InkPhysics

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

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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 → u (1). The decay emits an electron and an electron antineutrino (1). [2]

A3 An up quark changes into a down quark, u → 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 → (+1) + 0 + (+1) = +2 ✓ (1) [3]
Baryon number: 1 + 1 = 2 → 1 + 1 + 0 = 2 ✓ (1)
Both are conserved (1)

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 → (+1) + (−1) + 0 = 0 ✓ (1) [3]
Baryon number: 1 → 1 + 0 + 0 = 1 ✓ (1)
Lepton number: 0 → 0 + (+1) + (−1) = 0 ✓, so all are conserved (1)

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 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). [4]

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

SECTION C · Stretch

C1 Charge: $2 = 1 + 0 + q_X$ (1)
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) [4]

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

C3 Check each conserved quantity in turn: charge, baryon number and each 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). [3]

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

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