



ANSWER BOOK

Conservation laws

Particles · Year 12

AQA 3.2.1.7 · CIE 11.1.9, 11.2.5 · OCR A 6.4.2(h), 6.4.2(i), 6.4.2(j)

18 questions · 52 marks

NAVY EDITION

SECTION A · Warm-up

- A1** Any four of the following, one mark per two correct (2): charge; baryon number; lepton number; energy; momentum. [2]
- A2** A down quark changes into an up quark, $d \rightarrow u$ (1). The decay emits an electron and an electron antineutrino (1). [2]
- A3** An up quark changes into a down quark, $u \rightarrow d$ (1); a positron and an electron neutrino are emitted (1). [2]
- A4** Positron: $L_e = -1$ (1). Electron neutrino: $L_e = +1$; proton: $L_e = 0$ (1). [2]
- A5** Its total after the interaction is the same as its total before (1). [1]

SECTION B · Standard

- B1** Charge: $(+1) + (+1) = +2 \rightarrow (+1) + 0 + (+1) = +2$ ✓ (1)
Baryon number: $1 + 1 = 2 \rightarrow 1 + 1 + 0 = 2$ ✓ (1)
Both are conserved (1) [3]
- B2** If strangeness is conserved, the interaction can proceed by the strong interaction (1). If strangeness changes (by ± 1), it cannot be strong and must proceed by the weak interaction (1), which is the only one that can change strangeness (1). [3]
- B3** Charge: $0 \rightarrow (+1) + (-1) + 0 = 0$ ✓ (1)
Baryon number: $1 \rightarrow 1 + 0 + 0 = 1$ ✓ (1)
Lepton number: $0 \rightarrow 0 + (+1) + (-1) = 0$ ✓, so all are conserved (1) [3]
- B4** Lepton number is not conserved (1): the left side has 0, but the positron on the right has $L_e = -1$, giving -1 (1). An electron neutrino ($L_e = +1$) must also be emitted to conserve lepton number (1). [3]
- B5** Lepton number must be conserved separately for each family (1). Muon lepton number falls from 1 to 0, so it is not conserved (1); electron lepton number rises from 0 to 1, also not conserved. Either failure forbids the decay (1). [3]
- B6** Strangeness changes from $+1$ to 0, so $\Delta S = -1$ (1). The strong interaction conserves strangeness exactly, so it cannot be responsible (1). Only the weak interaction allows strangeness to change by ± 1 , so the decay proceeds by the weak interaction (1). [3]

B7 Total rest energy of the products = $939.6 + 0.511 = 940.1$ MeV (1). This exceeds [4]
the proton's rest energy of 938.3 MeV (1). A free proton has no source for the extra
energy, so energy conservation forbids the decay (1). Inside a nucleus the binding
energies of parent and daughter differ, and that difference can supply the shortfall,
which is why bound protons can undergo beta-plus decay (1).

B8 A strange quark changes into an up quark, $s \rightarrow u$ (1). Strangeness changes [2]
(from -1 to 0), so the decay must proceed by the weak interaction (1).

SECTION C · Stretch

C1 Charge: $2 = 1 + 0 + q_x$ (1) [4]
so $q_x = +1$ (1)
Baryon number: $2 = 1 + 1 + B_x$, so $B_x = 0$ (1)
X is therefore a positive meson (for example a π^+) (1)

C2 The initial particles (π^- and p) have strangeness 0 (1), so the total must stay 0 [4]
in a strong interaction (1). Since K^0 has strangeness +1 (1), X must have strangeness -1
so that $(+1) + (-1) = 0$ (1).

C3 Check each conserved quantity in turn: charge, baryon number and each [3]
lepton number must total the same before and after (1); strangeness must be
unchanged if the interaction is strong (1); energy and momentum must also be
conserved. If any one check fails, the interaction cannot occur (1).

C4 (i) Charge: $+1 - 1 = 0 \rightarrow +1 - 1 = 0$ ✓; baryon number: $+1 - 1 = 0 \rightarrow 0 + 0 = 0$ ✓; all [4]
lepton numbers zero throughout, so (i) is allowed (1). (ii) Baryon number: $1 \rightarrow 0$, not
conserved (and electron lepton number $0 \rightarrow -1$), so (ii) is forbidden (1). (iii) Charge: $0 + 0$
 $= 0 \rightarrow +1 - 1 = 0$ ✓; baryon number: $0 + 1 = 1 \rightarrow 1 + 0 = 1$ ✓ (1); electron lepton number: $+1 +$
 $0 = +1 \rightarrow 0 + 1 = +1$ ✓, so (iii) is allowed (1).

C5 Charge: $-1 + 1 = 0 \rightarrow 0 + q_x$, so $q_x = 0$ (1). Baryon number: $0 + 1 = 1 \rightarrow 1 + B_x$ [4]
 $= 0$ (1). The interaction is strong, so strangeness is conserved: $-1 + 0 \rightarrow 0 + S_x$, giving $S_x =$
 -1 (1). The candidate with charge 0, $B = 0$ and $S = -1$ is the anti- K^0 (1).