7.3 The Structure of Matter

Mark Schemes

Course	DP IB Physics
Section	7. Atomic, Nuclear & Particle Physics
Topic	7.3 The Structure of Matter
Difficulty	Medium

To be used by all students preparing for DP IB Physics SL
Students of other boards may also find this useful

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The correct answer is **B** because:

- Compare both sides of the equation with the appropriate conservation laws

$$\Sigma^+ \rightarrow X + p$$

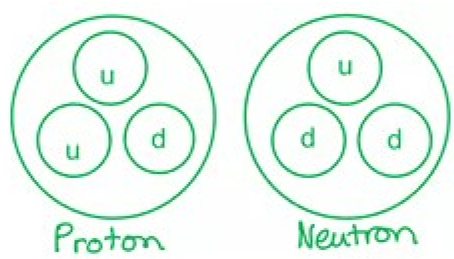
- Charge:
  - +1 = X + 1 therefore, X has a charge of 0
  - This eliminates options **A** and **C**
- Baryon number:
  - +1 = X + 1 therefore, X has a baryon number of 0
  - This eliminates option **D**
- Lepton number:
  - 0 = 0 + 0 therefore X has a lepton number of 0

A is incorrect as	from charge conservation, X has a charge of 0 (not –1)
C is incorrect as	from charge and baryon number conservation, X has a charge of 0 and baryon number of 0
D is incorrect as	from baryon number and lepton number conservation, X has a baryon number of 0 and lepton number of 0 too

2

The correct answer is **B** because:

- There are two types of hadron:
  - Baryons: three quarks or three antiquarks
  - Mesons: a quark and an anti-quark pair
- Protons and neutrons are baryons composed of up and down quarks
- They are both made of three quarks as shown in the diagram



- A quark (of charge $\frac{2}{3}$ e) and a $\bar{d}$ quark (of charge $-\frac{1}{3}$ e) together has an overall charge of +1
  - Therefore, a positive pion, π^+, is a meson is made up of an u and $\bar{d}$
- Therefore, option **B** is correct

A is incorrect as	a proton is a baryon but has two up quarks and one down quark (uud)
C is incorrect as	a neutron is not a type of meson; a meson contains one quark and one anti-quark bound by a gluon
D is incorrect as	a negative pion is a meson but consists of one $\bar{u}$ and d one quark

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The correct answer is **D** because:

- The presence of the W boson indicates that this is a weak interaction
- The minus sign (W^-) indicates it will either be β-minus decay or an electron-proton collision
- In an electron-proton collision:
  - A proton collides with a β^- particle (the electron) and a neutron and an electron-neutrino are produced
  - This can be represented by the equation: $p + \beta^- \rightarrow n + v_e$
- When a proton (uud) turns into a neutron (udd), an up quark turns into a down quark: uud ⟶ udd (or simply u ⟶ d)
  - This can be represented by the equation: $u + \beta^- \rightarrow d + v_e$
- In this case, we would expect the particles to be positioned on the Feynman diagram as follows:
  - 1 = proton or up quark
  - 2 = neutron or down quark
  - 3 = β^- particle
  - 4 = electron neutrino
- This eliminates options **A** & **C**

- In β-minus decay:
  - A neutron turns into a proton and a β^- particle and an electron anti-neutrino are produced
  - This can be represented by the equation: $n \rightarrow p + \beta^- + \bar{v}_e$
- When a neutron (udd) turns into a proton (uud), a down quark turns into an up quark: udd ⟶ uud (or simply d ⟶ u)
  - This can be represented by the equation: $d \rightarrow u + \beta^- + \bar{v}_e$
- In this case, we would expect the particles to be positioned on the Feynman diagram as follows:
  - 1 = neutron or down quark
  - 2 = proton or up quark
  - 3 = anti-electron neutrino
  - 4 = β^- particle
- This is shown by option **D**

A is incorrect as	this is an electron-proton collision in which the particles are correct, but the electron neutrino and the beta particle would need to swap places
B is incorrect as	this is beta-minus decay, so we would expect to see an anti-electron neutrino to conserve electron lepton number
C is incorrect as	this is an electron-proton collision, so we would expect to see an electron neutrino to conserve electron lepton number

4

The correct answer is **A** because:

- Due to conservation of charge, the overall charge of X and Y must be neutral
  - This is because both the kaon and the anti-electron neutrino are neutral
  - Charge is conserved in all particle interactions
- Due to conservation of lepton number, either X or Y must be a lepton with lepton number +1
  - This eliminates option **C**, as only one of the particles can be a lepton
  - This is because the antielectron neutrino has a lepton number of –1 and there are no leptons originally
- The leptons must be of the same type, hence the lepton must be an electron
  - This eliminates options **B** and **D**
- Since the baryon number on both sides is 0, the other particle must be a positive meson
  - This means particles X and Y must be π^+ and e^-
- Therefore, option **A** is correct

The easiest way to set out problems like this is to write out the reaction and to check

For the decay:

$$K^0 \rightarrow \pi^+ + e^- + \bar{\nu}_e$$

Electron lepton number: $0 \rightarrow 0 + 1 + (-1)$ **conserved**

B is incorrect as	For the decay $K^0 \rightarrow \pi^- + e^+ + \bar{\nu}_e$ Electron lepton number: $0 \rightarrow 0 + (-1) + (-1)$ **not conserved**
C is incorrect as	For the decay $K^0 \rightarrow \mu^+ + e^- + \bar{\nu}_e$ Electron lepton number: $0 \rightarrow 0 + 1 + (-1)$ **conserved** Muon lepton number: $0 \rightarrow (-1) + 0 + 0$ **not conserved**
D is incorrect as	For the decay $K^0 \rightarrow \pi^+ + \mu^- + \bar{\nu}_e$ Electron lepton number: $0 \rightarrow 0 + 0 + (-1)$ **not conserved** Muon lepton number: $0 \rightarrow 0 + 1 + 0$ **not conserved**

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The correct answer is **D** because:

- The question states that two leptons are produced
  - This eliminates option **B**
- A reaction involving leptons is only possible if the lepton number, as well as the lepton type, is conserved

- Consider option **D**: check if charge is conserved:
  - $\pi^+ \rightarrow \mu^+ + v_\mu$
  - $1 \rightarrow 1 + 0$
  - Charge is **conserved** in this reaction
- Check if muon lepton number is conserved:
  - $\pi^+ \rightarrow \mu^+ + v_\mu$
  - $0 \rightarrow (-1) + 1$
  - Muon lepton number is **conserved** in this reaction
- Hence, reaction **D** is possible

A is incorrect as	For the decay $\pi^0 \rightarrow \mu^+ + v_e$ Electron lepton number: $0 \rightarrow 0 + 1$ **not conserved** Muon lepton number: $0 \rightarrow (-1) + 0$ **not conserved**
B is incorrect as	For the decay $\pi^0 \rightarrow \pi^+ + \mu^-$ Muon lepton number: $0 \rightarrow 0 + 1$ **not conserved**
C is incorrect as	For the decay $\pi^+ \rightarrow e^+ + v_\mu$ Electron lepton number: $0 \rightarrow (-1) + 0$ **not conserved** Muon lepton number: $0 \rightarrow 0 + 1$ **not conserved**

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The correct answer is **A** because:

- This Feynman diagram is showing beta-plus decay
- In β-plus decay:
    - A proton turns into a neutron and a β^+ particle and an electron neutrino are produced
    - This can be represented by the equation: $p \rightarrow n + \beta^+ + \nu_e$
    - The exchange particle is the W^+ boson
- The Feynman diagram shows particle **1** turning into particle **4**, so comparing to the equation we can see that **1** is a proton and **4** is the neutron
    - This leaves lines **A** and **C** as possible answers
- They Feynman diagram also shows that position **3** is the exchange particle, meaning that **3** must be a W+ boson
    - This eliminates **C** and leaves **A** as the right answer
- Since there is one more particle, we can use this to check our answer
- Position **2** on the Feynman diagram must be the neutrino, since the label is already filled in
    - In row **A**, the neutrino is at position **2**, so we can be confident in our answer

B is incorrect as	lepton number must be conserved, so position 2 must be a neutrino
C & **D** are incorrect as	the exchange particle is the W^+ boson

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The correct answer is **B** because:

- All baryons eventually decay into protons, while leptons tend to decay into electrons
- Meanwhile, there are no stable mesons
  - This eliminates option **D**
- Only charged particles interact via electromagnetic force
  - This eliminates option **C**
- Leptons interact via the weak and electromagnetic forces and do **not** interact via the strong force
  - This eliminates option **A**
- Consider option **B**:
  - Protons are the most stable baryon
  - Electrons are leptons, hence they interact via the weak force
  - Muons are negatively charged, hence they interact via the electromagnetic force
  - Neutrons are baryons, hence they interact via the strong force

A is incorrect as	neutrinos do not interact via the strong force
C is incorrect as	neutrons do not interact via the electromagnetic force
D is incorrect as	kaons are mesons, which are unstable

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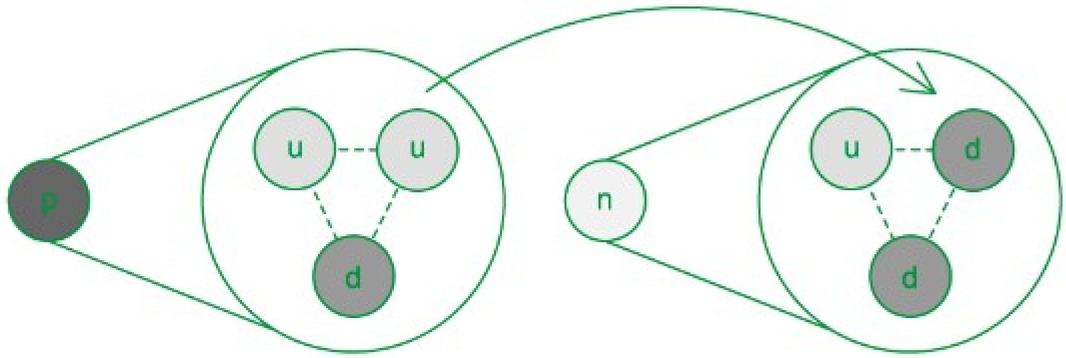
The correct answer is **B** because:

- The question shows a proton changing to a neutron with the exchange of a W+ boson and the emission of a positron and a neutrino
  - Therefore, this interaction is β-plus decay

- Protons consist of two up and one down quarks
- Neutrons consist of one up and two down quarks
- The change of an up quark to a down quark will achieve this



A is incorrect as	it shows the exchange of quarks in β-minus decay
C is incorrect as	the diagram is almost correct except for the W boson, which has changed sign from + to –
D is incorrect as	the diagram is quite mixed up. The quarks show β-plus decay, but the exchange particle and leptons show β-minus decay

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The correct answer is **D** because:

- The Geiger-Marden experiment showed that a very small percentage of α particles shot at a gold foil were backscattered by large angles
- This observation suggests the majority of the mass and all of the positive charge must be concentrated within a nucleus

A is incorrect as	the vast number of α particles passed through the foil undeflected, suggesting that the atom must be predominantly empty space
B is incorrect as	the results suggest the presence of a positively charged nucleus within the atom, but does not suggest what the nucleus is comprised of

C is incorrect as	this particular experiment did not set out to measure the kinetic energy of alpha particles, only their positions after being scattered by gold foil

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The correct answer is **A** because:

- Until the discovery of the electron, it was assumed that atoms were the fundamental constituents of matter
- Once protons and neutrons were discovered, it was unclear how they could be bound together in the nucleus solely by an electromagnetic interaction
- Quarks were hypothesised as a way to explain the behaviour of particles in the nucleus
- Quarks were also used to predict the existence of particles discovered through high-energy atomic collisions
- To do this, this required to develop patterns in properties of elementary particles

B is incorrect as	nuclear emission and absorption spectra arise from radioactive decay mechanisms such as alpha, beta and gamma emission
C is incorrect as	neutrinos were hypothesised in order to account for the missing energy and momentum in beta decay, not quarks
D is incorrect as	isotopes depend on numbers of protons and neutrons contained within in a nucleus; knowledge of quarks is not necessary to explain this