# 7.3 The Structure of Matter

## Mark Schemes

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| 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 HL
Students of other boards may also find this useful

1

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

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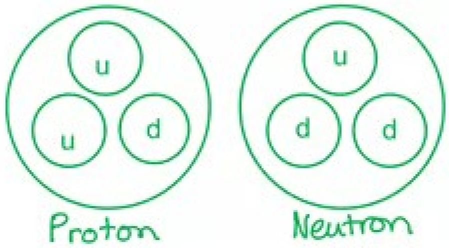
| **A** is incorrect as | from charge conservation, X has a charge of 0 (not –1) |
| **C** is incorrect as | from charge and baryon number conservation, X has a charge of 0 and baryon number of 0 |
| **D** is incorrect as | from baryon number and lepton number conservation, X has a baryon number of 0 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, $\pi^+$ , is a meson is made up of an $u$ and $\bar{d}$
- Therefore, option **B** is correct

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| **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 |

3

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 $\beta^-$ 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 = $\beta^-$ particle
    - 4 = electron neutrino
- This eliminates options **A** & **C**



- In β-minus decay:
    - A neutron turns into a proton and a $\beta^-$ 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 = $\beta^-$ particle
- This is shown by option **D**

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| **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 $\pi^+$ 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**

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



5

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

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

6

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 $\beta^+$ 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



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| **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 |

7

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

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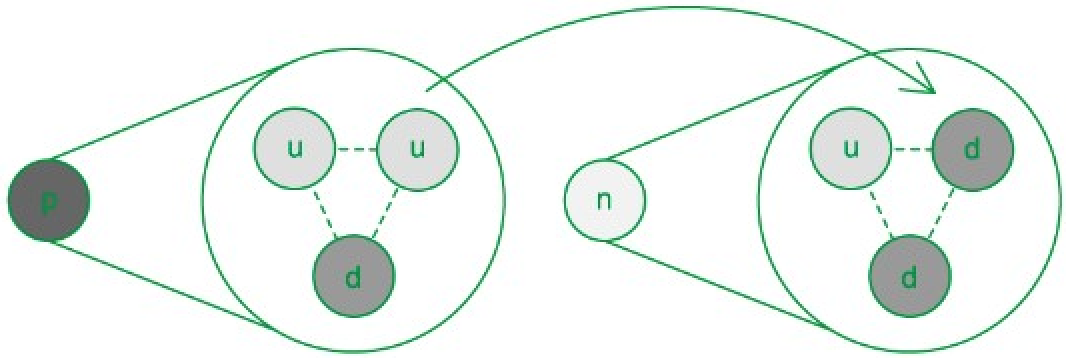
| **A** is incorrect as | neutrinos do not interact via the strong force |
| **C** is incorrect as | neutrons do not interact via the electromagnetic force |
| **D** is incorrect as | kaons are mesons, which are unstable |

8

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

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| **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 |

9



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

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| **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 |

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| **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 |

10

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

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| **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 |