# OCR A Level Physics

Your notes

## Fundamental Particles

### Contents

## Antimatter

Your notes

# Antimatter

- The universe is made up of **matter** particles (protons, neutrons, electrons etc.)
- All matter particles have antimatter counterparts
  - **Antimatter particles are identical to their matter counterpart but with the opposite charge**
- This means if a particle is positive, its antimatter particle is negative and vice versa
- Common matter-antimatter pairs are shown in the diagram below:

**Matter-Antimatter Table**

| Matter | Charge | Antimatter | Charge |
|---|---|---|---|
| Electron $e^-$ | −1 | Positron $e^+$ | +1 |
| Proton $p$ | +1 | Anti-proton $\bar{p}$ | −1 |
| Neutron $n$ | 0 | Anti-neutron $\bar{n}$ | 0 |
| Neutrino $\nu$ | 0 | Anti-neutrino $\bar{\nu}$ | 0 |



- Apart from electrons, the corresponding antiparticle pair has the same name with the prefix **'anti-'** and a line above the corresponding matter particle symbol
- A neutral particle, such as a neutron or neutrino, **is its own antiparticle**

### Examiner Tips and Tricks

Your notes

> You must learn each fundamental particle, its symbol, and its corresponding antiparticles and symbols. Don't let the symbols catch you out in diagrams for this unit.

## Properties of Antimatter

- Although antimatter particles have the opposite charges to their matter counterparts, they still have **identical mass and rest mass-energy**
  - The rest mass-energy of a particle is the energy equivalent to the mass of the particle at rest
- The datasheet provides the masses in kg and rest-mass energies in MeV for a proton, neutron, electron and neutrino
- These masses are identical for their corresponding antiparticles (antiproton, antineutron, positron and antineutrino respectively)

**Mass & Rest Mass Energy Table**

| Particle/ Antiparticle | Mass (kg) | Rest Mass Energy (MeV) |
|---|---|---|
| Proton/ antiproton | $1.67(3) \times 10^{-27}$ | 938.257 |
| Neutron/ antineutron | $1.67(5) \times 10^{-27}$ | 939.551 |
| Electron/ positron | $9.11 \times 10^{-31}$ | 0.510999 |
| Neutrino/ antineutrino | 0 | 0 |

Your notes

## Hadrons & Leptons

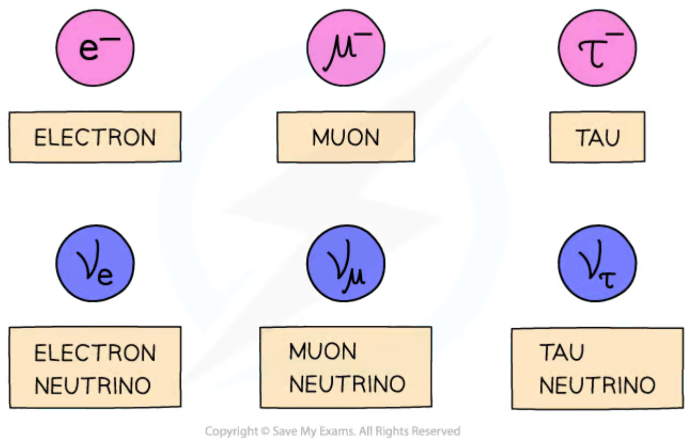
# Hadrons

- Hadrons are particles made up of **quarks**
  - This means they are affected by the **strong nuclear force**
- There are two classes of hadrons:
  - **Baryons** (3 quarks)
  - **Mesons** (quark and anti-quark pair)
- The most common baryons are protons and neutrons
- The most common mesons are pions and kaons
- If charged they experience the **electromagnetic force**
- They decay via the **weak nuclear force**
- Quarks have never been discovered on their own, always in pairs or groups of three
- The large hadron collider at CERN (LHC) is used to look inside fundamental particles

# Leptons

- Leptons are **fundamental particles**
  - This means they have no internal structure and cannot be divided or split into smaller particles
- Unlike hadrons, they are not composed of **quarks**
  - This means they are **not** affected by the strong nuclear force
- There are 6 leptons in total and 3 different **flavours** (types) of lepton:
  - Electron, e
  - Muon, μ
  - Tau, τ

Your notes




*The six leptons are all fundamental particles*

- Electrons, muon and tau particles **all** have a charge of –1e
  - This means they experience the **electromagnetic force**
- Muon and tau particles are very similar to electrons but with slightly **larger masses**
  - The mass of an electron is about 0.0005u, whereas the mass of a muon is about 0.1u and the mass of a tau is about 2u
  - Where u is the unified atomic mass unit, equal to $1.661 \times 10^{-27}$ kg
- There are also three **flavours** of neutrino
  - The electron neutrino, $\nu_e$
  - The muon neutrino, $\nu_\mu$
  - The tau neutrino, $\nu_\tau$
- Neutrinos are the most abundant leptons in the universe
  - They have **no charge** and **negligible** mass (almost 0)
- Neutrinos are produced in particle interactions which also involve the other leptons
  - For example, if an electron is produced in a particle interaction, an electron neutrino will also be produced
- Leptons interact through the weak interaction, electromagnetic force and gravitational forces
- However, they do **not** interact with the strong force

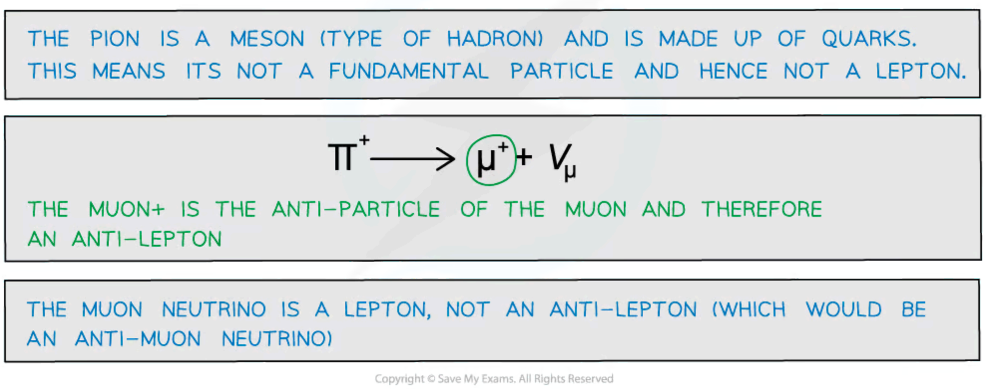
- Although quarks are fundamental particles too, they are not classed as leptons
- Leptons do **not** interact with the strong force, whilst quarks do

## Worked Example

Circle all the anti-leptons in the following decay equation.

$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

**Answer:**







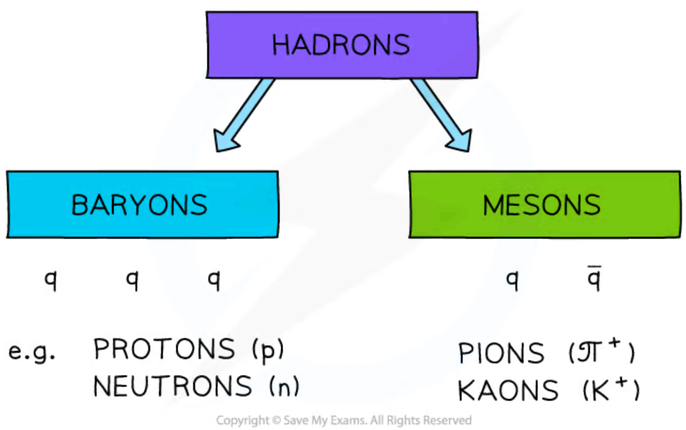
Your notes

## The Quark Model

Your notes

# Quark Model of Hadrons

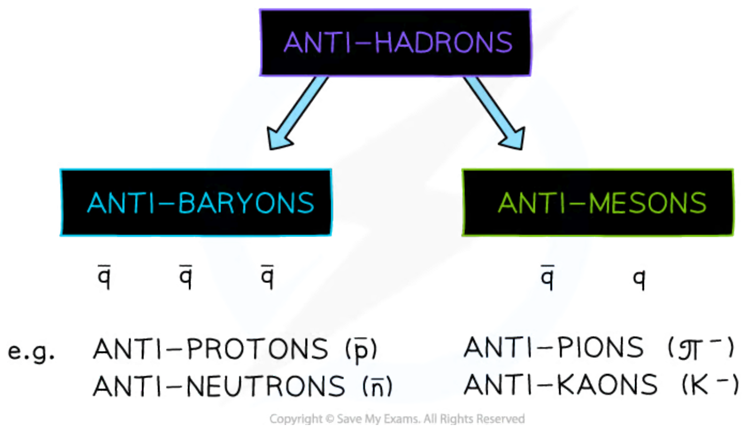
- **Hadrons** are a group of subatomic particles that are made up of quarks
- These may be either a:
    - **Baryon (3 quarks)**
    - **Meson (quark and anti-quark pair)**




***Hadrons may be either a baryon or a meson***

- Quarks have never been discovered on their own, always in pairs or groups of three
- Anti-hadrons can be either
    - **Anti-baryons (3 anti-quarks)**
    - **Anti-meson (quark and anti-quark pair)**

Your notes




***Anti-hadrons may be either an anti-baryon or an anti-meson***

- Note that all baryons or mesons have integer (whole number) charges eg. +1e, -2e etc.
- This means quarks in a baryon are either all quarks or all anti-quarks. Combination of quarks and anti-quarks don't exist in a baryon
  - e.g.


- The anti-particle of a meson is still a quark-antiquark pair. The difference being the quark becomes the anti-quark and vice versa

## Worked Example

The baryon $\Delta^{++}$ was discovered in a particle accelerator using accelerated positive pions on hydrogen targets. Which of the following is the quark combination of this particle?

**A.** uuu **B.** $cd\bar{s}$ **C.** $\bar{u}d$ **D.** $\bar{c}\bar{c}\bar{c}$

Your notes

ANSWER: A

STEP 1

SINCE IT'S A BARYON, IT'S MADE UP OF THREE QUARKS
THIS RULES OUT OPTION C (A MESON)

STEP 2

BARYONS ARE MADE UP OF 3 QUARKS OR ANTI-BARYONS MADE UP OF 3 ANTI-QUARKS
THIS RULES OUT OPTION B (YOU CANNOT HAVE A COMBINATION OF QUARKS AND ANTIQUARKS)

STEP 3

THE $\Delta^{++}$ BARYON HAS A CHARGE OF +2 (FROM THE ++)

STEP 4

ADDING UP THE CHARGES OF THE QUARKS IN A AND D
A. $uuu = +2/3 + 2/3 + 2/3 = +2$
D. $\bar{c}\bar{c}\bar{c} = -2/3 - 2/3 - 2/3 = -2$

STEP 5

ITS QUARK COMBINATION MUST THEREFORE BE uuu (OPTION A)



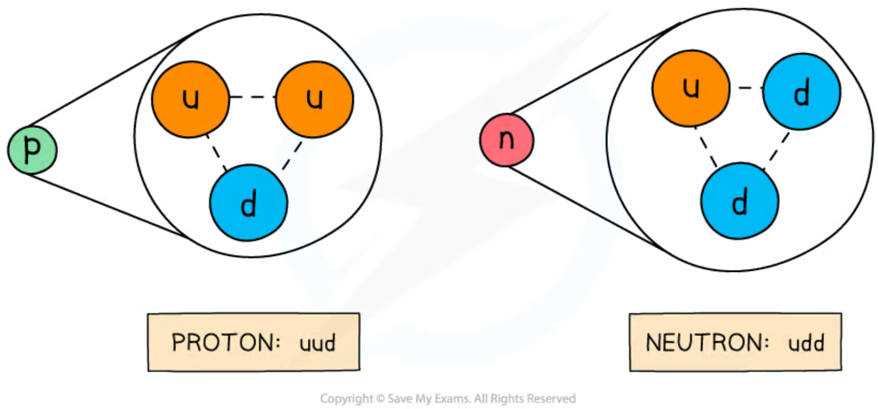
### Examiner Tips and Tricks

Remembering quark combinations is useful for the exam. However, as long as you can remember the charges for each quark, it is possible to figure out the combination by making sure the combination of quarks add up to the charge of the particle (just like in the worked example)

## Quark Model of the Proton and Neutron

- Protons and neutrons are **not** fundamental particles. They are each made up of three quarks
- **Protons** are made up of **two up quarks and a down quark**
- **Neutrons** are made up of **two down quarks and an up quark**

Your notes




*Protons and neutrons are made up of three quarks*

- You will be expected to remember these quark combinations for exam questions

## Worked Example

In the nucleus of Iron $^{56}_{26}Fe$, how many 'up' quarks are there?

**Answer:**

**Step 1:** Calculate number of protons:

- The number of protons is from the proton number = 26 protons

**Step 2:** Calculate number of neutrons:

- The number of neutrons = nucleon number - proton number = 56 - 26 = 30 neutrons

**Step 3:** Up quarks in a proton:

- Protons are made up of **uud** quarks = 2 up quarks

**Step 4:** Up quarks in a neutron:

- Neutrons are made up of **udd** quarks = 1 up quark

**Step 5:** Total number of up quarks:

- 26 protons x 2 up quarks = 52 up quarks

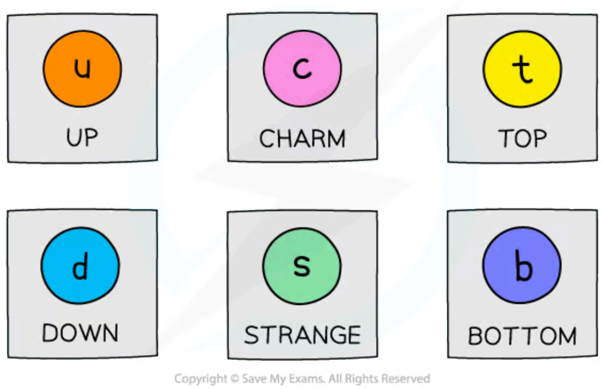
- 30 neutrons x 1 up quark = 30 up quarks
- 52 + 30 = 82 up quarks

Your notes

# Charges of Quarks

## Types of Quark

- Quarks are **fundamental particles** that make up other subatomic particles such as **protons and neutrons**
- Protons and neutrons are in a category of particles called **hadrons**
  - Hadrons are defined as any particle made up of quarks
- **Fundamental** means that quarks are not made up of any other particles. Another example is electrons
- Quarks have never been observed on their own, they're either in pairs or groups of three
- There are six flavours (types) of quarks that exist:



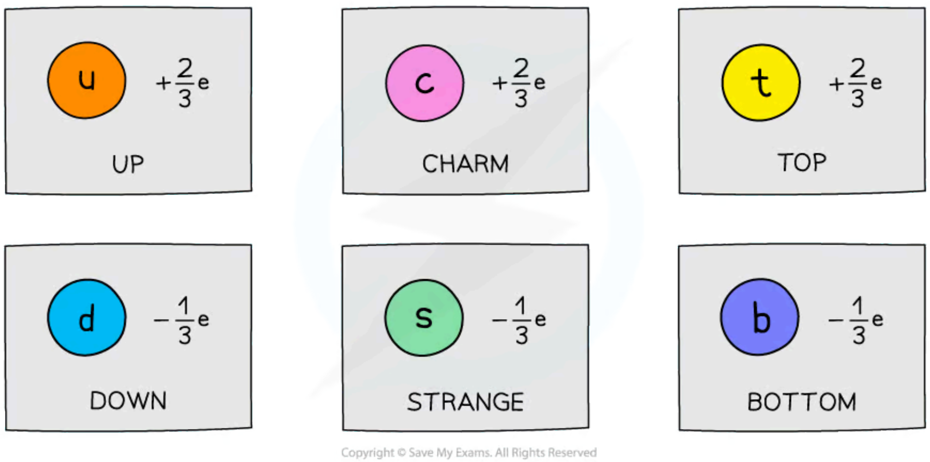

*The six flavours of quarks*

**You only need to know about up, down and strange, as well as their antiquarks.**

## Charges of Quark

- The charge of a hadron is determined by the sum of the charges of its quarks
- Each flavour of quark has a certain relative charge:

Your notes




***Each flavour of quark has a charge of either +⅔e or -⅓e***

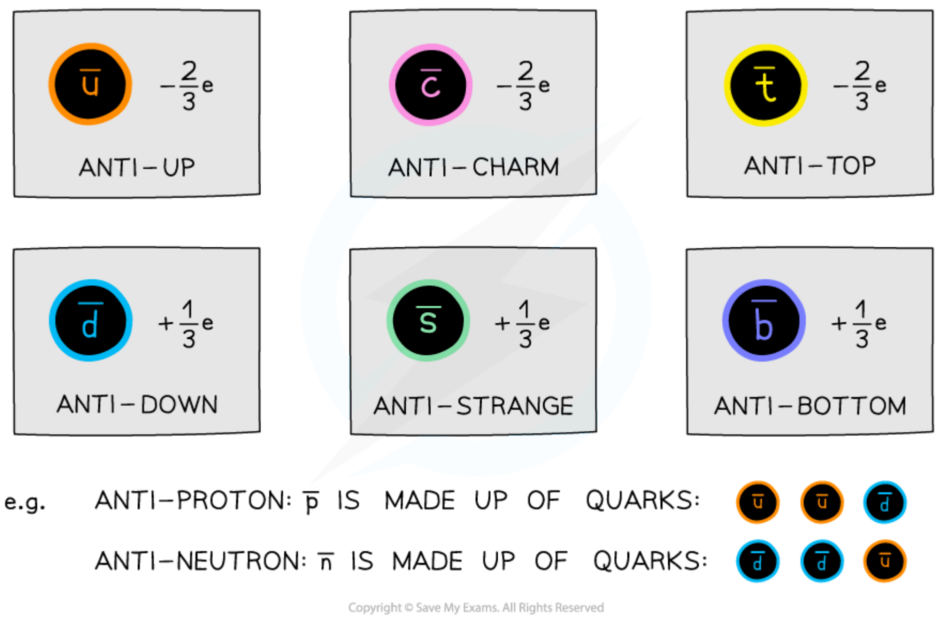
**You only need to know about up, down and strange, as well as their antiquarks.**

- For example, a proton is made up of two up quarks and a down quark. Adding up their charges gives the charge of a proton:

$$+\tfrac{2}{3}e + \tfrac{2}{3}e - \tfrac{1}{3}e = +1e$$

- The equivalent antiparticle of the quark is the anti-quark
- These are identical to quarks except with opposite relative charges

Your notes




***Each flavour of anti-quark has a charge of either -⅔e or +⅓e. The quark composition of anti-protons and anti-neutrons changes to anti-quarks***

**You only need to know about up, down and strange, as well as their antiquarks.**

## Worked Example

Particles are made up of a combination of three quarks or two quarks. Which quark combination would give a particle a charge of -1?

**A.** up, strange, strange

**B.** up, up, down

**C.** anti-up, anti-strange

**D.** anti-up, anti-up, anti-strange

**Answer: D**

- Each answer option has the following quarks and charges:

- A: $uss = +\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$
- B: $uud = +\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$
- C: $\overline{us} = -\frac{2}{3} + \frac{1}{3} = -\frac{1}{3}$
- D: $\overline{uus} = -\frac{2}{3} - \frac{2}{3} + \frac{1}{3} = -1$

- We can see that the correct answer is **D** the combination anti-up, anti-up, anti-strange give a charge of -1

### Examiner Tips and Tricks

You will be expected to remember the charge of each quark. However, instead of memorising the charges of anti-quarks too, just remember they are identical but with opposite signs.

Your notes

## Beta Minus & Beta Plus Decay

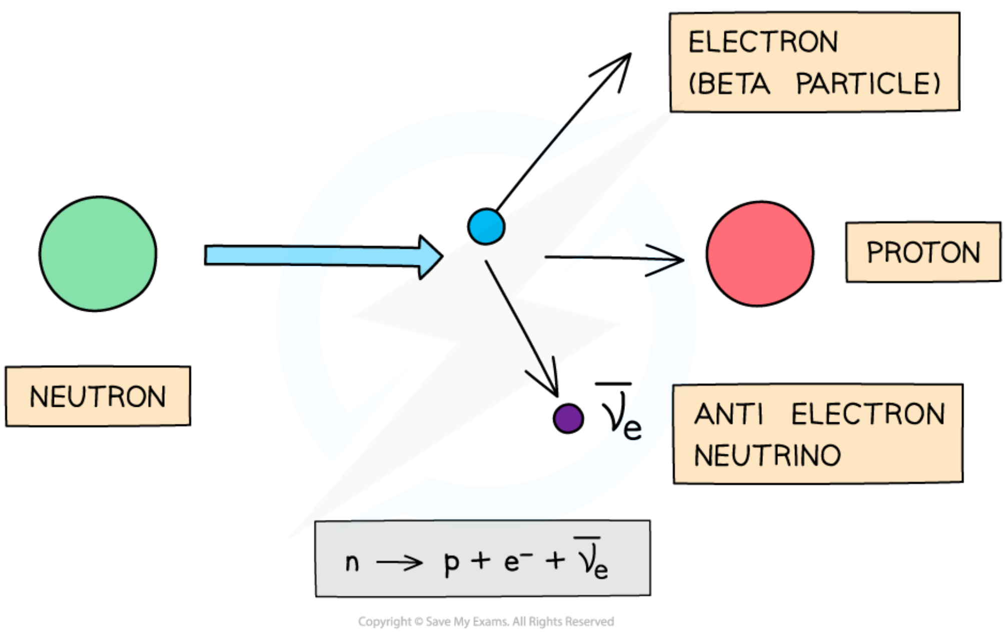
Your notes

# Beta Minus and Beta Plus Decay

- Beta decay happens via the **weak interaction**
  - This is one of the four fundamental forces and it's responsible for radioactive decays

## Beta-Minus Decay

- A beta-minus, $\beta^-$, particle is a high energy electron emitted from the nucleus
- $\beta^-$ decay is when a **neutron turns into a proton emitting an electron and an anti-electron neutrino**




- When a $\beta^-$ particle is emitted from a nucleus:
  - The number of protons increases by 1: **proton number increases by 1**
  - The total number of nucleons stays the same: **nucleon number remains the same**

Your notes

$$^{A}_{Z}X \rightarrow \, ^{A}_{Z+1}Y + \, ^{0}_{-1}\beta + \, ^{0}_{0}\bar{\nu}_e$$

$$\text{e.g.} \quad ^{14}_{6}C \rightarrow \, ^{14}_{7}N + \, ^{0}_{-1}\beta + \, ^{0}_{0}\bar{\nu}_e$$

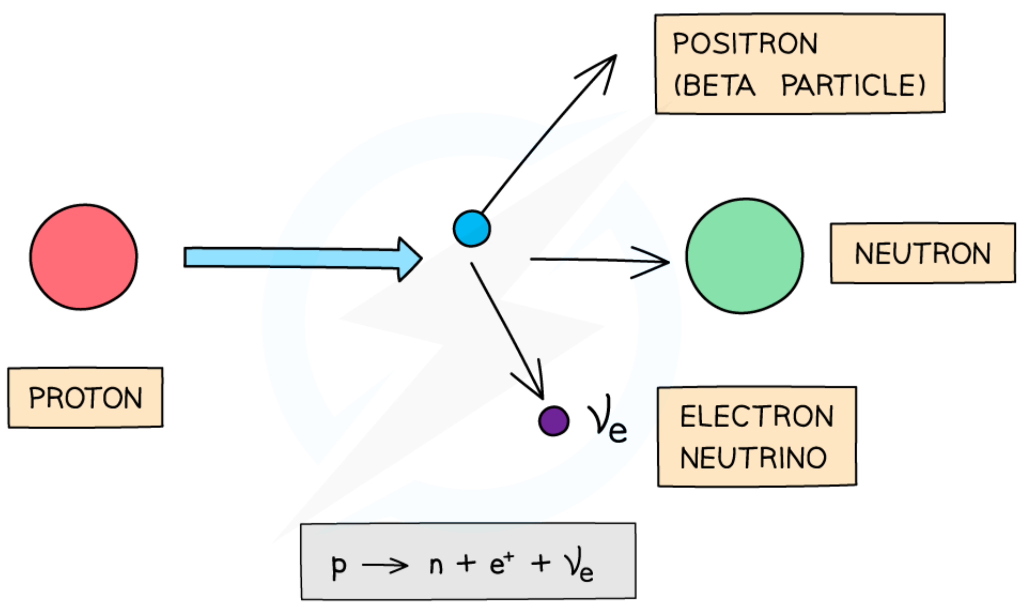


***Equation for beta minus emission***

- The new nucleus formed from the decay is called the "daughter" nucleus (nitrogen in the example above)

## Beta-Plus Decay

- A beta-plus, $\beta^+$, particle is a high energy positron emitted from the nucleus
- $\beta^+$ decay is when a **proton turns into a neutron emitting a positron (anti-electron) and an electron neutrino**






- When a $\beta^+$ particle is emitted from a nucleus:
  - The number of protons decreases by 1: **proton number decreases by 1**

- The total number of nucleons stays the same: **nucleon number remains the same**

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta + {}^{0}_{0}\nu_e$$

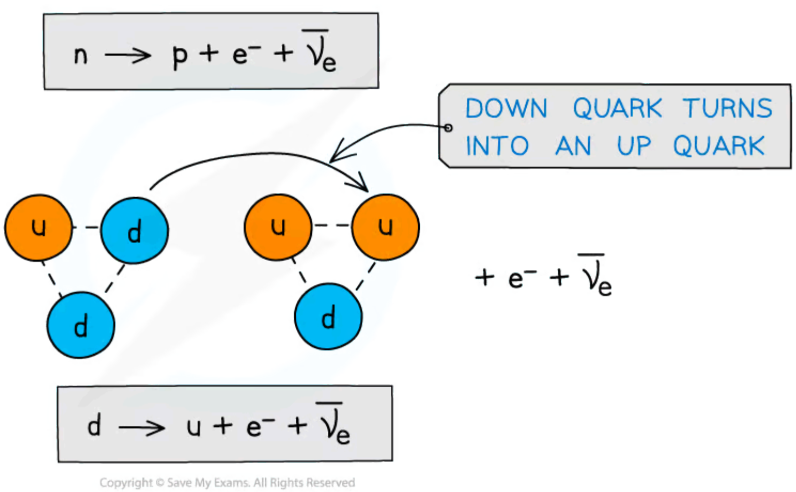
$$\text{e.g.} \quad {}^{12}_{6}C \longrightarrow {}^{12}_{5}B + {}^{0}_{+1}\beta + {}^{0}_{0}\nu_e$$



*Equation for beta plus emission*

# Quark Model of Beta Minus Decay

- Recall that $\beta^-$ **decay is when a neutron turns into a proton emitting an electron and anti-electron neutrino**
- More specifically, a neutron turns into a proton because a **down quark turning into an up quark**



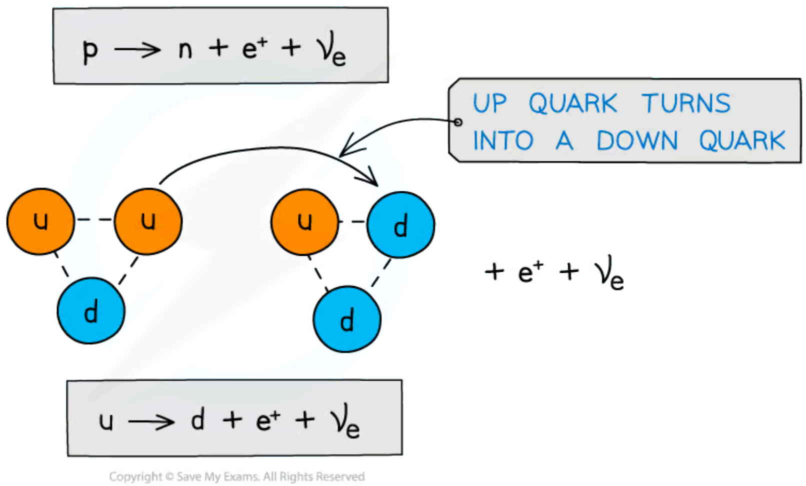

*Beta minus decay is when a down quark turns into an up quark*

# Quark Model of Beta Plus Decay

- Recall that $\beta^+$ **decay is when a proton turns into a neutron emitting an positron and an electron neutrino**
- More specifically, a proton turns into a neutron because an **up quark turns into a down quark**

Your notes

Your notes




***Beta minus decay is when an up quark turns into a down quark***

## Quarks in Particle Decay Equations

Your notes

# Balancing Quark transformation equations

- By looking at the **transformation of quarks** inside the protons and neutrons in **beta decay** it is possible to analyse the decay of specific quarks inside

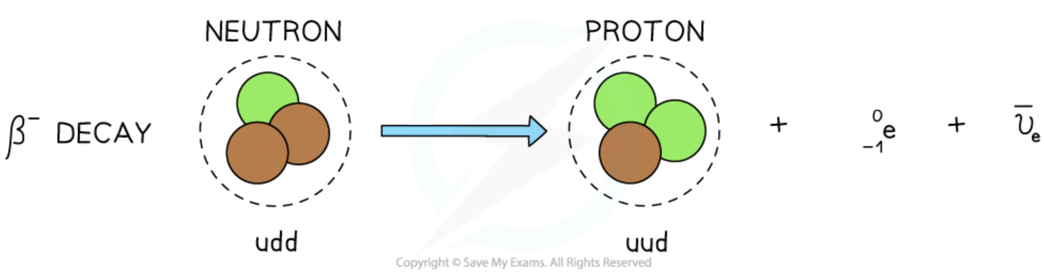
## Beta-minus decay

- In **beta-minus decay**, one of the **neutrons** in a nucleus is converted into a **proton** in a process that may be written as:

$$n \rightarrow p + e^- + \bar{V}_e$$

- The **neutron**, n has the quark composition udd
- The **proton**, p has the quark composition uud
- So the **beta-minus decay** must involve a **down quark** converting to an **up quark**

$$d \rightarrow u + e^- + \bar{V}_e$$




**Balancing Charge**

- The charge on the left side of the equation is $-\frac{1}{3}$ e
- The total charge on the right side is $\frac{2}{3}$ e + (-1)e + 0 = $-\frac{1}{3}$ e
- So, the decay equation is **balanced** in terms of charge

## Beta-plus Decay

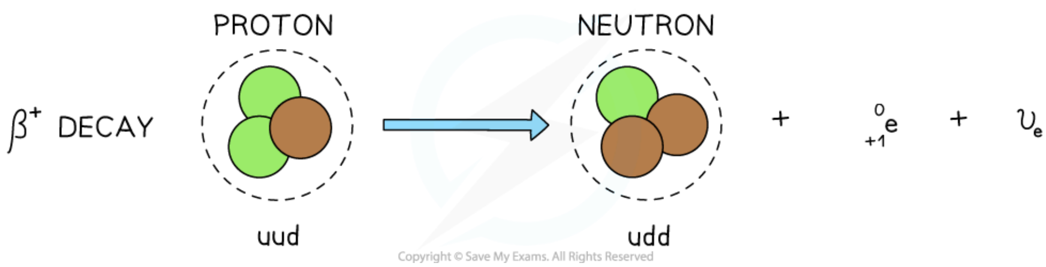
Your notes

- In **beta-plus decay** a proton is converted into a neutron with the emission of a positron and an electron neutrino in a process that may be written as:

$$p \rightarrow n + e^+ + v_e$$

- The **proton**, p has the quark composition uud
- The **neutron**, n has the quark composition udd
- So, the **beta-plus decay** must involve an **up quark** converting to a **down quark**

$$u \rightarrow d + e^+ + v_e$$




**Balancing Charge**

- The charge on the left side of the equation is $+\frac{2}{3}$ e
- The total charge on the right side is $-\frac{1}{3}$ e + e + 0 = $+\frac{2}{3}$ e
- So the decay equation is **balanced** in terms of charge

**Charge must be conserved in any reaction or decay equation**

## Worked Example

The equation for $\beta^-$ decay is

$$n \rightarrow p + e^- + \bar{\nu}_e$$

Using the quark model of beta decay, prove that the charge is conserved in this equation.

**Answer:**

STEP 1

$\beta^-$ DECAY IS WHEN A DOWN QUARK CHANGES TO AN UP QUARK
THIS CHANGES A NEUTRON INTO A PROTON

STEP 2

CHARGE OF THE LEFT HAND SIDE OF THE EQUATION
THE QUARK COMPOSITION OF A NEUTRON IS **udd**

STEP 3

ADDING UP THE QUARK CHARGES:

$$+2/3 - 1/3 - 1/3 = 0$$

THE LEFT HAND SIDE HAS A CHARGE OF 0

STEP 4

CHARGE ON THE RIGHT HAND SIDE OF THE EQUATION
THE QUARK COMPOSITION OF A PROTON IS **uud**

STEP 5

ADD UP THE QUARK CHARGES:

$$+2/3 + 2/3 - 1/3 = +1$$

STEP 6

THE ELECTRONS CHARGE IS −1
THE ANTI−NEUTRINOS CHARGE IS 0
THE RIGHT HAND SIDE HAS A CHARGE OF $+1 - 1 + 0 = 0$

STEP 7

SINCE THE CHARGES ARE EQUAL ON BOTH SIDES, IT IS CONSERVED IN THE BETA DECAY EQUATION



Your notes