

## Key concept (age 14-16)

### PMA5.2: Radioactive decay

#### Progression toolkit: Alpha decay

Learning focus	Some large nuclei, which are unstable because they contain too many protons, decay spontaneously by alpha radiation because of repulsive forces between protons.				
As students' conceptual understanding progresses they can:	<div> <div>CONCEPTUAL PROGRESSION</div> <div></div> </div>				
	Describe the effect of the electrostatic force within an atomic nucleus. <b>P</b>	Interpret nuclear equations to describe the alpha decay of radioactive nuclei.	Describe what happens to an atom and its nucleus during an alpha decay.	Explain why large nuclei with too many protons emit alpha particles rather than protons. <b>B</b>	Explain why a nucleus usually emits gamma radiation after an alpha decay.
Diagnostic questions	Unstable nucleus	Alpha decay	Alpha decay story	Why alpha?	After alpha
Response activities			Explaining alpha decay		Alpha and gamma

Key:

**P** Prior understanding from earlier stages of learning

**B** Bridge to later stages of learning

Unstable nucleus	Alpha decay	Alpha decay story	Why alpha?	After alpha																																							
<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Unstable nucleus</b></p> <p>The nucleus of an atom is made of protons and neutrons.</p> <p>A nucleus made of 4 protons. A nucleus made of 4 protons and 4 neutrons.</p> <p>A B</p> <p>1. Which nucleus is most unstable? Put a tick (✓) in the box next to the best answer.</p> <p>A. Nucleus of just protons. <input type="checkbox"/></p> <p>B. Nucleus of protons and neutrons. <input type="checkbox"/></p> <p>C. Each is as unstable as the other. <input type="checkbox"/></p> <p>2. What is the best reason for your best answer? Put a tick (✓) in the box next to the best answer.</p> <p>A. Each has the same number of protons. <input type="checkbox"/></p> <p>B. The protons are closer together. <input type="checkbox"/></p> <p>C. The protons are further apart. <input type="checkbox"/></p> <p>D. It has neutrons. <input type="checkbox"/></p> <p><small>Developed by the University of York Science Education Group, the Salter's Institute and the Institute of Physics. The document may have been edited. Download the original from <a href="http://www.BestEvidenceScienceTeaching.org">www.BestEvidenceScienceTeaching.org</a> © University of York Science Education Group. Distributed under a Creative Commons Attribution-NonCommercial (CC BY-NC) license.</small></p>	<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Alpha decay</b></p> <p>The nucleus on the left is plutonium-240. A plutonium-240 nucleus is unstable. It can decay by emitting an alpha particle.</p> <p>This is a nuclear equation that shows what happens:</p> ${}_{94}^{240}\text{Pu} \rightarrow {}_{92}^{236}\text{U} + {}_2^4\alpha$ <p>What does this tell you about the alpha decay of plutonium-240? For each statement, tick (✓) one column to show what you think.</p> <table border="1"> <thead> <tr> <th></th> <th>I am sure this is right.</th> <th>I think this is right.</th> <th>I think this is wrong.</th> <th>I am sure this is wrong.</th> </tr> </thead> <tbody> <tr> <td>A. A new nucleus is made that is a different element.</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>B. A plutonium nucleus is stable.</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>C. An alpha particle has a positive electric charge.</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>D. A plutonium nucleus loses 2 protons and 2 neutrons.</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table> <p><small>Some students might not make more than one tick in alpha decay. (Others can be made more careful in different sorts of radioactive decay.)</small></p> <p><small>Developed by the University of York Science Education Group, the Salter's Institute and the Institute of Physics. The document may have been edited. Download the original from <a href="http://www.BestEvidenceScienceTeaching.org">www.BestEvidenceScienceTeaching.org</a> © University of York Science Education Group. Distributed under a Creative Commons Attribution-NonCommercial (CC BY-NC) license.</small></p>		I am sure this is right.	I think this is right.	I think this is wrong.	I am sure this is wrong.	A. A new nucleus is made that is a different element.					B. A plutonium nucleus is stable.					C. An alpha particle has a positive electric charge.					D. A plutonium nucleus loses 2 protons and 2 neutrons.					<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Alpha decay story</b></p> <p>This nucleus is unstable because it is large and has too many protons. An unstable nucleus like this can emit an alpha particle.</p> <p>Describe alpha decay. Pick one statement in each row to explain how.</p> <table border="1"> <tbody> <tr> <td>1. A large nucleus is unstable if it has too many protons.</td> <td>In the nucleus, the electrostatic force pushes protons apart.</td> <td>In the nucleus, the strong nuclear force pushes protons apart.</td> </tr> <tr> <td>2. If the force is big enough, an alpha particle is emitted from the nucleus.</td> <td>An alpha particle is made of two protons.</td> <td>An alpha particle is made of two protons and two neutrons.</td> </tr> <tr> <td>3. It is emitted at a speed in the order of 20 000 000 m/s.</td> <td>It is emitted at a speed in the order of 30 000 m/s.</td> <td></td> </tr> <tr> <td>4. The nucleus is destroyed.</td> <td>The nucleus is pulled back to the other way.</td> <td></td> </tr> <tr> <td>5. The atom is now a different element.</td> <td>The atom does not exist anymore.</td> <td>The atom is the same element, it moves slowly.</td> </tr> </tbody> </table> <p><small>*Protons can be emitted on their own too.</small></p> <p><small>Developed by the University of York Science Education Group, the Salter's Institute and the Institute of Physics. The document may have been edited. Download the original from <a href="http://www.BestEvidenceScienceTeaching.org">www.BestEvidenceScienceTeaching.org</a> © University of York Science Education Group. Distributed under a Creative Commons Attribution-NonCommercial (CC BY-NC) license.</small></p>	1. A large nucleus is unstable if it has too many protons.	In the nucleus, the electrostatic force pushes protons apart.	In the nucleus, the strong nuclear force pushes protons apart.	2. If the force is big enough, an alpha particle is emitted from the nucleus.	An alpha particle is made of two protons.	An alpha particle is made of two protons and two neutrons.	3. It is emitted at a speed in the order of 20 000 000 m/s.	It is emitted at a speed in the order of 30 000 m/s.		4. The nucleus is destroyed.	The nucleus is pulled back to the other way.		5. The atom is now a different element.	The atom does not exist anymore.	The atom is the same element, it moves slowly.	<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>After alpha</b></p> <p>A large unstable nucleus emits an alpha particle.</p> <p>1. What happens to the nucleus after the alpha particle is emitted?</p> <p>A. Nothing. <input type="checkbox"/></p> <p>B. Its particles jiggle about faster. <input type="checkbox"/></p> <p>C. It moves backwards. <input type="checkbox"/></p> <p>D. Its particles jiggle about faster and it moves backwards. <input type="checkbox"/></p> <p>2. How does an excited nucleus reduce the energy it has?</p> <p>Put a tick (✓) in the box next to the best answer.</p> <p>A. Motion between protons and neutrons slows them down. <input type="checkbox"/></p> <p>B. It waits time to let its neutrons. <input type="checkbox"/></p> <p>C. It emits light. <input type="checkbox"/></p> <p>D. It emits gamma radiation. <input type="checkbox"/></p> <p><small>Developed by the University of York Science Education Group, the Salter's Institute and the Institute of Physics. The document may have been edited. Download the original from <a href="http://www.BestEvidenceScienceTeaching.org">www.BestEvidenceScienceTeaching.org</a> © University of York Science Education Group. Distributed under a Creative Commons Attribution-NonCommercial (CC BY-NC) license.</small></p>
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<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Explaining alpha decay</b></p> <p>A large, proton rich and unstable nucleus often decays by emitting an alpha particle.</p> <p>Match each statement about what happens in a large, proton rich and unstable nucleus to a reason, to explain how alpha decay can happen.</p> <p><b>What happens in a nucleus.</b></p> <table border="1"> <tbody> <tr> <td>A proton is attracted to nearby protons and neutrons.</td> <td>•</td> <td>The combination of protons and neutrons are held very strongly together.</td> </tr> <tr> <td>A proton is repelled from all other protons.</td> <td>•</td> <td>By the electrostatic force.</td> </tr> <tr> <td>An alpha particle can form.</td> <td>•</td> <td>When a charge of +2.</td> </tr> <tr> <td>An alpha particle behaves as a single particle.</td> <td>•</td> <td>By the strong nuclear force.</td> </tr> <tr> <td>An alpha particle is repelled by the protons.</td> <td>•</td> <td>It also has a positive charge.</td> </tr> <tr> <td>An alpha particle is repelled more strongly than a proton.</td> <td>•</td> <td>Protons and neutrons jiggle about at high speeds.</td> </tr> </tbody> </table> <p><b>or your own words:</b> Explain how alpha decay can happen.</p> <p><small>Developed by the University of York Science Education Group, the Salter's Institute and the Institute of Physics. The document may have been edited. Download the original from <a href="http://www.BestEvidenceScienceTeaching.org">www.BestEvidenceScienceTeaching.org</a> © University of York Science Education Group. Distributed under a Creative Commons Attribution-NonCommercial (CC BY-NC) license.</small></p>	A proton is attracted to nearby protons and neutrons.	•	The combination of protons and neutrons are held very strongly together.	A proton is repelled from all other protons.	•	By the electrostatic force.	An alpha particle can form.	•	When a charge of +2.	An alpha particle behaves as a single particle.	•	By the strong nuclear force.	An alpha particle is repelled by the protons.	•	It also has a positive charge.	An alpha particle is repelled more strongly than a proton.	•	Protons and neutrons jiggle about at high speeds.	<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Alpha and gamma</b></p> <p>Americium-241 is a radioactive isotope. It is used in smoke to make alpha radiation. Alpha radiation can be blocked with a piece of aluminium.</p> <p>Some students are discussing why the Geiger-Müller tube is still detecting radiation from the americium-241.</p> <p>Gerbil: Some alpha radiation can pass through the aluminium.</p> <p>Hannah: Gamma radiation can pass through the aluminium.</p> <p>Kieran: Gamma radiation is made after every alpha decay of americium-241.</p> <p>Isla: Americium-241 can decay to make either alpha radiation or gamma radiation.</p> <p>Josh: Americium-241 is slowly changing into a different element.</p> <p><b>To answer:</b></p> <p>1. Who is right about why the G-M tube is detecting radiation? Explain your answer.</p> <p>2. Who is wrong about why the G-M tube is detecting radiation? What would you say to help them understand?</p> <p><small>Developed by the University of York Science Education Group, the Salter's Institute and the Institute of Physics. The document may have been edited. Download the original from <a href="http://www.BestEvidenceScienceTeaching.org">www.BestEvidenceScienceTeaching.org</a> © University of York Science Education Group. Distributed under a Creative Commons Attribution-NonCommercial (CC BY-NC) license.</small></p>																								
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## Progression toolkit: Beta decay

Learning focus	Some nuclei, which are unstable because they have too many neutrons, decay spontaneously by beta radiation because neutrons are unstable away from the close proximity of protons.				
As students' conceptual understanding progresses they can:	<div> <div>CONCEPTUAL PROGRESSION</div> <div></div> </div>				
	Restate, in own words, the reasons why a nucleus cannot be made of just neutrons.	Interpret nuclear equations to describe the beta decay of radioactive nuclei.	Describe what happens to an atom and its nucleus during a beta decay.	Explain why a nucleus can often emit gamma radiation after a beta decay.	Explain why the chances of beta decay increase with the proportion of neutrons to protons in a nucleus. <b>B</b>
Diagnostic questions	Differently unstable	Beta decay	Beta origin	After beta	Neutron rich
Response activities			Beta decay story		The chances of beta

Key:

**B** Bridge to later stages of learning

Differently unstable	Beta decay	Beta origin	After beta	Neutron rich																				
<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Differently unstable</b></p> <p>The nucleus of an atom is made of protons and neutrons.</p> <p>A nucleus made of 6 protons.</p> <p>A nucleus made of 7 protons and 6 neutrons.</p> <p>A. Which nucleus is most unstable? Put a tick (✓) in the box next to the best answer.</p> <p>B. Nucleus of just neutrons.</p> <p>C. Nucleus of protons and neutrons.</p> <p>D. Each is as unstable as the other.</p> <p>E. What is the best reason for your last answer? Put a tick (✓) in the box next to the best answer.</p> <p>F. Neutrons do not repel each other.</p> <p>G. Protons repel each other.</p> <p>H. The strong nuclear force is the same in each.</p> <p>I. Neutrons are attracted away from protons.</p>	<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Beta decay</b></p> <p>The nucleus on the left is carbon-14. A carbon-14 nucleus is unstable. It can decay by emitting a beta particle.</p> <p>This is a nuclear equation that shows what happens:</p> ${}_{6}^{14}\text{C} \rightarrow {}_{7}^{14}\text{N} + {}_{-1}^{0}\beta$ <p>What does this tell you about the beta decay of carbon-14? For each statement, tick (✓) and explain to show what you think.</p> <table border="1"> <thead> <tr> <th></th> <th>Don't agree. This is right.</th> <th>I think this is wrong.</th> <th>Don't know. This is wrong.</th> </tr> </thead> <tbody> <tr> <td>A. A new nucleus is made that is a different element.</td> <td></td> <td></td> <td></td> </tr> <tr> <td>B. A beta particle is a type of proton.</td> <td></td> <td></td> <td></td> </tr> <tr> <td>C. A beta particle has a negative electric charge.</td> <td></td> <td></td> <td></td> </tr> <tr> <td>D. A proton turns into a neutron and a beta particle.</td> <td></td> <td></td> <td></td> </tr> </tbody> </table> <p>Some unstable nuclei are much more stable than others. Others can decay by different sorts of radioactive decay.</p>		Don't agree. This is right.	I think this is wrong.	Don't know. This is wrong.	A. A new nucleus is made that is a different element.				B. A beta particle is a type of proton.				C. A beta particle has a negative electric charge.				D. A proton turns into a neutron and a beta particle.				<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Beta origin</b></p> <p>A beta particle is a high-speed electron. Carbon-14 decays by beta-decay: a beta particle is emitted.</p> <p>Where does the beta particle come from? Put a tick (✓) in the box next to the best answer.</p> <p>A. It shoots out of the nucleus of an atom.</p> <p>B. It is one of the electrons around an atom that shoots out.</p> <p>C. It is one of the electrons around an atom that the nucleus forces out when it decays.</p>	<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>After beta</b></p> <p>This unstable nucleus emits a beta particle. At the same time, a neutron decays into a proton.</p> <p>1. What happens to the nucleus after the beta particle is emitted?</p> <p>A. Nothing.</p> <p>B. Its particles jiggle about faster.</p> <p>C. It moves backwards.</p> <p>D. Its particles jiggle about faster and it moves backwards.</p> <p>2. How does an excited nucleus reduce the energy it has?</p> <p>A. It emits gamma rays.</p> <p>B. It emits alpha rays.</p> <p>C. It emits light.</p> <p>D. It emits gamma radiation.</p>	<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Neutron rich</b></p> <p>Carbon-12 is a stable isotope of carbon. Carbon-14 is radioactive because it can decay by emitting a beta particle.</p> <p>A. Carbon-12 nucleus: 6 protons, 6 neutrons.</p> <p>B. Carbon-14 nucleus: 6 protons, 8 neutrons.</p> <p>Carbon-12 is not radioactive and carbon-14 is radioactive.</p> <p>What is different about carbon-14 that makes it radioactive? Put a tick (✓) in the box next to the best answer.</p> <p>A. Its neutrons are likely to be far enough away from a proton to decay.</p> <p>B. Its neutrons are too close together and they are further from protons.</p> <p>C. It has more neutrons, so it is more likely that one will decay.</p>
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<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>Beta decay story</b></p> <p>This nucleus is unstable because it has too many neutrons. An unstable nucleus like this can emit a beta particle.</p> <p>Describe beta decay: Put one statement in each box to explain how.</p> <table border="1"> <tbody> <tr> <td>1. Neutrons are unstable when they are not very close to protons.</td> <td>2. They are more likely to be far away from protons in a neutron-rich nucleus.</td> </tr> <tr> <td>3. An unstable nucleus is likely to decay into a proton and a neutron.</td> <td>4. A beta particle is emitted that carries the nuclear surplus away.</td> </tr> <tr> <td>5. A beta particle is a high-speed electron from the nucleus.</td> <td>6. A beta particle is emitted that destroys the nucleus.</td> </tr> <tr> <td>7. The atom is now a different element.</td> <td>8. The atom does not lose any mass.</td> </tr> <tr> <td>9. The atom is the same element, but it has more protons and fewer neutrons.</td> <td></td> </tr> </tbody> </table> <p>To answer: What else can you say about the nucleus that remains?</p>	1. Neutrons are unstable when they are not very close to protons.	2. They are more likely to be far away from protons in a neutron-rich nucleus.	3. An unstable nucleus is likely to decay into a proton and a neutron.	4. A beta particle is emitted that carries the nuclear surplus away.	5. A beta particle is a high-speed electron from the nucleus.	6. A beta particle is emitted that destroys the nucleus.	7. The atom is now a different element.	8. The atom does not lose any mass.	9. The atom is the same element, but it has more protons and fewer neutrons.		<p><b>BEST</b> STUDENT WORKSHEET</p> <p><b>The chances of beta</b></p> <p>The atoms of some radioactive isotopes have nuclei that are neutron-rich. These isotopes usually decay by emitting a beta particle.</p> <p>Some students are discussing why a neutron-rich nucleus is likely to emit a beta particle.</p> <p><b>Aiden:</b> If a nucleus is far enough from a proton it will decay.</p> <p><b>Billy:</b> The arrangement of protons and neutrons affects the probability that a nucleus will decay.</p> <p><b>Charlie:</b> A neutron is made of a proton and an electron.</p> <p><b>Crystal:</b> The closer a neutron is to protons, the less likely it is to decay.</p> <p>To answer: 1. Who is right about why a neutron-rich nucleus is likely to emit a beta particle? Explain your answer. 2. Who is wrong about why a neutron-rich nucleus is likely to emit a beta particle? What would you say to help them understand?</p>													
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