Physics with Synno – Matter – Lesson 6

M.5.2 Radioactive Decay

Video: Radiation and Radioactive Decay

When a nucleus decays it becomes a nucleus of a different atom. The original nucleus is called the parent nucleus and the remaining nucleus is called the daughter nucleus. The emitted particles and the daughter nucleus are called decay products.
In radioactive decay the mass number and the atomic number must balance.

M.5.2.1 α-particle Decay

The α-particle decay process emits a Helium nucleus He^{2+}.

Examples.

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He^{2+} + energy \quad \text{or} \quad ^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}\alpha^{2+} + energy$$

In this example Uranium-238 is the parent nucleus and Thorium-234 is the daughter nucleus. The energy released is mainly the kinetic energy of the α-particle

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He^{2+} + energy \quad \text{or} \quad ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}\alpha^{2+} + energy$$

We notice that the mass number of the atom decreases by four and the atomic number of the atom decreases by two.
In general

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He^{2+} + energy$$

Overall the number of nucleons remains the same. i.e. the sum of atomic and mass numbers remains the same before and after the decay process.

Question:
What is the nuclide Y in the following equation?

$$^{232}_{90}Th \rightarrow Y + ^{4}_{2}He^{2+} + energy \qquad ^{228}_{88}Ra$$

M.5.2.2 β-particle Decay

The β-particle decay process emits an electron or a positron. For the purpose of writing equations the electron is written as ${}_{-1}^{0}e$ (no mass, -ve charge) or ${}_{-1}^{0}\beta$. And the positron as ${}_{+1}^{0}\beta$ (no mass, +ve charge). Positrons have the same properties as an electron, except for their electrical charge, which is positive.
Example

$${}_{90}^{234}Th \rightarrow {}_{91}^{234}Pa + {}_{-1}^{0}e + energy$$

Thorium is the parent nucleus and Protactinium is the daughter.

Atomic and mass numbers balance.

Note: 1. the electron comes from the nucleus when a neutron decays.

$${}_{0}^{1}n \rightarrow {}_{1}^{1}H + {}_{-1}^{0}e$$

this particular decay includes γ-ray emission

2. the positron comes from the nucleus when a proton decays.

$${}_{1}^{1}H \rightarrow {}_{0}^{1}n + {}_{+1}^{0}\beta^{+}$$

When a nucleus undergoes β^{-} -decay the mass number stays the same, but the atomic number increases by one.
In general

$${}_{Z}^{A}X \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}e + energy$$

When a nucleus undergoes β^{+} -decay the mass number stays the same, but the atomic number decreases by one.
In general

$${}_{Z}^{A}X \rightarrow {}_{Z-1}^{A}Y + {}_{+1}^{0}\beta + energy$$

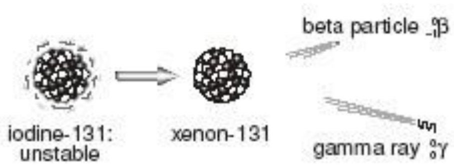
Question: What is the nuclide Y when ${}_{89}^{228}Ac$ undergoes β-decay according to the following equation?

$${}_{89}^{228}Ac \rightarrow Y + {}_{-1}^{0}e + energy$$

${}_{90}^{228}Th$

M.5.2.3 γ-ray Emission

Since γ-ray emission is the emission of a photon of energy rather than a particle it causes no change to the atomic or mass numbers. Often after decay by alpha or beta emission the nucleus has excess energy this energy is released in the form of gamma emission. Thus γ-rays are not usually emitted by themselves, but after an α-or β-particle. A common example is iodine-131.



Gamma decay alone occurs when a nucleus is left in an energised or excited state following an alpha or beta decay.
This excited state is known as a metastable state and it usually only lasts for a short time. An example of this is the radioactive decay of iodine-131, usually a two-stage process.
First, a beta particle is emitted and the excited nuclide xenon-131m is formed. Then, the nucleus undergoes a second decay by emitting a gamma ray:

$$^{131}_{53}I \rightarrow {}^{131m}_{54}Xe + {}^{0}_{-1}e$$

$$^{131m}_{54}Xe \rightarrow {}^{131}_{54}Xe + \gamma$$

The ‘m’ denotes an unstable or metastable state. Cobalt-60 and Technetium-99 also exist in metastable states.

Example 1

Strontium-90 decays by radioactive emission to form Yttrium-90. The equation is:
$^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + X + \gamma$
Determine the atomic and mass numbers for X and identify the type of radiation that is emitted during this decay.

Atomic -1 Mass 0 β^{-} *electron emitted*

Example 2

Iodine-131, a radioisotope that is used in the treatment of thyroid cancer, is produced in a two-stage process. Firstly, Tellurium-130 $\left({}^{130}_{52}Te\right)$is bombarded with neutrons inside the core of a nuclear reactor. This results in the formation of the very unstable Tellurium-131 and a gamma ray.

a) Write down the balanced nuclear equation for the process of creating Tellurium-131.

$$^{130}_{52}Te + {}^{1}_{0}n \rightarrow {}^{131}_{52}Te$$

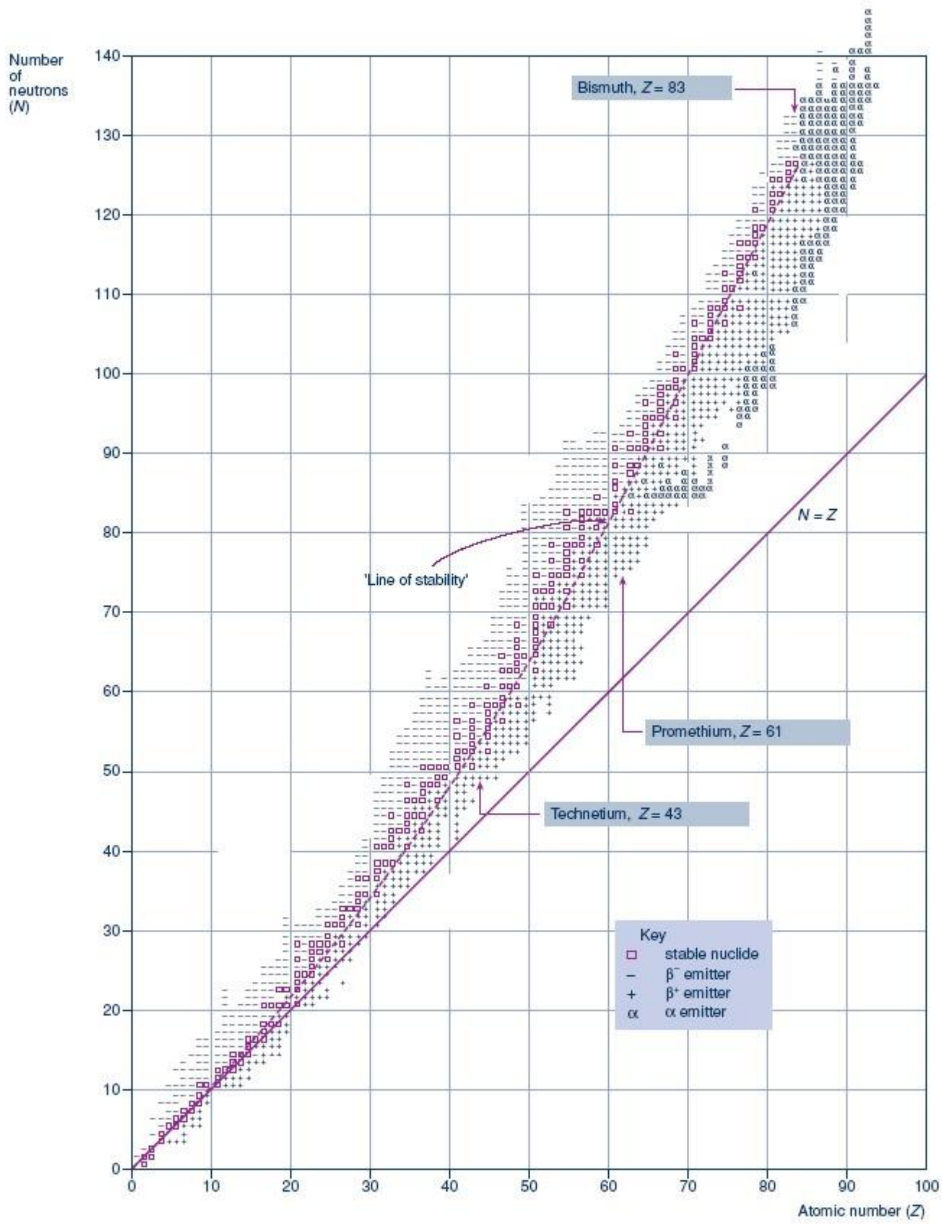
b) Tellurium-131 decays by beta (electron) emission to produce a daughter nuclide. Identify the daughter nuclide.

$${}^{131}_{52}Te \rightarrow {}^{131}_{53}I + {}^{0}_{-1}e$$

M.5.3 Why are Some Atoms Unstable?

Video: Strong Nuclear Force
The Weak Nuclear Force
The Weak and Strong Nuclear Forces

The two forces acting in the nucleus are the electrostatic force of repulsion and the nuclear force of attraction. There is a delicate balance between these forces. For the lighter elements there is one neutron for every proton, but for the heavier elements there needs to be more neutrons to dilute the repelling forces so that the atom remains stable. Elements heavier than Bismuth have too much repulsive force and additional neutrons are unable to make them stable.



From this table of stable isotopes and radioisotopes, it is evident that for larger nuclei there is a distinct imbalance between the number of protons and neutrons. The 'line of stability' of the stable nuclides can be seen as a line that curves away from the $N = Z$ line. Notice that every element, up to and including bismuth, has stable isotopes, except for Technetium and Promethium. Also notice that every isotope of every element beyond bismuth is radioactive.

Problem Set #6: Text Page 212 All Questions (ask how to read the graph for Q6)