Name: ______________________________________ Date: ________________________

Student Exploration: Nuclear Decay

Vocabulary: alpha particle, atomic number, beta particle, daughter product, gamma ray, isotope, mass number, nuclear decay, positron, radioactive, subatomic particle

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)
The chart below gives the locations, charges, and approximate masses of three **subatomic particles**. The approximate mass of each particle is given in universal mass units (u).

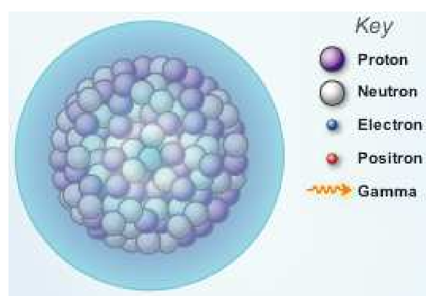
Particle	Location	Charge	Approximate mass
Proton	Nucleus	1^+	1 u
Neutron	Nucleus	0	1 u
Electron	Orbitals	1^-	0 u

1. The **mass number** of an atom is equal to the sum of protons and neutrons in the nucleus.

   A helium atom has 2 protons and 2 neutrons. What is the mass number of this atom? _____

2. The **atomic number** of an element is equal to the number of protons in each atom of the element. All helium atoms have 2 protons. What is the atomic number of helium? _____

Gizmo Warm-up
While most atoms are stable, some are **radioactive**, which means that they have a tendency to undergo spontaneous **nuclear decay**. The decay of radioactive atoms generally results in the emission of particles and/or energy.



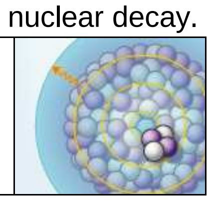
Several types of nuclear decay can be explored with the *Nuclear Decay* Gizmo™. On the Gizmo, check that **Alpha decay** and **Uranium** are selected.

1. Click **Play** ( ) and then click **Pause** ( ) when the **alpha particle** is clearly visible.

   What is an alpha particle made of? ____

2. Click **Play** and observe. Besides the alpha particle, what else is emitted from the nucleus during alpha decay? ____

   Gamma rays are energetic electromagnetic waves; they are often emitted in nuclear decay.

Activity A: **Alpha decay**	Get the Gizmo ready: • Click **Reset** ( ). • Check that **Alpha decay** and **Uranium** are selected.	

Question: How does alpha decay change the nucleus of a radioactive atom?

1. Predict: As you observed in the warm-up activity, an alpha particle consists of two protons and two neutrons. How will the emission of an alpha particle affect the following?

   A. The atomic number of the atom: ____

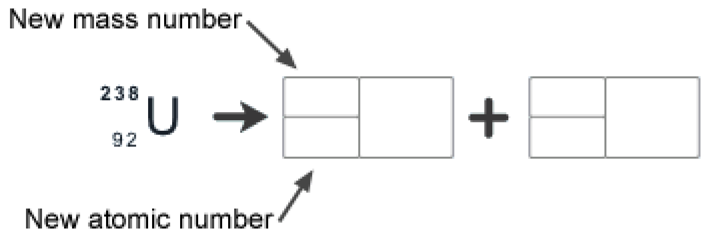
   B. The mass number of the atom: ____

2. Calculate: Turn on **Write equation**. What you see is an equation that shows the original uranium atom on the left. The boxes on the right represent the **daughter product**—the atom produced by radioactive decay—and the emitted alpha particle.

   A. In the top left box, write the mass number of the daughter product and press “Enter” on your keyboard. What is this number? ______________

B. In the bottom left box, write the atomic number of the daughter product and press “Enter.” What is this number? _______________

C. In the next set of boxes, enter the mass number and atomic number of the alpha particle, which has the same composition as the nucleus of a helium (He) atom. After filling in the boxes in the Gizmo, write the completed equation below:

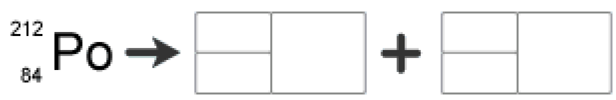


D. According to your equation, what **isotope** remains after the alpha decay of uranium-238? (Note: You can look up element symbols on the periodic table.)

____

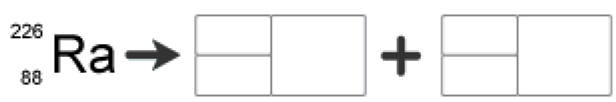
3. Check: Turn on **Show equation**, and click **Play**. The equation will appear at the end of the animation. Was your prediction correct? ______________ If not, modify your equation above.

4. Practice: Click **Reset**, turn off **Show equation**, and select **Polonium**. Write an equation for the alpha decay of polonium, and then use the Gizmo to check your answer.



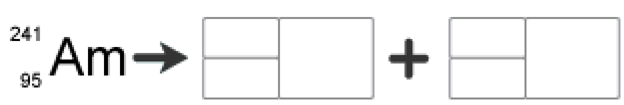
What isotope remains after the alpha decay of polonium-212? _________________________

5. Practice: Click **Reset**, turn off **Show equation**, and select **Radium**. Write an equation for the alpha decay of radium, and then use the Gizmo to check your answer.



What dangerous gas is produced by the decay of radium-226? _________________________

6. Practice: Americium-241 is a radioactive isotope used in smoke detectors. Write an equation for the alpha decay of Americium-241 below.



7. Analyze: In each equation, how is the mass number on the left side of the arrow related to the sum of mass numbers on the right side of the arrow? Is this true for atomic numbers?

____

____

8. Summarize: In general, how can you determine the mass number of the daughter product after alpha decay has taken place? How can you determine the atomic number?

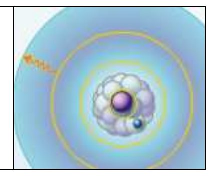
____

____

9. Think and discuss: Helium is the second most abundant element in the universe, but it is rare in Earth’s atmosphere. Most of the helium used to fill balloons and blimps must be extracted from Earth’s crust. How do you think this helium formed?

____

____

Activity B: **Beta decay**	Get the Gizmo ready: • Click **Reset**, and turn off **Show equation**. • Select **Beta decay** from the **Type of decay** menu. • Check that **Carbon** is selected.	

Question: How does beta decay change the nucleus of a radioactive atom?

1. Observe: Click **Play** and watch the animation.

   A. What happens to the decaying neutron during beta decay? ____________________

   ____

   B. What is emitted from the nucleus during beta decay? _________________________

   C. What is the mass number and charge of the emitted particle?

   Mass number: _______ Charge: _______

2. Predict: During beta decay, a neutron is transformed into a proton and an electron (the **beta particle**), which is emitted. Gamma rays are often emitted during beta decay as well. How will beta decay affect the atomic number and mass number of the atom?

   ____

3. Calculate: Turn on **Write equation**. Fill in the first set of boxes with the mass number and atomic number of the daughter product and the next set of boxes with the mass number and atomic number of the beta particle. (Note: The atomic number of an electron is -1.)

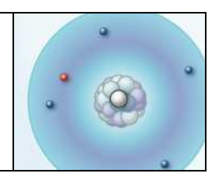
   $${}^{14}_{6}\mathrm{C} \rightarrow \boxed{}\boxed{} + \boxed{}\boxed{}$$

   Check your answer by turning on **Show equation** and clicking **Play**. Modify your equation if necessary. What isotope is produced by the beta decay of carbon-14? ________________

4. Practice: Turn off **Show equation**. Fill in the equations for the beta decay of iodine-131 and sodium-24 in the spaces below. Use the Gizmo to check your answers.

   $${}^{131}_{53}\mathrm{I} \rightarrow \boxed{}\boxed{} + \boxed{}\boxed{}$$

   $${}^{24}_{11}\mathrm{Na} \rightarrow \boxed{}\boxed{} + \boxed{}\boxed{}$$

Activity C: **Protons into neutrons**	Get the Gizmo ready: • Click **Reset**, and turn off **Show equation**. • Select **Positron emission**. • Check that **Carbon** is selected.	

Introduction: A **positron** is a type of antimatter that is equivalent to an electron. If a positron and an electron meet, they will annihilate one another in a burst of gamma rays.

Question: How do positron emission and electron capture change an atom?

1. Observe: Click **Play** and watch the animation.

   A. What happens to the decaying proton during positron emission? ________________

   ____

   B. What is the mass number and charge of the emitted positron? __________________

   Mass number: _______ Charge: _______

2. Predict: During positron emission, a proton is transformed into a neutron and a positron, which is emitted. The positron will fly through space until it encounters an electron. How will positron emission affect the atomic number and mass number of the atom?

   ____

3. Calculate: Turn on **Write equation**. Fill in the first set of boxes with the mass number and atomic number of the daughter product and the next set of boxes with the mass number and atomic number of the positron. (Note: The atomic number of a positron is 1.)

$$^{11}_{6}\text{C} \rightarrow {}^{\square}_{\square}\square + {}^{\square}_{\square}\square$$

Check your answer by turning on **Show equation** and clicking **Play**. Modify your equation if necessary. What isotope is produced when carbon-11 emits a positron? _______________

4. Practice: Turn off **Show equation**. Fill in the equations for the positron emission of xenon-118 and manganese-50 in the spaces below. Use the Gizmo to check your answers.

$$^{118}_{54}\text{Xe} \rightarrow {}^{\square}_{\square}\square + {}^{\square}_{\square}\square$$

$$^{50}_{25}\text{Mn} \rightarrow {}^{\square}_{\square}\square + {}^{\square}_{\square}\square$$

5. Observe: Click **Reset**. Select **Electron capture**, and make sure **Tungsten** is selected. Click **Play** and watch the animation.

   A. What happened to the proton after absorbing an electron? ____________________

   ____

   B. What is the mass number and charge of the absorbed electron?

   Mass number: _______ Charge: _______

6. Predict: During electron capture, an electron is absorbed into the nucleus, causing a proton to transform into a neutron. How will electron capture affect the atomic number and mass number of the atom?

____

7. Calculate: Note that in this equation the particle is absorbed, rather than emitted. Fill in the first set of boxes with the mass number and atomic number of the absorbed electron. Fill in the last set of boxes with the mass number and atomic number of the daughter product.

$$^{179}_{74}\text{W} + {}^{\square}_{\square}\square \rightarrow {}^{\square}_{\square}\square$$

Turn on **Show equation** and click **Play** to check. Modify your equation if necessary.

What isotope is produced when tungsten-179 absorbs an electron? ___________________

8. Practice: Turn off **Show equation**. Fill in the electron capture equations for gold-195 and neodymium-141 in the spaces below. Use the Gizmo to check your answers.

$$^{195}_{79}\text{Au} + {}^{\square}_{\square}\square \rightarrow {}^{\square}_{\square}\square$$

$$^{141}_{60}\text{Nd} + {}^{\square}_{\square}\square \rightarrow {}^{\square}_{\square}\square$$

9. Think and discuss: What do electron capture and positron emission have in common?

____

____

Student Exploration: Half-life

Vocabulary: daughter atom, decay, Geiger counter, half-life, isotope, neutron, radiation, radioactive, radiometric dating

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

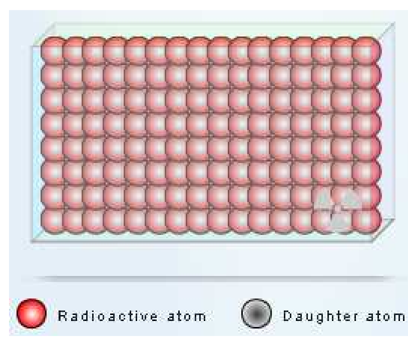
1. Have you ever made microwave popcorn? If so, what do you hear while the popcorn is in the microwave? ____

____

2. If you turn the microwave on for two minutes, is the rate of popping always the same, or does it change? Explain. ____

____

Gizmo Warm-up
Like an unpopped kernel in the microwave, a **radioactive** atom can change at any time. Radioactive atoms change by emitting **radiation** in the form of tiny particles and/or energy. This process, called **decay**, causes the radioactive atom to change into a stable **daughter atom**.



The *Half-life* Gizmo™ allows you to observe and measure the decay of a radioactive substance. Be sure the sound is turned on and click **Play** ( ).

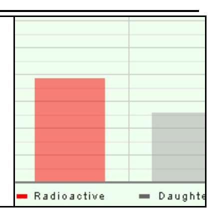
3. What do you see and hear? ____

____

Note: The clicking sound you hear comes from a **Geiger counter**, an instrument that detects the particles and energy emitted by decaying radioactive atoms.

4. What remains at the end of the decay process? ___________________________

5. Is the rate of decay fastest at the beginning, middle, or end of the process? __________

Activity A: **Decay curves**	<u>Get the Gizmo ready</u>: • Click **Reset** ( ). Be sure that **User chooses half-life** and **Random decay** are selected. • Check that the **Half-life** is 20 seconds and the **Number of atoms** is 128.	

Question: How do we measure the rate of radioactive decay?

10. <u>Observe</u>: Select the BAR CHART on the right side of the Gizmo and click **Play**.

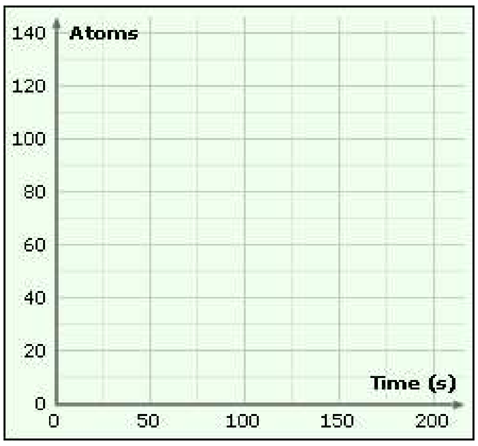
   A. What happens to the numbers of radioactive and daughter atoms as the simulation proceeds? ____

   ____

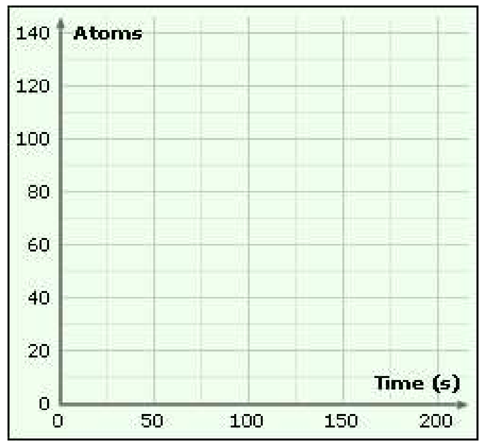
B. Do the numbers of radioactive and daughter atoms change at the same rate throughout the simulation? Explain. _______________________________________

____

11. Experiment: Click **Reset**, and select the GRAPH tab. Run a simulation with the **Half-life** set to 5 seconds, and then run another simulation with the **Half-life** set to 35 seconds. Sketch each resulting decay curve graph in the spaces below.



Half-life = 5 seconds



Half-life = 35 seconds

12. Interpret: How does the **Half-life** setting affect how quickly the simulated substance decays?

____

____

13. Collect data: Click **Reset**. Change the **Half-life** to 10 seconds and click **Play**. Select the TABLE tab and record the number of radioactive atoms at each given time below.

0 s: _____ 10 s: _____ 20 s: _____ 30 s: _____ 40 s: _____ 50 s: _____

14. Analyze: What pattern, if any, do you see in your data? _____________________________

____

15. Revise and repeat: Use your data from #4 above to fill in the first line of the data table below. Then repeat the experiment four more times. Calculate the average number of radioactive atoms for each time.

Trial	**0 s**	**10 s**	**20 s**	**30 s**	**40 s**	**50 s**
1						
2						
3						
4						
5						
Averages:						

16. Analyze: A **half-life** is defined as the amount of time it takes for half of the radioactive particles to decay. For the simulated substance, every 10 seconds represents one half-life.

How does your data demonstrate the definition of a half-life? _________________________

____

____

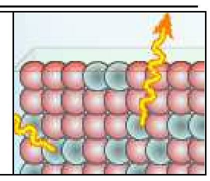
17. Revise and repeat: Click **Reset**. Real radioactive samples will contain billions of radioactive atoms. To model the decay of a large sample, change from **Random decay** to **Theoretical decay** on the SIMULATION pane. Click **Play** and record the numbers of radioactive atoms:

    0 s: _____ 10 s: _____ 20 s: _____ 30 s: _____ 40 s: _____ 50 s: _____

    How does this data demonstrate the meaning of half-life? ___________________________

    ____

    ____

Activity B: **Measuring half-life**	Get the Gizmo ready: • Click **Reset**. • Select **Isotope A** from the left drop-down menu. • Check that **Theoretical decay** is selected.	

Introduction: Different **isotopes** of the same element have the same number of protons but different numbers of **neutrons** in the nucleus. Some isotopes are radioactive.

Question: How do we find the half-life of a radioactive isotope?

1. Observe: Select the GRAPH tab, and click **Play**. Based on the graph, what is your estimate of the half-life of isotope A? _________________________

2. Measure: Turn on the **Half-life probe**. Use the probe to measure how long it takes for exactly one-half of the original radioactive atoms to decay.

   What is the exact half-life of isotope A? _________________________

3. Collect data: In the first row of the table below, write how many seconds represent one half-life, two half-lives, and so forth. On the next row, predict the number of radioactive atoms that will be present at each time. Then use the probe to find the actual values.

Half-life	0	1	2	3	4	5
Time (seconds)						
Predicted # radioactive atoms						
Actual # radioactive atoms						

4. Calculate: Calculate the percentage of radioactive atoms that are left after each half-life.

Half-life	0	1	2	3	4	5
Percentage radioactive atoms						

5. Apply: Suppose you found a material in which 12.5% of the original radioactive atoms were present. If the half-life is 47 years, how old is the material? ___________________________

6. Apply: Use the Gizmo to find the half-life of **Isotope B**. What is it? _____________________

7. Practice: Click **Reset**. Select the **Mystery half-life** from the left menu. In this setting, the half-life will be different each time you run the simulation. Run at least three trials. In each trial, measure the half-life using the **Half-life probe** on the graph.

8. Explore: Use the Gizmo to explore whether the number of atoms present affects the half-life that you measure. Describe your findings below:

____

____

____

____

9. Extend your thinking: The slow decay of radioactive materials can be used to find the age of rocks, fossils, and archaeological artifacts. In a process called **radiometric dating**, scientists measure the proportions of radioactive atoms and daughter atoms in an object to determine its age. Carbon-14 is a useful isotope because it is found in wood, ash, bone, and any other organic materials.

   You can use the *Half-life* Gizmo to model the decay of Carbon-14, which has a half-life of approximately 6,000 years (actual value is 5,730 years). In the Gizmo, select **User chooses half-life** and **Theoretical decay**. Set the **Half-life** to 6 seconds (to represent 6,000 years) and the **Number of atoms** to 100.

   Use the Gizmo to estimate the age of each of the objects below. For these questions, each second in the Gizmo represents 1,000 years.

Description	**Age (years)**
Egyptian papyrus with 63% of its original carbon-14 atoms	
Aboriginal charcoal with 22% of its original carbon-14 atoms.	
Mayan headdress with 79% of its original carbon-14 atoms	
Neanderthal skull with 3% of its original carbon-14 atoms	