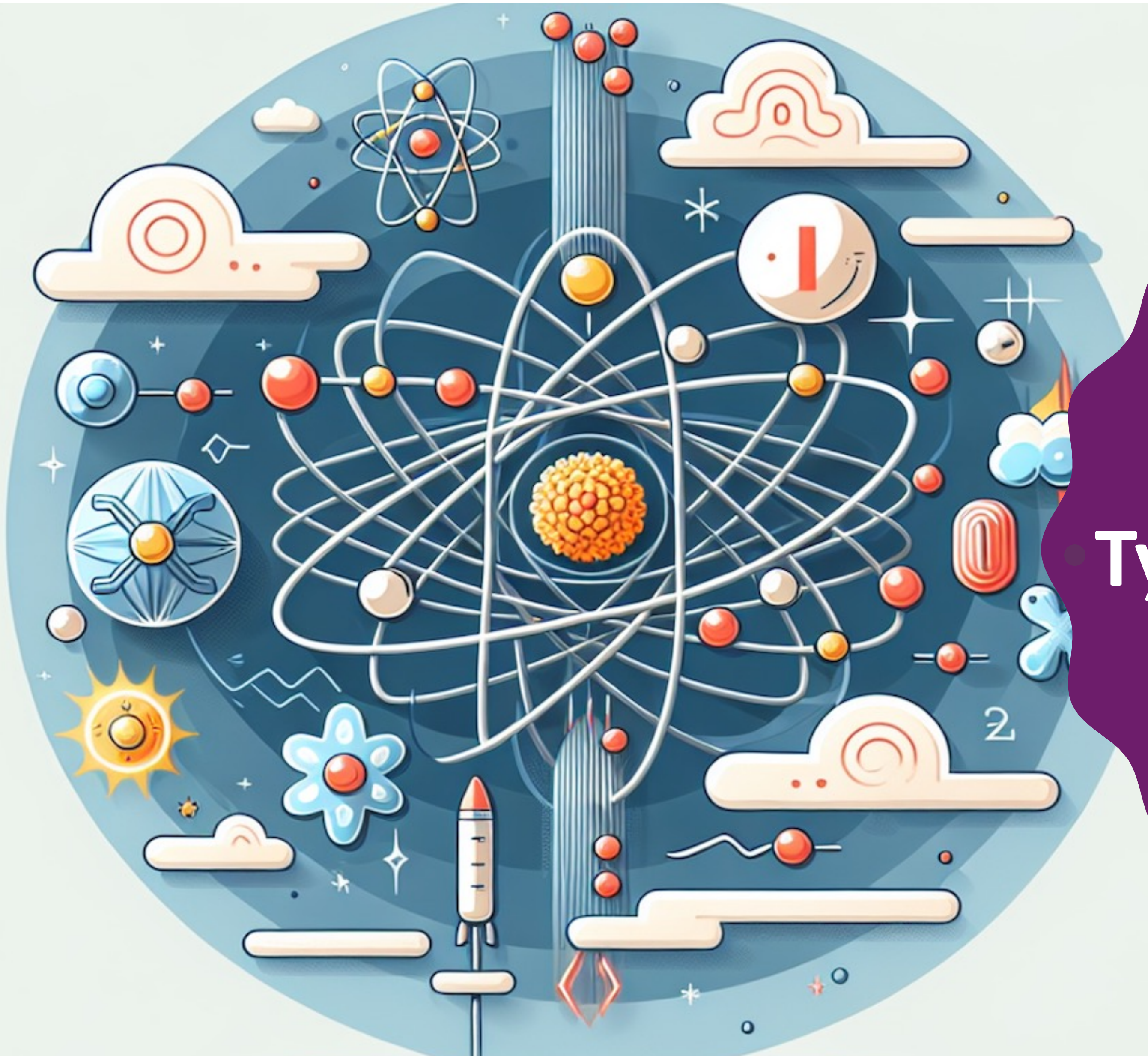
SPACED RETRIEVAL / INTERLEAVING

RETRIEVAL PRACTICE

3 minutes

1. Describe the latent heat of fusion

2. State the Zeroth and First law of thermodynamics



LESSON 3

Types of Radioactive Decay

LEARNING OBJECTIVES

By the end of the next two lessons, you should be able to:

- ❑ **Describe** alpha, beta positive, beta negative and gamma radiation, including the properties of penetrating ability, charge, mass and ionisation ability.
- ❑ **Explain** how an excess of mass, protons or neutrons in a nucleus can result in alpha, beta positive, beta negative decay
- ❑ **Describe** spontaneous alpha, beta positive and beta negative decay using decay equations.
- ❑ **Solve** problems involving balancing nuclear equations.
- ❑ **Explain** how a radionuclide will, through a series of spontaneous decays, become a stable nuclide.

LESSON CONTENT

NUCLEAR INSTABILITY

Last lesson we discussed 3-4 reasons why a nucleus might be unstable and therefore will decay to become more stable.

We described stability in terms of energy. A nucleus with high kinetic energy is unstable. Nuclear decay reduces the kinetic energy and increases the binding energy per nucleon – making it more stable.

Remember! A nucleus with more binding energy means it is HARDER to remove the nucleons (that means the nucleus has less kinetic energy).

This lesson we will discuss four forms of radioactive decay:

- Alpha, α
- Beta Positive, β^+
- Beta Negative, β^-
- Gamma, γ

In each case, the goal is to reduce the kinetic energy within the nucleus – where the method of decay depends on the original state of the parent nuclide.

The first three – alpha, beta+ & beta- all involve the emission of a particle with mass, while gamma does not.

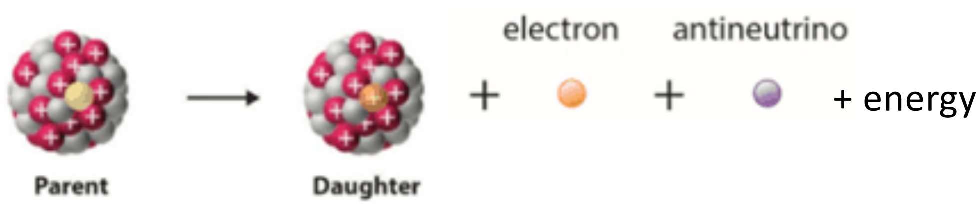
All four emit energy in the form of Electromagnetic Radiation (light).

NUCLEAR TRANSMUTATION

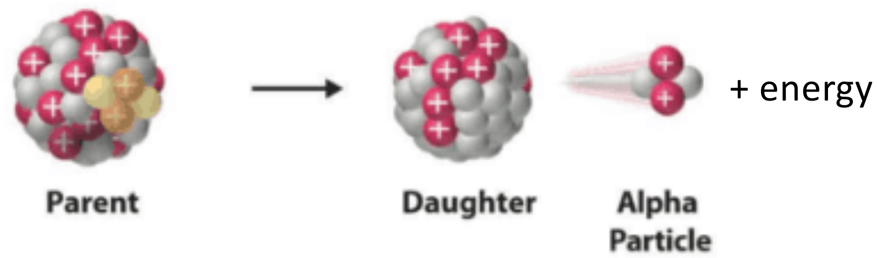
A radioactive nucleus will emit energy and a particle(s) (α, β^{+}, β^{-}) to become stable. The unstable nucleus is known as the **parent nucleus.** The stable nucleus that remains after the decay is known as the **daughter nucleus.**

Depending on the method of decay, different particles will be emitted which can result in a daughter being a different element than the parent (such that it has a different atomic number, number of protons).

This change of element due to decay is referred to as **nuclear transmutation.**



$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^{-} + \bar{\nu}_e + \gamma$$



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

CHECK FOR UNDERSTANDING

LEARNING CHECK

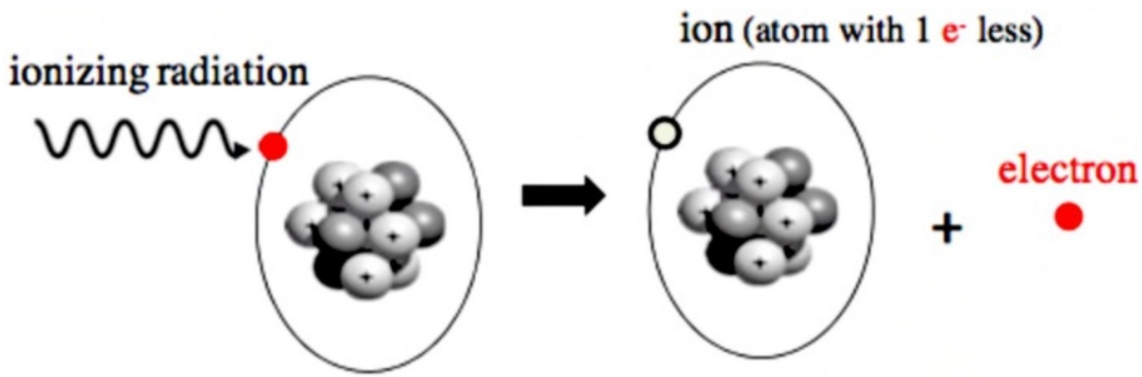
The daughter nucleus is the:

- **A** Original unstable particle
- **B** Resulting stable particle
- **C** Emitting particle (α, β^{+}, β^{-})
- **D** Energy released during radioactive decay

IONISING RADIATION

Ionising radiation – radiation that can remove an electron from an atom and create a heavy positive ion and free electron.

The energy released from α, $\beta+$, $\beta-$ and γ radiation is approximately a million times greater than visible light. This energy can break molecular bonds and remove electrons from atoms (resulting in a positive ion and free electrons).

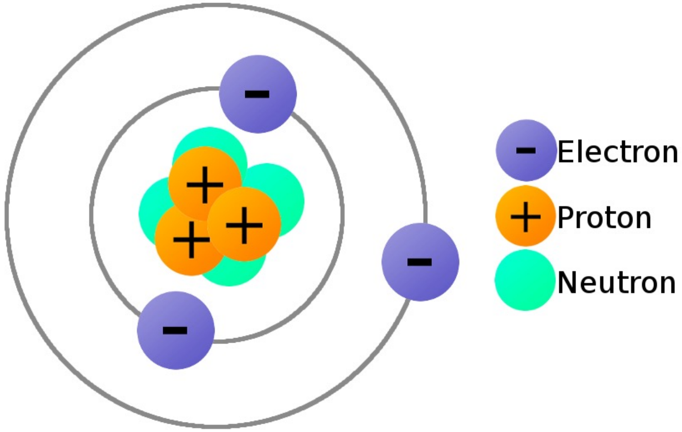


Regardless of the type (alpha, beta positive, beta negative or gamma), radioactivity decay **always** involves the emission of energy in the form of electromagnetic radiation or 'light waves' represented by the symbol γ, gamma.

LESSON CONTENT

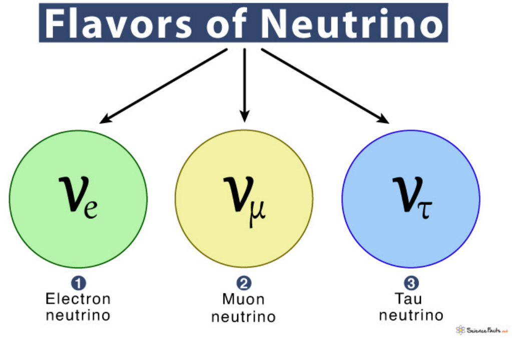
MATTER MATTERS!

Physics at its most fundamental level is the study of matter. **Matter** is a physical substance that **occupies space** and **possesses mass**.



In this topic, we are concerned with nuclear matter. That is – particles that constitute the nuclei of various elements.

Examples of matter particles you may be familiar with include protons, neutrons, and electrons.

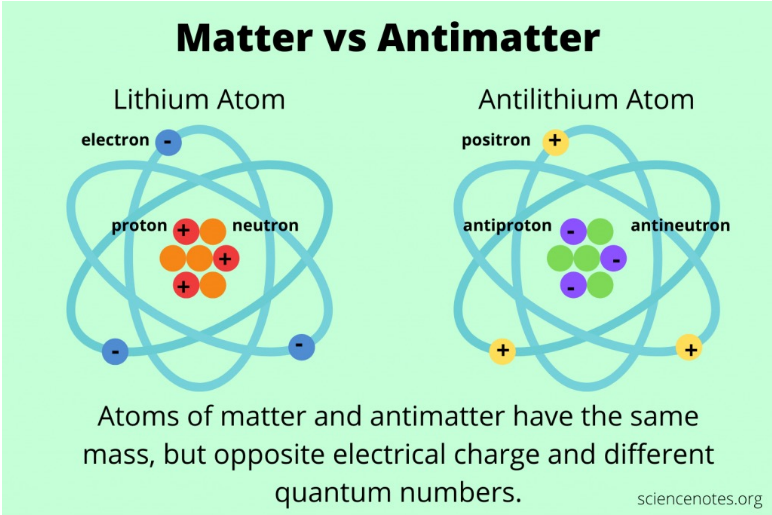


In this topic we will also introduce new matter particles that you may not be familiar with (neutrinos), as well as a completely new family of particles – the **antimatter particles**.

LESSON CONTENT

MATTER VS ANTIMATTER

Antimatter is the same as matter, however it is composed entirely of the anti-particles (opposites) of the corresponding particles in "normal" matter.



An **anti-particle** is one which has an **identical mass** as it's corresponding matter particle, however it has **opposite charge and spin**.

Examples of anti-matter that we will encounter in this topic include positrons (anti-electrons) and anti-neutrinos.

Anti-particles are difficult to observe and study as they are extremely short lived, whenever a matter particle and anti-matter particle meet in space they annihilate one another – converting their mass completely into energy.

TASK / ACTIVITY

POSTER TIME!

Using the following slides and/or research, in your table groups you will create a summary poster that covers the three main types of decay you need to be able to explain:

- Alpha Decay
- Beta Positive Decay
- Beta Negative Decay

For each type of decay you need to include:

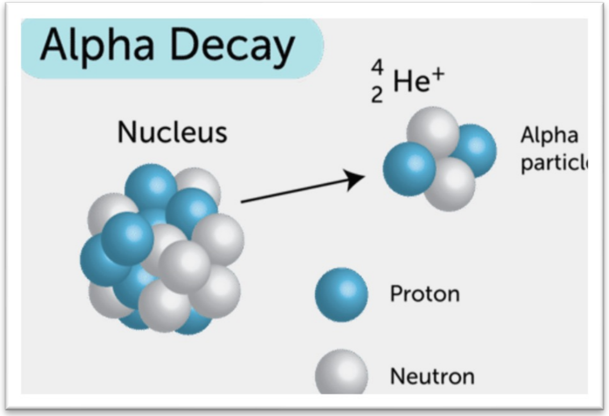
- Its properties
  - The symbol used
  - The nature of the particle/s emitted
  - The charge
  - Penetrating ability
  - Ionising ability

- An explanation of the decay including:
  - The cause
  - A description of the process
  - A description of the outcome/radiation emission

LESSON CONTENT

ALPHA DECAY

Definition	A heavy radioactive nucleus becomes more stable by emitting an alpha particle which is comprised of 2 protons and 2 neutrons (a helium nucleus).
Symbol	${}^{4}_{2}\mathrm{He}$ or ${}^{4}_{2}\alpha$
Particle emitted	Helium-4 nucleus
Charge of particle	+2
Energy	Has a large mass and therefore has less energy compared to other types of decay (moves at approximately 10% of speed of light = 30000km/s)
Penetrating ability	Low (due to low energy). Can be stopped by a sheet of paper
Ionising ability	High ionising ability due to the 2+ charge



Alpha Decay occurs because there is an excess of protons *and* neutrons in the nucleus such that the size of the nucleus exceeds the range of the SNF.

An alpha particle is emitted which reduces the size of the nucleus by emitting excess mass.

The alpha particle (helium nucleus) reduces the size of the nucleus by 4 nucleons, increasing stability.

TASK / ACTIVITY

ALPHA DECAY EXAMPLE

You may need to access your Periodic Table (QCAA Databook)

Thorium-188 is the daughter nucleus of a parent nucleus which has undergone alpha decay. Determine the parent nucleus & write the decay equation for this process.

ALPHA DECAY EXAMPLE: SOLUTION

Thorium-188 can be written as	${}^{188}_{90}Th$ ($Z = 90$, $A = 188$ and $N = A - Z = 98$)
If the parent nucleus has undergone alpha decay, it has lost an alpha particle (a Helium-4 isotope)	${}^{4}_{2}He$ ($Z = 2$, $A = 4$ and $N = A - Z = 2$)
This means that the parent nucleus originally had 2 additional protons, and two additional neutrons.	${}^{A}_{Z}X$ $Z = 90 + 2$, $A = 188 + 4$ and $N = 98 + 2$
The parent nucleus is therefore Uranium-192	${}^{192}_{92}U$

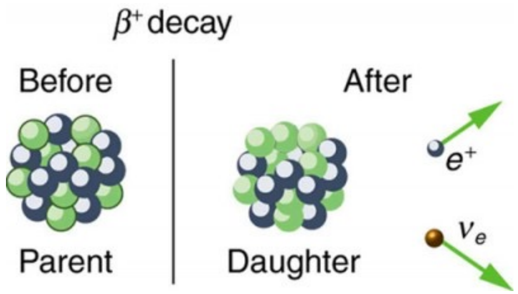
$$ {}^{A}_{Z}X = {}^{188}_{90}Th + {}^{4}_{2}He $$
$$ Z = 90 + 2 $$
$$ A = 188 + 4 $$
$$ {}^{A}_{Z}X = {}^{192}_{92}U $$

Decay equation: ${}^{192}_{92}\mathrm{U} \rightarrow {}^{188}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} + \gamma$

BETA + DECAY

Beta decay allows a parent nucleus to become more stable by rearranging the number of protons and neutrons into a more energy favourable ratio. Comes in two forms: beta positive and beta negative.

	BETA POSITIVE
Definition	A proton changes into a neutron and a positron (a positively charged electron) is emitted from the nucleus. Typical for radioactive nuclei that have too many protons for the number of neutrons.
Symbol	Beta positive: ${}^{0}_{1}\beta, \beta^{+}$ or ${}^{0}_{1}e$
Particle emitted	Beta positive: high speed positron and a neutrino.
Charge of particle	+1e
Energy	High speed electron or positron with very small mass (moves at approximately 99% of the speed of light)
Penetrating ability	High speed and smaller charge allows it to travel further than alpha decay. Stopped by 3mm thick aluminium and can travel a few cm in air
Ionising ability	Moderately ionising due to the -1 or +1 charge



Beta positive decay occurs when there is an excess of protons in the nucleus. The excess positive charge creates excess electrostatic repulsion.

A proton turns into a neutron, reducing the atomic number by 1 while keeping atomic mass the same.

A beta positive particle (positron) is emitted to conserve charge, as well as a neutrino, resulting in a more stable daughter nucleus

TASK / ACTIVITY

BETA +

You may need to access your Periodic Table (QCAA Databook)

Fluorine-18 is the parent nucleus that undergoes beta positive decay. Determine the daughter nucleus & write the decay equation.

BETA+ DECAY EXAMPLE: SOLUTION

Fluorine-18 can be written as	${}^{18}_{9}\mathrm{F}$ ($Z = 9$, $A = 18$ and $N = A - Z = 9$)
If the parent nucleus has undergone beta+, it has lost a proton, and gained a neutron, and emitted a positron	${}^{0}_{1}e$
This means that the daughter nucleus has one less proton, and has gained a neutron (same A).	${}^{A}_{Z}X$ $Z = 9 - 1 = 8$, $A = 18$ and $N = 9 + 1 = 10$
The daughter nucleus is therefore Oxygen-18	${}^{18}_{8}\mathrm{O}$

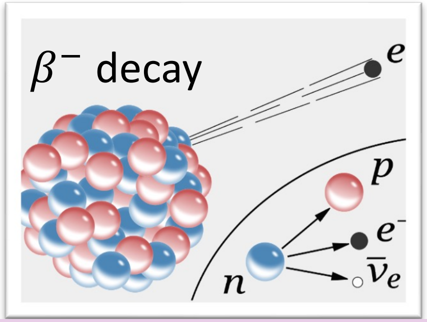
Decay equation: ${}^{18}_{9}\mathrm{F} \rightarrow {}^{18}_{8}\mathrm{O} + {}^{0}_{1}\mathrm{e} + {}^{0}_{0}\nu_e + \gamma$

LESSON CONTENT

BETA - DECAY

Beta decay allows a parent nucleus to become more stable by rearranging the number of protons and neutrons into a more energy favourable ratio. Comes in two forms: beta positive and beta negative.

	BETA NEGATIVE
Definition	A neutron changes into a proton and an electron is emitted from the nucleus. Typical for radioactive nuclei that have too many neutrons for the number of protons.
Symbol	Beta negative: ${}_{-1}^{0}\beta, \beta^{-},$ or ${}_{-1}^{0}e$
Particle emitted	Beta negative: high speed electron and an antineutrino.
Charge of particle	-1e
Energy	High speed electron or positron with very small mass (moves at approximately 99% of the speed of light)
Penetrating ability	High speed and smaller charge allows it to travel further than alpha decay. Stopped by 3mm thick aluminium and can travel a few cm in air
Ionising ability	Moderately ionising due to the -1 or +1 charge



Beta negative decay occurs when there is an excess of neutrons in the nucleus. This creates an unstable ratio of nucleons.

A neutron turns into a proton, increasing the atomic number by 1 while keeping the atomic mass the same.

A beta negative particle (electron) is emitted to conserve charge, as well as an anti-neutrino, resulting in a more stable daughter nucleus

TASK / ACTIVITY

BETA -

You may need to access your Periodic Table (QCAA Databook)

Calcium-40 is the daughter nucleus of an isotope that that undergoes beta negative decay. Determine the parent nucleus & write the decay equation.

BETA- DECAY EXAMPLE: SOLUTION

Calcium-40 can be written as	${}^{40}_{20}\mathrm{Ca}$ ($Z = 20$, $A = 40$ and $N = A - Z = 20$)
If the parent nucleus has undergone beta-, it has lost a neutron, and gained a proton, and emitted an electron	${}^{0}_{-1}e$
This means that the daughter nucleus has one more proton, and has lost a neutron (same A).	${}^{A}_{Z}X$ $20 = \mathrm{Z} + 1 \Rightarrow Z = 19$, $A = 40$ and $20 = N - 1 \Rightarrow N = 21$
The parent nucleus is therefore Potassium-40	${}^{40}_{19}\mathrm{K}$

Decay equation: ${}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{20}\mathrm{Ca} + {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\overline{\nu}_e + \gamma$

NEUTRINOS

A neutrino is a tiny, neutral and almost massless particle that is always seen in association with a positron (anti-electron).

An anti-neutrino has almost the same properties as a neutrino but is seen in association with an electron.

NOTATION

antineutrino $({}^{0}_{0}\overline{\nu}_e)$	**Comes with Beta$^-$ particle (electron)** $({}^{0}_{-1}\beta \text{ or } {}^{0}_{-1}\bar{e})$
neutrino $({}^{0}_{0}\nu_e)$	**Comes with Beta$^+$ particle (positron)** $({}^{0}_{1}\beta \text{ or } {}^{0}_{1}\bar{e})$

The reasoning behind these neutrinos existence will be covered in Unit 4 Topic 3 – Standard Model next year.

CHECK FOR UNDERSTANDING

LEARNING CHECK

A proton decays into a neutron. The other products of the decay are

A Positron and neutrino

B Positron and antineutrino

C Electron and neutrino

D Electron and antineutrino

TASK / ACTIVITY

CHECKING FOR UNDERSTANDING

5 minutes

Determine the daughter nuclide in the following two decays.

1. Caesium 137 undergoes Beta negative decay

2. Copper 64 decays via Beta positive decay

GAMMA RADIATION

Sometimes, to make the nucleus more stable, gamma decay reduces energy by emitting **gamma radiation (ray/s).** However gamma radiation is most commonly observed in alpha and beta decay as the emission of all of the energy that was destabilizing the nucleus.

Gamma radiation a form of high electromagnetic radiation (light), and as such travel at the speed of light (3.00×10^8 m/s).

Since gamma radiation has no charge and no mass, it can pass straight through tissue of most materials. This causes indirect ionization through interaction with atoms and the subsequent beta particles they create. However if the gamma ray directly strikes an electron it will eject the electron from the atom.

TASK / ACTIVITY

CONSOLIDATION - TEXTBOOK

Complete the following to consolidate your learning:

Check your learning 5.2:
Questions 1, 4

Check your learning 5.6:
Q4, Q5