8.4 Nuclear instability

We have seen that some nuclei are naturally unstable and will decay by emitting alpha or beta particles and/or gamma photons. Large nuclei can also split. This is called nuclear fission.

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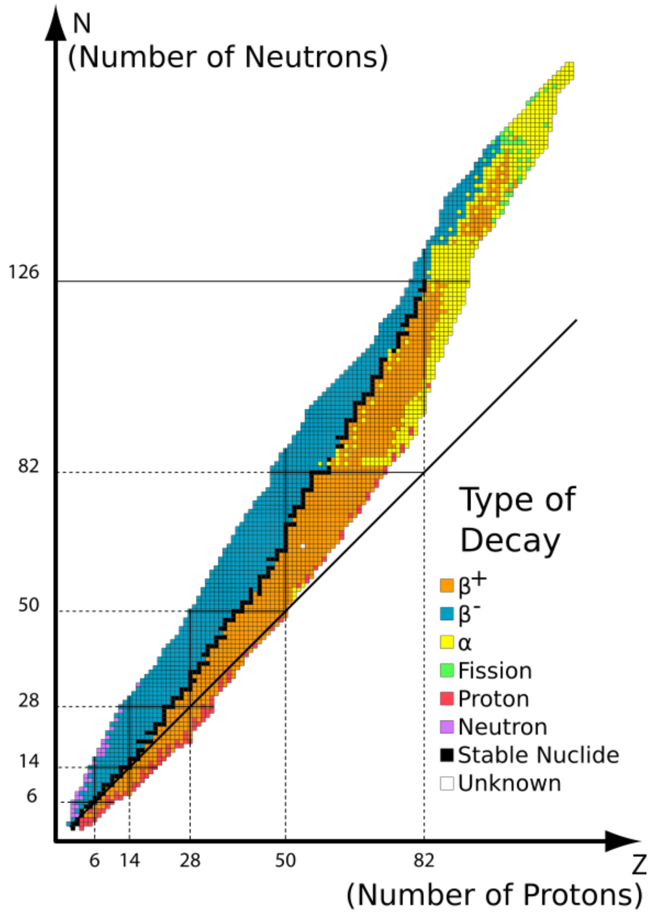
Consider the following graph, which shows the number of neutrons plotted against the number of protons for different atomic nuclei.



The nuclei which are stable (shown in black) lie along a line which initially follows the line N=Z (up to Z≈20), and then it becomes steeper as Z increases beyond this. This shows that the nuclei require more neutrons than protons, above Z≈20, in order to remain stable.

The two forces, responsible for nuclear stability, are the strong nuclear and the electrostatic forces. The strong nuclear force is very short range and acts to bind the nucleons together. The electrostatic is long range and repulsive. As the number of protons in the nucleus builds up, the repulsive force increases. The only way of reducing the repulsive force is to move protons further apart. This can be achieved by introducing more, uncharged, neutrons.

The stable nuclei run along what is termed the "valley of stability".

Unstable nuclei

Unstable nuclei will decay in order to achieve a more stable ratio of protons to neutrons. This may not occur in one step, but may require several decays.

Beta minus decay

Beta minus decay occurs for nuclei which are proton poor.

(1)✏Where are β^- emitters located relative to the valley of stability, in the diagram above?

(2)✏Carbon-14 decays emitting a β^- particle. Write a nuclear equation for this decay.

(3)✏Work out the proton to neutron ratio of carbon-14.

(4)✏Work out the proton to neutron ratio of nitrogen-14.

(5)✏Compare the ratios above. What do you notice.

Alpha decay

Alpha decay occurs for nuclei which are proton rich.

(6)✏Where are α emitters located relative to the valley of stability, in the diagram above?

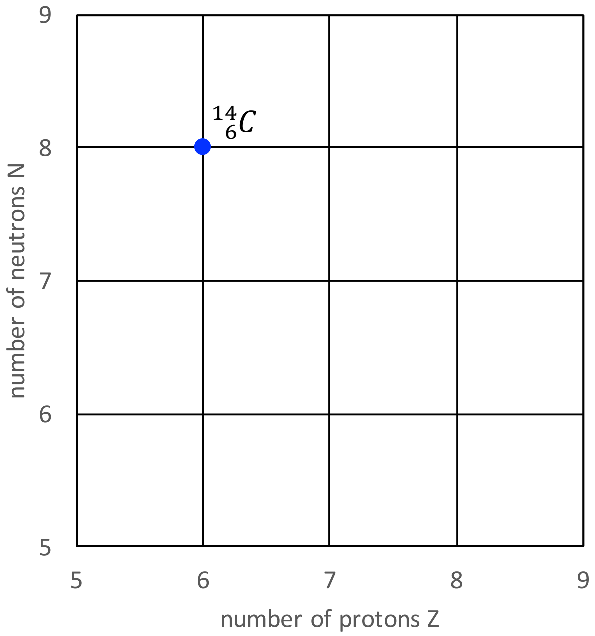
(7)✏Thorium-234 decays by emitting an α particle. Write a nuclear equation for this decay.

(8)✏Work out the proton to neutron ratio of thorium-234.

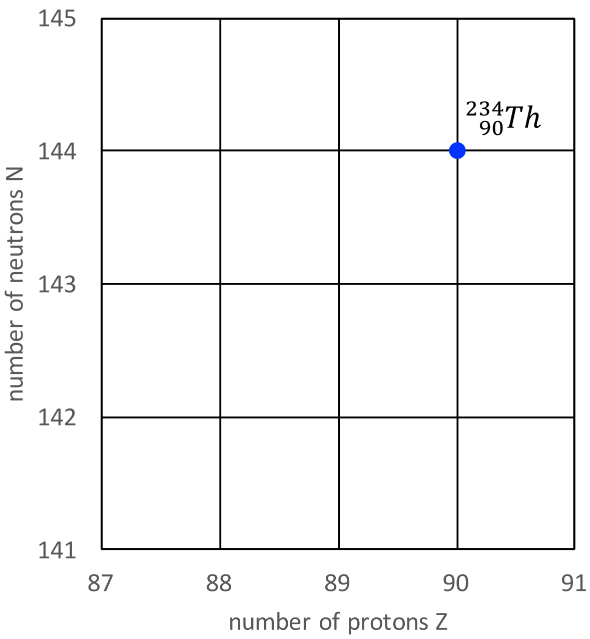
(9)✏Work out the proton to neutron ratio of radium-230.

(10)✏Compare the ratios above. What do you notice.

Showing changes on an N-Z graph



(11) ✏ The position of carbon-14 is plotted on the graph, left. Plot the position of the nuclei after β^- emission. Draw an arrow linking the start position to the final position.

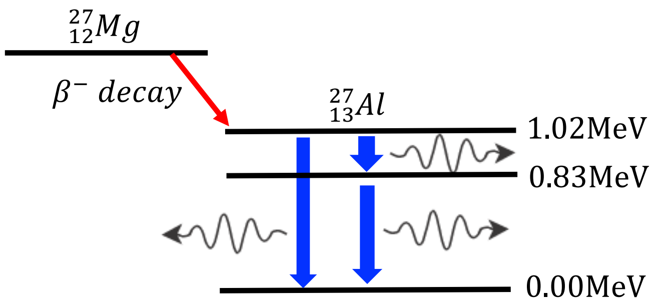


(12) ✏ The position of thorium-234 is plotted on the graph, left. Plot the position of the nuclei after α emission. Draw an arrow linking the start position to the final position.

Gamma emission

Like electrons, the nucleus can occupy different energy levels. After alpha or beta emission, the nucleus may be left in an excited state. In transitioning to the lowest energy 'ground' state, energy is released as a gamma photon.

Consider the following decay diagram for a radioactive isotope of magnesium.



Magnesium-27 undergoes beta minus decay. This leaves the daughter nuclei of aluminium-27 in an excited state. When the nucleus de-excites, energy is released as gamma ray photons. This may occur in one jump (in which case one photon is produced), or in two jumps (in which case two photons are produced).

(13)✐Work out the frequencies of the 3 possible gamma rays produced.