Radioactive Atom: Teacher Background Information.*

7. Provide students with a copy of the *Atomic Calculations Worksheet*. Direct them to complete the handout using the periodic table as a reference.

8. Optional activity or extension: NOTE: This information may serve as a prerequisite for *Activity 6: Radioactive Decay Chain*.
   - Explain that as scientists identified the nuclear properties of elements and found different forms of elements (called isotopes), they needed an easy way to write and keep track of the basic nuclear properties. Scientists developed atomic shorthand that combines the defining pieces of information about the various forms of an element. There is more than one way the shorthand may be written as shown in the examples.
   - Display the following:

     $_{Z}X^{A}$ $\qquad$ ${}^{A}_{Z}X$

     - X = the chemical symbol of an element.
     - A = the atomic mass of an element (number of protons and neutrons).
     - Z = the atomic number of an element (number of protons).

   - Ask students to describe the notations in the examples.
   - Display the following (or similar) examples of elemental shorthand or notations and ask students to decipher them. The notations are for two forms (or isotopes) of iron with different atomic masses: iron-54 and iron-56.

     $_{26}Fe^{54}$ $\qquad$ $_{26}Fe^{56}$ $\qquad$ ${}^{54}_{26}Fe$ $\qquad$ ${}^{56}_{26}Fe$

9. Play *Radiation Baseball* to test students' newly acquired knowledge.
   - Prepare questions in advance or have students create questions for the game (e.g., Identify the number of protons in an iron (Fe) atom. How many nucleons are in a boron (B) atom?).
   - Draw a baseball diagram on the board or laminate a copy of the *Radiation Baseball* game sheet (and use a dry erase marker to track runs).
   - Divide the students into two teams. Students can select their team names (e.g., Particles or Rays).
   - Determine which team will start first. Each person that comes up to bat must answer a question. Incorrect responses equal a strike. Three strikes equal an out and the next team bats. A correct response means the student can move to the next base. You can mark students' progress with their name, a unique color or mark, or even small objects or magnets based on the surface you are using. As players cross home plate, they score a run. Tally or add the runs in the score area. NOTE: If time is limited, you can limit the number of strikes or questions per inning. The team with the most runs wins.

10. Conclude by having students share one or two things they learned about atomic structure and the periodic table.

Periodic Table of Elements

Period	Group 1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1	Hydrogen 1 H 1.008																	Helium 2 He 4.003
2	Lithium 3 Li 6.94	Beryllium 4 Be 9.012											Boron 5 B 10.81	Carbon 6 C 12.01	Nitrogen 7 N 14.01	Oxygen 8 O 16.00	Flouride 9 F 19.00	Neon 10 Ne 20.18
3	Sodium 11 Na 22.99	Magnesium 12 Mg 24.31											Aluminium 13 Al 26.98	Silicon 14 Si 28.09	Phosphorus 15 P 30.97	Sulfur 16 S 32.06	Chlorine 17 Cl 35.45	Argon 18 Ar 39.95
4	Potassium 19 K 39.10	Calcium 20 Ca 40.08	Scandium 21 Sc 44.96	Titanium 22 Ti 47.88	Vanadium 23 V 50.94	Chromium 24 Cr 52.00	Manganese 25 Mn 54.94	Iron 26 Fe 55.85	Cobalt 27 Co 58.93	Nickel 28 Ni 58.69	Copper 29 Cu 63.55	Zinc 30 Zn 65.39	Gallium 31 Ga 69.72	Germanium 32 Ge 72.64	Arsenic 33 As 74.92	Selenium 34 Se 78.96	Bromine 35 Br 79.90	Krypton 36 Kr 83.79
5	Rubidium 37 Rb 85.47	Strontium 38 Sr 87.62	Yttrium 39 Y 88.91	Zirconium 40 Zr 91.22	Niobium 41 Nb 92.91	Molybdenum 42 Mo 95.94	Technetium 43 Tc (98)	Ruthenium 44 Ru 101.1	Rhodium 45 Rh 102.9	Palladium 46 Pd 106.4	Silver 47 Ag 107.9	Cadmium 48 Cd 112.4	Indium 49 In 114.8	Tin 50 Sn 118.7	Antimony 51 Sb 121.8	Tellurium 52 Te 127.6	Iodine 53 I 126.9	Xenon 54 Xe 131.3
6	Caesium 55 Cs 132.9	Barium 56 Ba 137.3	57-70 *	Hafnium 72 Hf 178.5	Tantalum 73 Ta 180.9	Tungsten 74 W 183.9	Rhenium 75 Re 186.21	Osmium 76 Os 190.2	Iridium 77 Ir 192.2	Platinum 78 Pt 195.1	Gold 79 Au 197.0	Mercury 80 Hg 200.5	Thallium 81 Tl 204.4	Lead 82 Pb 207.2	Bismuth 83 Bi 209.0	Polonium 84 Po (209)	Astatine 85 At (210)	Radon 86 Rn (222)
7	Francium 87 Fr (223)	Radium 88 Ra (226)	89-102 **	Rutherfordium 104 Rf (265)	Dubnium 105 Db (268)	Seaborgium 106 Sg (271)	Bohrium 107 Bh (270)	Hassium 108 Hs (277)	Meitnerium 109 Mt (276)	Darmstadtium 110 Ds (281)	Roentgenium 111 Rg (280)	Copernium 112 Cn (285)	Ununtrium 113 Uut (284)	Ununquadium 114 Uuq (289)	Ununpentium 115 Uup (288)	Ununhexium 116 Uuh (293)	Ununseptium 117 Uus (294)	Ununoctium 118 Uuo (294)

Element Name
Atomic Number
Symbol
Atomic Weight

- Alkali metals
- Alkaline earth metals
- Transition metals
- Post-transition metals
- Metalloid
- Lanthanides
- Actinides
- Nonmetals
- Halogens
- Noble gases

* Lanthanoids	Lanthanum 57 La 138.9	Cerium 58 Ce 140.1	Praseodymium 59 Pr 140.9	Neodymium 60 Nd 144.2	Promethium 61 Pm (145)	Samarium 62 Sm 150.4	Eurpoium 63 Eu 152.0	Gadolinium 64 Gd 157.2	Terbium 65 Tb 158.9	Dysprosium 66 Dy 162.5	Holmium 67 Ho 164.9	Erbium 68 Er 167.3	Thulium 69 Tm 168.9	Ytterbium 70 Yb 173.0	Lutetium 71 Lu 175.0
** Actinoids	Actinium 89 Ac (227)	Thorium 90 Th 232	Proactinium 91 Pa 231	Uranium 92 U 238	Neptunium 93 Np (237)	Plutonium 94 Pu (242)	Americium 95 Am (243)	Curium 96 Cm (247)	Berkelium 97 Bk (247)	Californium 98 Cf (251)	Einsteinium 99 Es (252)	Fermium 100 Fm (257)	Mendelevium 101 Md (258)	Bobelium 102 No (259)	Lawrencium 103 Lr (262)

Atomic Calculations Worksheet

Name: ___________________________________ Date: ____________________

Use the *Periodic Table of Elements* to complete the following.

1. Determine the number of protons, neutrons and electrons for the following elements.

Elements	Number of Protons	Number of Neutrons	Number of Electrons
Hydrogen (H)			
Lithium (Li)			
Boron (B)			
Oxygen (O)			

2. Which element has a greater number of protons – Potassium (K) or Selenium (Se)?

   ____

3. Which element has a smaller number of electrons – Copper (Cu) or Silver (Ag)?

   ____

4. Which element has a greater number of neutrons – Magnesium (Mg) or Tin (Sn)?

   ____

Atomic Calculations Teacher Answer Key

1. Determine the number of protons, neutrons and electrons for the following elements.

Example Elements	Number of Protons	Number of Neutrons	Number of Electrons
Hydrogen (H)	1	0	1
Lithium (Li)	3	4	3
Boron (B)	5	6	5
Oxygen (O)	8	8	8

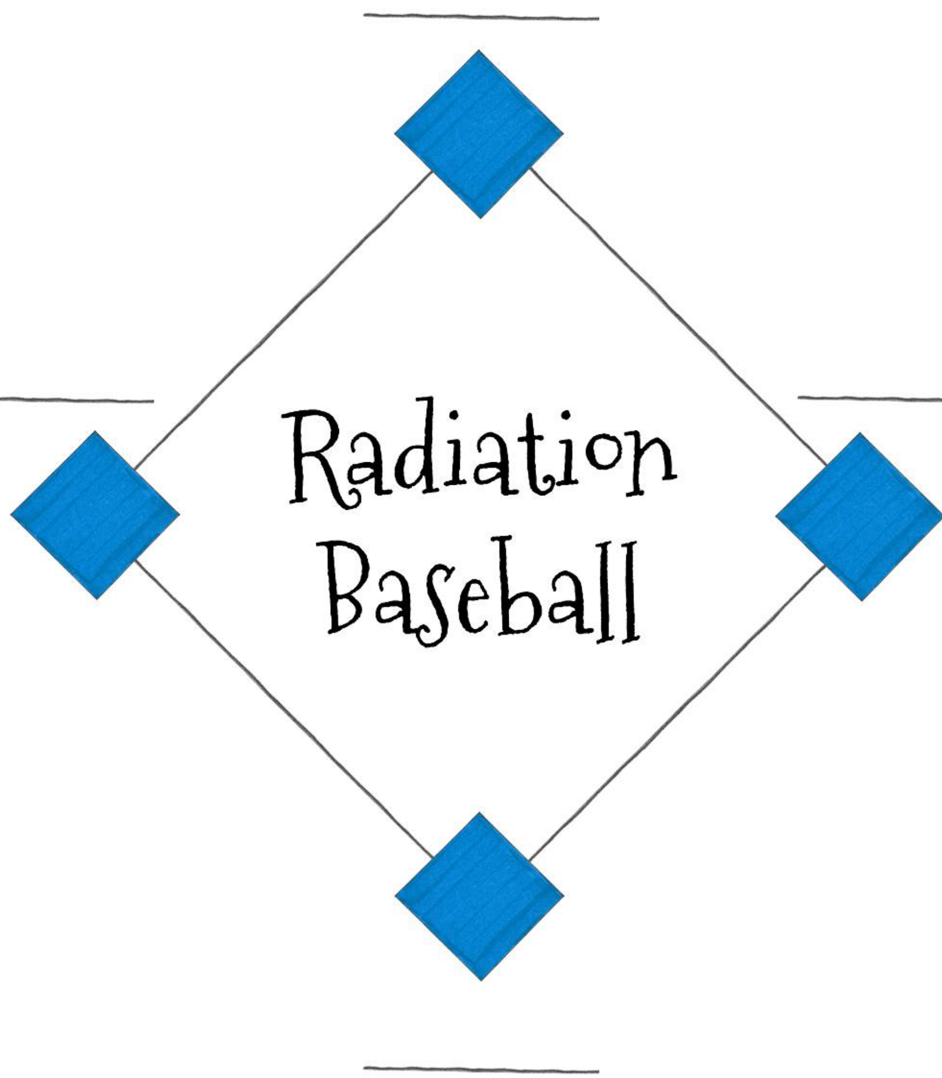
2. Which element has a greater number of protons – Potassium (K) or **Selenium (Se)**? **Potassium has 19 protons and Selenium has 34 according to the elements' atomic numbers.**

3. Which element has a smaller number of electrons – **Copper (Cu)** or Silver (Ag)? **Copper has 29 electrons, and Silver has 47 electrons, equaling the number of protons in each element.**

4. Which element has a greater number of neutrons – Magnesium (Mg) or **Tin (Sn)**? **Magnesium has 12 neutrons and Tin has 69, calculated by subtracting the atomic number from the atomic mass (rounded to a whole number).**

Radiation Baseball

	1	2	3	4	5	6	7	8	9	Total



Activity 3: Strong Nuclear Forces

Objectives

Students will:

- Learn about the delicate balance of forces that hold an atom together while electromagnetic forces try to pull the nucleus apart.
- Demonstrate the concept of the strong nuclear force.
- Discuss what occurs when the balance of forces is upset.

Next Generation Science Standards

The concepts in this activity can be used to support the following science standards:

- PS1. Structure and Properties of Matter.
- PS2. Forces and Interactions.

Materials and Resources

- *Evolution of a Radioactive Atom: Teacher Background Information.*
- *Vocabulary Materials.*
- *Strong Nuclear Forces Worksheet* (one per student, pair or group) and *Strong Nuclear Forces Teacher Answer Key*.
- Two magnets (per group).
- One small ball (e.g., ping pong ball) or object that can be tossed; attach a short string (1 to 2 feet long) to it to represent a meson.

Time

45-60 minutes.

Vocabulary

- Atom
- Electron
- Ionizing radiation
- Meson
- Neutron
- Nucleus
- Proton
- Radioactive atom
- Strong nuclear force

Directions

1. Start with a vocabulary activity if students are not familiar with radiation and the terms used in this activity, or provide students with the terms and definitions.

2. Ask students to hypothesize or explain why some elements are radioactive or what makes them radioactive. If needed, prompt them to think about the smallest form of an element — the atom — and what might occur within the atom, or more specifically the nucleus of an atom, to make an element radioactive. **Any change in the number, the arrangement, or energy of the nucleons can upset this balance and cause the nucleus to become unstable or radioactive.**

3. Explain that the upset of the delicate balance of forces in a nucleus can occur naturally (through radioactive decay) or through man-made processes (e.g., fission or the splitting of atoms to produce energy). Ask students to provide examples of how we benefit from and use unstable, or radioactive atoms. **We use radioactive atoms to generate electric power in power plants and in space probes, kill cancer cells, kill bacteria, perform medical scans of internal organs and conduct some manufacturing processes.**

4. Provide students with a copy of the *Strong Nuclear Forces Worksheet* and magnets. Have students work in small groups to answer questions 1 through 3. The questions are related to the structure of forces at play within the nucleus of an atom. Resources, if needed, may include student textbooks and the *Rutherford-Bohr Theory of Atomic Structure* section of the *Evolution of a Radioactive Atom: Teacher Background Information*.

5. Explain that while there are electromagnetic forces (observed by students when answering question 2) trying to pull the positively charged protons and the nucleus apart, there is also a strong nuclear force holding the nucleus together (proton-to-proton, neutron-to-neutron and proton-to-neutron). The strong nuclear force is helped by:
   - The presence of neutrons (to help counter the competing or repelling forces of protons).
   - The exchange of a particle, called a meson.

   The exchange of a meson creates an extremely strong nuclear force that holds the nucleons together. The strong nuclear force only extends a very short distance, so the nucleons must remain close to each other to remain tightly bound.

6. Demonstrate the concept of the strong nuclear force with students.
   - Ask for three student volunteers.
   - Identify two of the volunteers as protons and neutrons in the nucleus of an atom and have them stand close together — within 1 to 2 feet from each other.
   - Ask the third volunteer to stand off to the side — at least two 2 feet away.
   - Have the two close volunteers lightly toss the small ball or object with a string (meson) to each other. NOTE: The person tossing the object should hold onto the string to show the connection between the two.
   - Explain that they are connected by the meson (object being tossed between them).
   - Have one of the volunteers standing together try to toss the meson to the volunteer standing further away. NOTE: the person tossing the object should hold onto the string and the meson should fall to the ground.
   - **Explain that changes in the number, the arrangement or the energy of the nucleons can upset the balance of forces and cause the nucleus to become unstable or radioactive. Generally, this occurs in atoms (or nuclei) with more than**

82 protons. Unstable atoms will attempt to become stable by changing into a new form (e.g., a new isotope or element), and energy is released in the form of ionizing radiation (e.g., alpha particles, beta particles and gamma rays). The meson (small object that they are tossing) represents the energy being expelled from an unstable nucleus.

7. Direct students back to their *Strong Nuclear Forces Worksheet* to answer question 4. Review their responses and answer any questions.

8. Conclude by asking students what they learned about atoms and the forces at play in stable and unstable atoms.

Strong Nuclear Forces Worksheet

Name: ___________________________________ Date: ____________________

Answer the following questions as directed.

1. What three particles make up an atom and what are the electrical charges of the three particles?

   ____

   ____

2. Try placing the like poles of two magnets together. What happens? How might protons react in a nucleus?

   ____

   ____

3. Hypothesize or explain how the nucleus of an atom is held together.

   ____

   ____

4. Based on what you learned, do you agree with your response to question 3? Explain your answer.

   ____

   ____

Strong Nuclear Forces Teacher Answer Key

1. What three particles make up an atom and what are the electrical charges of the three particles?
   Protons, neutrons and electrons. Protons have a positive (+) charge. Neutrons have a neutral charge (no charge). Electrons have a negative charge (-).

2. Try placing the like poles of two magnets together. What happens? How might protons react in a nucleus?
   The magnets repel due to the electromagnetic forces causing like poles/charges to repel. Electromagnetic forces cause protons to repel.

3. Hypothesize or explain how the nucleus of an atom is held together. **Answers will vary.**

4. Based on what you learned, do you agree with your response to question 3? Explain your answer. **Answers will vary.**

Activity 4: Atomic Stability

Objectives

Students will learn what happens as atoms attempt to reach stability.

NOTE: Students should have a base knowledge in determining atomic structure (e.g., the atomic mass and atomic number of an atom based on the number of nucleons).

Next Generation Science Standards

The concepts in this activity can be used to support the following science standard:

- PS1. Structure and Properties of Matter.

Materials and Resources

- *Evolution of a Radioactive Atom: Teacher Background Information*.
- *Vocabulary Materials.*
- *Atomic Stability Worksheet* (one per student, pair or group) and *Atomic Stability Teacher Answer Key*.
- At least 21 objects per group (e.g., candy or small pieces of paper).
  - 10 objects should be the same color or marked with a plus (+) symbol to indicate they are protons.
  - 10 objects will represent neutrons with no electrical charge.
  - 1 object should be a different color or marked with a minus (-) symbol to indicate it is an electron.
- Student computers with Internet access (optional):
  - Radiation Basics, Types of Ionizing Radiation: http://www2.epa.gov/radiation/radiation-basics#tab-2
  - Radioactive Decay: http://www2.epa.gov/radiation/radioactive-decay

Time

45-60 minutes, not including optional activities or extensions.

Vocabulary

- Alpha particles
- Atom
- Beta particles
- Electron
- Ionizing radiation
- Neutron
- Nucleus
- Proton
- Radiation
- Radioactive atom
- Radioactive decay

Directions

1. Start with a vocabulary activity if students are not familiar with radiation and the terms used in this activity, or provide students with the terms and definitions.

2. Ask students to hypothesize:
   - Why some elements are radioactive (unstable). **When the atoms of an element have extra neutrons or protons it creates extra energy in the nucleus and causes the atom to become unbalanced or unstable.**
   - Whether radioactive elements can become stable and if so, how. **The unstable nucleus of radioactive atoms emit radiation. When this occurs, a new atom and element are formed. This process is called radioactive decay. It continues until the forces in the unstable nucleus are balanced.**

   NOTE: Images and videos demonstrating radioactive decay and alpha and beta emissions are available online if you would like to share them with students. Sources may include TeacherTube or other allowed Internet sources.

3. Distribute the *Atomic Stability Worksheet* and objects that represent protons, neutrons and an electron.

4. Explain that the focus of this activity will be on two types of radiation, alpha particles and beta particles, and how the release of alpha and beta particles changes the structure of the atom or nucleus. Pretend elements will be used in the activity to keep the number of nucleons small and manageable. Generally, the atoms of radioactive elements have a large number of nucleons.

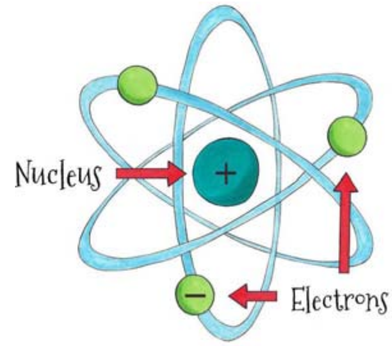
5. Guide students through the activity or perform the activity as a class if needed. Students should see that the emission of an alpha particle reduces the number of protons and neutrons by two. With the emission of a beta particle, the number of protons increases by one and the number of neutrons decreases by one.

6. Conclude by having students share what they learned about radioactive atoms the emission of alpha and beta particles.

7. Optional activity or extension: Ask students to:
   - Examine the properties, uses and health effects of alpha- and beta-emitters. Resources include:
   - Radiation Basics, Types of Ionizing Radiation: http://www2.epa.gov/radiation/radiation-basics#tab-2
   - Radioactive Decay: http://www2.epa.gov/radiation/radioactive-decay
   - Examine radioactive decay chains and determine whether each step was the result of an alpha or beta emission. See *Activity 6: Radioactive Decay Chain.*

Atomic Stability Worksheet

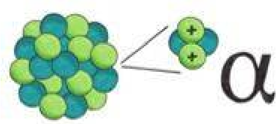
Name: ______________________________ Date: ________________

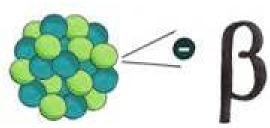


All elements are formed by atoms that are made up of:

- A nucleus containing protons and neutrons.
- Protons: positively (+) charged particles within the nucleus.
- Neutrons: particles within the nucleus that have no electrical charge (neutral).
- Electrons: particles that orbit the nucleus as a cloud and have a negative (–) charge.

The atoms of radioactive elements have an unstable nucleus. As the nucleus tries to become stable it releases energy (ionizing radiation) and extra protons or neutrons in the form of alpha or beta particles.





An **alpha particle** is made up of two protons (+2) and two neutrons from the atom's nucleus. Alpha particles have a positive charge (+2).

Before a **beta particle** is released a neutron changes into a proton and an electron (-1). The proton stays in the nucleus and the electron is released or ejected from the nucleus in the form of beta particles. Beta particles have a negative charge (-1).

Collect the materials and follow the directions to learn how the release of alpha and beta particles changes the structure of an atom.

Materials:

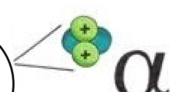
- 10 objects to represent neutrons.
- 10 objects to represent protons.
- 1 object to represent an electron.

1. Create a pretend radioactive nucleus for Element 1 including 5 neutrons (N) and 6 protons (P).

   Element 1 — N: 5 P: 6

2. Demonstrate what happens to Element 1 when the pretend radioactive nucleus emits an alpha particle and a new element (Element 2) is formed. Then enter the number of neutrons and protons in the nucleus of Element 2.

   Element 1 — N: 5 P: 6

   Element 2 — N: P:

What differences do you observe between the number of protons and neutrons in Element 2 and Element 1?

____

3. Return Element 2 to its original form: Element 1 (5 neutrons and 6 protons). Demonstrate what happens to Element 1 when it emits a beta particle and a new element (Element 3) is formed. Then enter the number of neutrons and protons in the nucleus of Element 3.

What differences do you observe between the number of protons and neutrons in Element 3 and Element 1?

____

4. Every element has a different number of protons. What happens to unstable (radioactive) atoms when they release an alpha or beta particle and the number of protons change?

____

____

____

5. Observe the changes in the number of protons and neutrons between the two elements below. Determine whether examples A and B show the release of an alpha particle or a beta particle. Circle the correct answer.

A

Polonium
Protons: 84
Neutrons: 126

→

Lead
Protons: 82
Neutrons: 124

Alpha particle

Beta particle

B

Cesium
Protons: 55
Neutrons: 82

→

Barium
Protons: 56
Neutrons: 81

Alpha particle

Beta particle

Atomic Stability Teacher Answer Key

1. Create a pretend radioactive nucleus for Element 1 including 5 neutrons (N) and 6 protons (P).

2. Demonstrate what happens to Element 1 when the pretend radioactive nucleus emits an alpha particle and a new element (Element 2) is formed. Then enter the number of neutrons and protons in the nucleus of Element 2. **Students should remove two protons and two neutrons.**

   What differences do you observe between the number of protons and neutrons in Element 2 and Element 1? **When a radioactive atom releases an alpha particle, the number of protons and neutrons decreases by two.**

3. Return Element 2 to its original form: Element 1 (5 neutrons and 6 protons). Demonstrate what happens to Element 1 when it emits a beta particle and a new element (Element 3) is formed. Then enter the number of neutrons and protons in the nucleus of Element 3. **Students should change a neutron to a proton and an electron (-1). The proton stays in the nucleus and the electron is released or ejected from the nucleus in the form of beta particles.**

   What differences do you observe between the number of protons and neutrons in Element 3 and Element 1? **The release of a beta particle decreases the number of neutrons by one and increases the number of protons by one.**

4. Every element has a different number of protons. What happens to unstable (radioactive) atoms when they release an alpha or beta particle and the number of protons change? **When the release of energy changes the number of protons in the nucleus, the atoms transform into a new radioactive element. Radioactive atoms decay and transform into new elements until they become stable.**

5. Observe the changes in the number of protons and neutrons between the two elements below. Determine whether examples A and B show the release of an alpha particle or a beta particle. Circle the correct answer.
   A: Alpha particle. The number of protons and neutrons decrease by two.
   B: Beta particle. The number of protons increases by one and the neutrons decrease by one.

Activity 5: Half-Life

Objectives

Students will:

- Learn about radioactive decay and decay chains.
- Demonstrate the concept of half-life.
- Calculate and chart the half-life of a given sample.
- Discuss the significance of knowing the half-life of radioactive elements.

Next Generation Science Standards

The concepts in this activity can be used to support the following science standard:

- PS1. Structure and Properties of Matter.

Materials and Resources

- *Evolution of a Radioactive Atom: Teacher Background Information.*
- *Vocabulary Materials.*
- *Half-Life Data Worksheet* (one per student, pair or group) and *Half-Life Data Teacher Answer Key*.
- 12 sheets of colored paper in two different colors – 6 sheets of each color
- Student calculators (optional).

Time

45-60 minutes.

Vocabulary

- Atom
- Decay chain
- Half-life
- Ionizing radiation
- Radiation
- Radioactive atom
- Radioactive decay

Directions

1. Start with a vocabulary activity if students are not familiar with radiation and the terms used in this activity, or provide students with the terms and definitions.

2. Ask students:
   - Do radioactive materials always remain unstable (radioactive)? **No. They will eventually become stable.**
   - How long does it take for unstable (radioactive) atoms to give off energy (radiation) and become stable or do all radioactive atoms lose energy and decay at the same rate? **Radioactive elements decay at different rates from fractions of seconds to millions and billions of years.**

3. Provide students with the *Half-Life Data Worksheet*. Have them read the initial statement and form a hypothesis.

4. Demonstrate the concept of half-life with the class by choosing from the following options:
   - Select three volunteers. Have the volunteers stand at a distance from an easily identifiable location (e.g., a wall or the classroom door). Direct each volunteer to move at varying rates (fast, moderate and slow) to represent half-lives of different elements. For example, radon has a half-life of 3.8 days, radium has a half-life of 1600 years, and uranium has a half-life of 4.5 billion years. Direct each volunteer to walk halfway toward the identifiable location at their designated rate and stop before continuing to the next halfway point between them and the identifiable location. They will continue this process until they cannot go any farther. You can mark the halfway points with string or paper if students need guidance.
   - Ask for 12 volunteers. Have the student volunteers line up in the front of the room. Provide each volunteer with two different colored sheets of paper to represent radon and polonium. Have all of the volunteers hold the radon paper out, facing the students. Have half of the volunteers (any 6 of the 12) place the polonium colored paper facing out to represent the half of the atoms that transferred into polonium. Then have the next half (3 of the 6 volunteers showing radon) place the polonium paper out, facing the students. In the next half-life, have one volunteer place the polonium paper out front and have another volunteer show half radon and half polonium by folding one or both of the papers in half. The remaining volunteer should then place the polonium paper out front and the volunteer showing half radon and half polonium should fold one or both papers to represent three-fourths radon and one-fourth polonium.
   - Show an online video or demonstration of half-life. Sources may include TeacherTube, other allowed Internet sources, or Colorado University's online applet that demonstrates half-life and radioactive decay.

5. Direct students to complete the remainder of the *Half-Life Data Worksheet*. The use of calculators is optional.

6. Ask students to share their observations and conclusions from the activity. A *Half-Life Data Teacher Answer Key* is provided.

Half-Life Data Worksheet

Name: ______________________________________ Date: _____________________

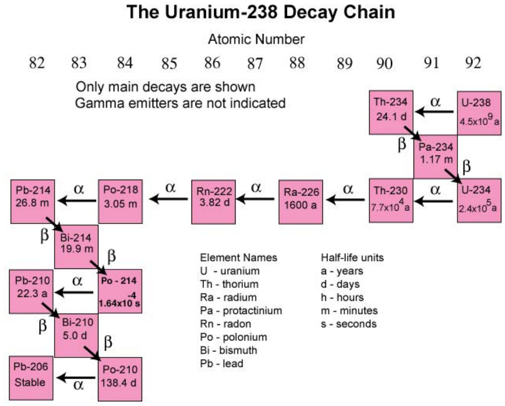
Follow the directions and answer the questions.

The following image shows how uranium-238 (a radioactive element) decays and changes to a stable element (lead-206). The half-life of each element is shown in years and days.

Hypothesize what half-life is:

____
____
____
____
____
____

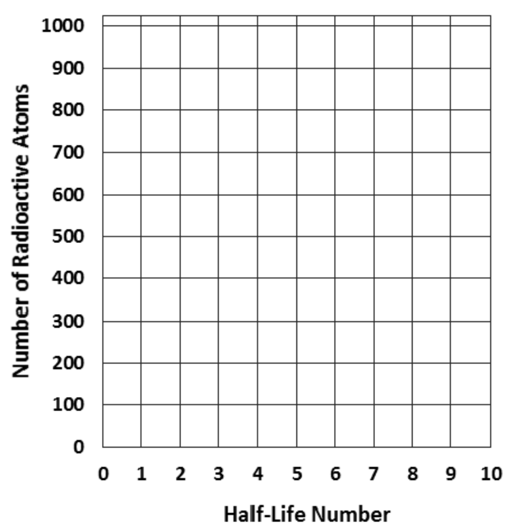
The Uranium-238 Decay Chain



Observe the half-life demonstration as directed by your teacher.

Calculate the number of radioactive atoms remaining after each half-life. Write the number of atoms in the “Number of Radioactive Atoms” column. Plot the number of radioactive atoms on the graph provided. Note that the number of unstable (radioactive) atoms decreases as they are being transformed into stable atoms.

Half-Life Number	Number of Radioactive Atoms
0	1024
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	



Observations: ____
____
____

Half-Life Data Worksheet

Questions:

1. If you had a sample of 4,000 radioactive atoms, how many atoms would remain after 5 half-lives?

Half-Life Number	Number of Radioactive Atoms
0	4000
1	
2	
3	
4	
5	

2. If you had a sample of 210 atoms, and you started with a sample of 3,360 atoms, how many half-lives have elapsed?

____

____

3. If the half-life of the sample from question 2 is 30 minutes, how many hours did it take to decay from 3,360 atoms to 210 atoms?

____

4. Can you determine the age of something (like a fossil) by examining its half-life? Explain.

____

____

____

____

5. In what other ways might it be useful to know a sample's half-life?

____

____

____

____

Half-Life Data Teacher Answer Key

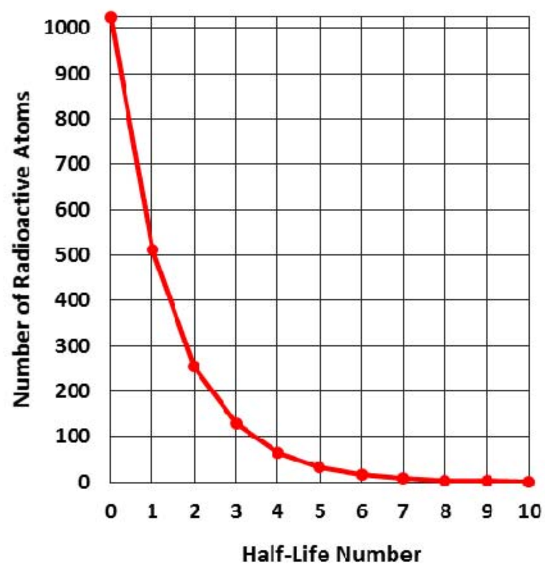
Hypothesize what half-life is:

Half-life is the amount of time it takes for approximately half of the radioactive atoms in a sample to decay into a more stable form. Every radioactive element has a different half-life.

Calculate the number of radioactive atoms remaining after each half-life. Write the number of atoms in the “Number of Radioactive Atoms” column. Plot the number of radioactive atoms on the graph provided. Note that the number of unstable (radioactive) atoms decreases as they are being transformed into stable atoms.

Observations: **Answers will vary, but students should recognize that the number of radioactive atoms decreases by half after each half-life.**

Half-Life Number	**Number of Radioactive Atoms**
0	1024
1	*512*
2	*256*
3	*128*
4	*64*
5	*32*
6	*16*
7	*8*
8	*4*
9	*2*
10	*1*



Questions:

1. If you had a sample of 4,000 radioactive atoms, how many atoms would remain after 5 half-lives? **125 radioactive atoms.**

Half-Life Number	**Number of Radioactive Atoms**
0	**4000**
1	**2000**
2	**1000**
3	**500**
4	**250**
5	**125**

2. If you had a sample of 210 atoms, and you started with a sample of 3,360 atoms, how many half-lives have elapsed? **4 half-lives.**

Half-Life Number	Number of Radioactive Atoms
0	3360
1	1680
2	840
3	420
4	210

3. If the half-life of that same sample is 30 minutes, how many hours did it take to decay from 3,360 atoms to 210 atoms? **2 hours.**

Half-Life Number	Number of Radioactive Atoms	Time that has passed (minutes)
0	3360	0
1	1680	30
2	840	60
3	420	90
4	210	120

4. Can you determine the age of something (like a fossil) by examining its half-life? Explain. **Yes, this process is called carbon dating. Basically, all living things are made of carbon that continuously cycles through the environment. A small portion of this carbon is in the form of carbon–14, an unstable (radioactive) element. Once an organism dies, the carbon–14 begins to disintegrate. Because it disintegrates at a steady known rate scientists can measure the amount of carbon–14 remaining and use a scientific formula to determine the age of the sample.**

5. In what other ways might it be useful to know a sample's half-life? **It helps in determining how long radioactive material must be safely stored, when radioactive material will be safe to handle, or how long a source will remain radioactive. For example, radioactive dye (called a tracer) and radioactive seeds are used in medical imaging and cancer treatment. Knowing the half-life helps doctors and patients know how long the radioactive material will be effective and when it will stop producing radiation.**

Activity 6: Radioactive Decay Chain

Objectives

Students will:

- Learn about radioactive decay and decay chains.
- Observe a decay chain.
- Identify types of radiation emitted with each step in the decay chain.

NOTE: Students should be familiar with atomic structure and the concept of radioactivity prior to completing this activity. The information presented in *Activity 2: Atomic Math and Shorthand* may help introduce the concepts needed to complete this activity.

Next Generation Science Standards

The concepts in this activity can be used to support the following science standard:

- PS1. Structure and Properties of Matter.

Materials and Resources

- *Evolution of a Radioactive Atom: Teacher Background Information.*
- *Vocabulary Materials.*
- Computer and/or projector to display information.
- *Decay Chain Examples* (display or distribute to students) and *Decay Chain Examples Teacher Answer Key*.
- *Decay Chain Worksheet* (one per student, pair or group) and *Decay Chain Teacher Answer Key* teacher answer key.
- *Periodic Table of Elements* (to display or distribute to students).
- Student computers with Internet access to *Radiation Basics:* http://www2.epa.gov/radiation/radiation-basics

Time

45-60 minutes, not including optional activities or extensions.

Vocabulary

- Atom
- Alpha particles
- Beta particles
- Decay chain
- Gamma rays
- Half-life
- Ionizing radiation
- Radiation
- Radioactive atom
- Radioactive decay

Directions

1. Start with a vocabulary activity if students are not familiar with radiation and the terms used in this activity, or provide students with the terms and definitions.

2. Ask students what happens when things (e.g., plants, food and wood) decay. **Students should address how the items change in composition over time.** Prompt students to hypothesize whether things decay at the same rate and in the same way.

3. Ask students to hypothesize how radioactive atoms or materials decay. **Radioactive decay occurs when an unstable (radioactive) atom gives off energy (in the form of ionizing radiation) as it attempts to become a stable atom and is no longer radioactive.**

4. Display or provide students with a copy of the *Decay Chain Examples.*

5. Review the examples and work through the questions listed on the *Decay Chain Examples* *Teacher Answer Key* with students.

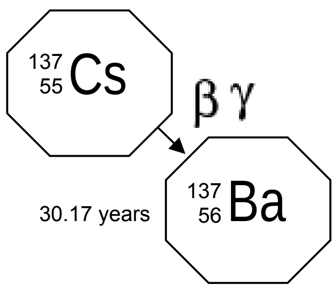
6. Distribute the *Decay Chain Worksheet* and the *Periodic Table of Elements*. Have students examine each decay chain, identify the elements (or isotopes) within each decay chain, and determine whether each transformation is due to the emission of an alpha or beta particle. The *Decay Chain* *Teacher Answer Key* provides questions and answers to review with students.

7. Have students share (orally or in writing):
   - What they have learned from the activity.
   - How we might use and benefit from radioactive elements that decay. **We use radioactive elements for many different purposes. Beta-emitting elements with short half-lives are used in nuclear medicine, imaging and gauges. For example, cesium-137 is used in medical therapy to treat cancer and in moisture-density gauges, leveling gauges and thickness gauges. Alpha-emitting elements with longer half-lives are used for industrial purposes. For example, americium-241 is used in nuclear gauges, plutonium-238 is an alpha-emitting isotope that is used for generation of electric power in space probes.**

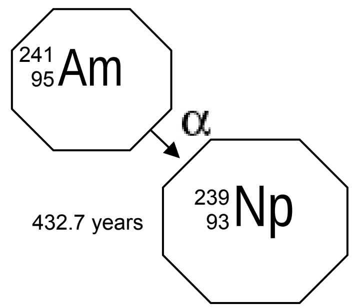
8. Optional activities or extensions: Have students:
   - Diagram a decay chain for a particular radioactive element. The diagram can be simple (e.g., use elements with shorter chains or use a portion of longer decay chains) or complex, based on the time available. The diagram can be completed on paper or electronically.
   - Plot decay chains (e.g., using the radon chain on the *Decay Chain Worksheet* or others that students create) on a graph with the atomic numbers identified on one axis (x or y) and the atomic mass on the other (x or y).

Decay Chain Examples

Cesium (Cs)



Americium (Am)

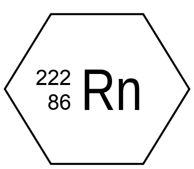


Key

Alpha particle: α

Beta particle: β

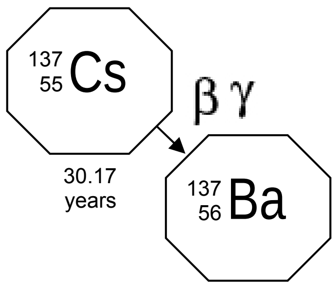
Gamma ray: γ



In the example, Rn is the atomic symbol for the element Radon. The number 222 indicates the atomic mass of the element (or isotope). The number 86 respresents the element's atomic number.

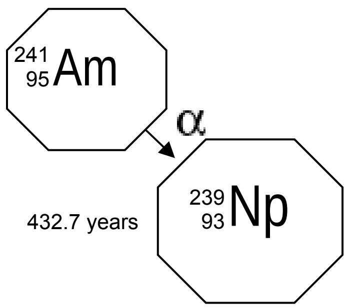
Decay Chain Examples Teacher Answer Key

Cesium (Cs)



Cesium–137 is an isotope of cesium that is produced when uranium and plutonium absorb neutrons and undergo fission (the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy; used to generate nuclear power).

Americium (Am)



Americium–241 is produced in the same process as Cesium-137; it is an isotope of americium that is used in ionizing smoke detectors and nuclear gauges.

The number of years listed in the example is the half-life for each element. Half-life is the amount of time it takes for approximately one-half of the radioactive atoms to decay. Radioactive elements decay at different rates (e.g., cesium has a half-life of 30.17 years and americium–241 has a half-life of 432.7 years).

1. What forms of radiation are released when cesium (Cs) converts to barium (Ba)?
   Beta particle and gamma rays.

2. What change occurs in the atomic properties of cesium (Cs) when it converts to barium (Ba)? Why?
   The number of protons increases by one and cesium (55) becomes barium (56) because before a beta particle is released a neutron changes into a proton and an electron. The proton stays in the nucleus and the electron is ejected from the nucleus in the form of beta particles. The release of a beta particle decreases the number of neutrons by one and *increases the number of protons by one*.

3. What form of radiation is released when americium (Am) converts to neptunium (Np)?
   Alpha particle.

4. What change occurs in the atomic properties of americium (Am) when it converts to neptunium (Np)? Why?
   An alpha particle is made up of two protons (+2) and two neutrons from the atom's nucleus. When the ratio of neutrons to protons in the nucleus is too low, certain atoms restore the balance by emitting alpha particles. This *reduces the number of protons by two*, changing americium (95) to neptunium (93).

Periodic Table of Elements

Element Name Atomic Number Symbol Atomic Weight

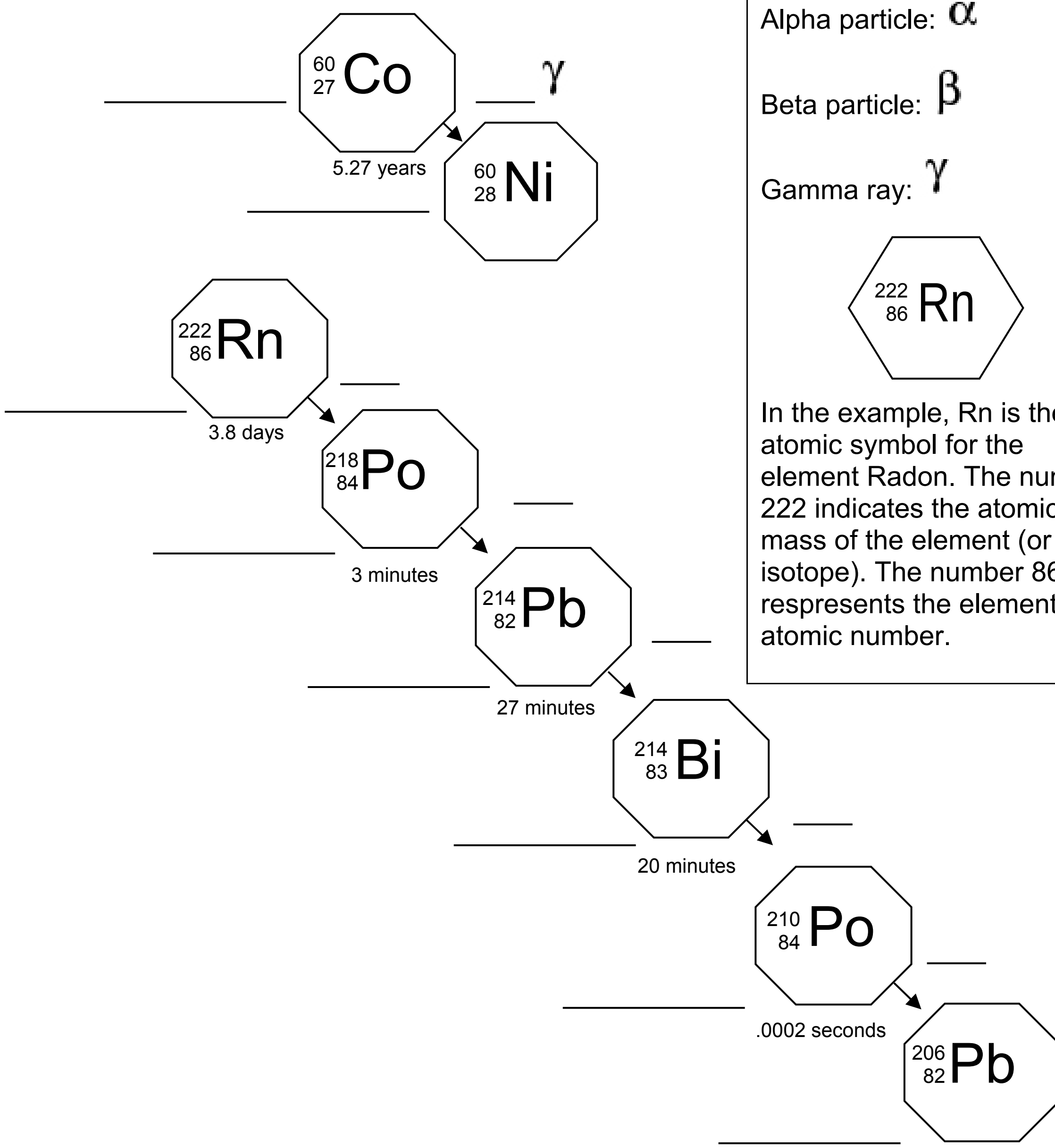
- Alkali metals
- Alkaline earth metals
- Transition metals
- Post-transition metals
- Metalloid
- Lanthanides
- Actinides
- Nonmetals
- Halogens
- Noble gases

Period \ Group	1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1	Hydrogen 1 H 1.008																	Helium 2 He 4.003
2	Lithium 3 Li 6.94	Beryllium 4 Be 9.012											Boron 5 B 10.81	Carbon 6 C 12.01	Nitrogen 7 N 14.01	Oxygen 8 O 16.00	Flouride 9 F 19.00	Neon 10 Ne 20.18
3	Sodium 11 Na 22.99	Magnesium 12 Mg 24.31											Aluminium 13 Al 26.98	Silicon 14 Si 28.09	Phosphorus 15 P 30.97	Sulfur 16 S 32.06	Chlorine 17 Cl 35.45	Argon 18 Ar 39.95
4	Potassium 19 K 39.10	Calcium 20 Ca 40.08	Scandium 21 Sc 44.96	Titanium 22 Ti 47.88	Vanadium 23 V 50.94	Chromium 24 Cr 52.00	Manganese 25 Mn 54.94	Iron 26 Fe 55.85	Cobalt 27 Co 58.93	Nickel 28 Ni 58.69	Copper 29 Cu 63.55	Zinc 30 Zn 65.39	Gallium 31 Ga 69.72	Germanium 32 Ge 72.64	Arsenic 33 As 74.92	Selenium 34 Se 78.96	Bromine 35 Br 79.90	Krypton 36 Kr 83.79
5	Rubidium 37 Rb 85.47	Strontium 38 Sr 87.62	Yttrium 39 Y 88.91	Zirconium 40 Zr 91.22	Niobium 41 Nb 92.91	Molybdenum 42 Mo 95.94	Technetium 43 Tc (98)	Ruthenium 44 Ru 101.1	Rhodium 45 Rh 102.9	Palladium 46 Pd 106.4	Silver 47 Ag 107.9	Cadmium 48 Cd 112.4	Indium 49 In 114.8	Tin 50 Sn 118.7	Antimony 51 Sb 121.8	Tellurium 52 Te 127.6	Iodine 53 I 126.9	Xenon 54 Xe 131.3
6	Caesium 55 Cs 132.9	Barium 56 Ba 137.3	57-70 *	Hafnium 72 Hf 178.5	Tantalum 73 Ta 180.9	Tungsten 74 W 183.9	Rhenium 75 Re 186.21	Osmium 76 Os 190.2	Iridium 77 Ir 192.2	Platinum 78 Pt 195.1	Gold 79 Au 197.0	Mercury 80 Hg 200.5	Thallium 81 Tl 204.4	Lead 82 Pb 207.2	Bismuth 83 Bi 209.0	Polonium 84 Po (209)	Astatine 85 At (210)	Radon 86 Rn (222)
7	Francium 87 Fr (223)	Radium 88 Ra (226)	89-102 **	Rutherfordium 104 Rf (265)	Dubnium 105 Db (268)	Seaborgium 106 Sg (271)	Bohrium 107 Bh (270)	Hassium 108 Hs (277)	Meitnerium 109 Mt (276)	Darmstadtium 110 Ds (281)	Roentgenium 111 Rg (280)	Copernium 112 Cn (285)	Ununtrium 113 Uut (284)	Ununquadium 114 Uuq (289)	Ununpentium 115 Uup (288)	Ununhexium 116 Uuh (293)	Ununseptium 117 Uus (294)	Ununoctium 118 Uuo (294)

* Lanthanoids	Lanthanum 57 La 138.9	Cerium 58 Ce 140.1	Praseodymium 59 Pr 140.9	Neodymium 60 Nd 144.2	Promethium 61 Pm (145)	Samarium 62 Sm 150.4	Eurpoium 63 Eu 152.0	Gadolinium 64 Gd 157.2	Terbium 65 Tb 158.9	Dysprosium 66 Dy 162.5	Holmium 67 Ho 164.9	Erbium 68 Er 167.3	Thulium 69 Tm 168.9	Ytterbium 70 Yb 173.0	Lutetium 71 Lu 175.0
** Actinoids	Actinium 89 Ac (227)	Thorium 90 Th 232	Proactinium 91 Pa 231	Uranium 92 U 238	Neptunium 93 Np (237)	Plutonium 94 Pu (242)	Americium 95 Am (243)	Curium 96 Cm (247)	Berkelium 97 Bk (247)	Californium 98 Cf (251)	Einsteinium 99 Es (252)	Fermium 100 Fm (257)	Mendelevium 101 Md (258)	Bobelium 102 No (259)	Lawrencium 103 Lr (262)

Decay Chain Worksheet

Examine each decay chain and identify the element. Then indicate whether each transformation is due to the emission of an alpha or beta particle by writing in the corresponding symbol. Sometimes gamma rays are released but because the release of gamma rays does not affect atomic mass or atomic number the exercise is focused on alpha and beta emissions.



Key

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Beta particle: β

Gamma ray: γ

In the example, Rn is the atomic symbol for the element Radon. The number 222 indicates the atomic mass of the element (or isotope). The number 86 respresents the element's atomic number.

Decay Chain Teacher Answer Key

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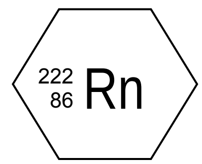

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