



ANSWER BOOK

Quarks and antiquarks

Particles · Year 12

AQA 3.2.1.6 · CIE 11.2.1, 11.2.2, 11.2.3, 11.2.4
OCR A 6.4.2(e), 6.4.2(f), 6.4.2(g), 6.4.2(i), 6.4.2(k), 6.4.2(l)

19 questions · 52 marks

NAVY EDITION

SECTION A · Warm-up

- A1** Up quark: $+2/3 e$ (1). Down quark: $-1/3 e$ (1). [2]
- A2** Proton: up, up, down (uud) (1). Neutron: up, down, down (udd) (1). [2]
- A3** A quark has baryon number $+1/3$ (1); an antiquark has $-1/3$ (1). [2]
- A4** Strange quark: strangeness -1 (1). Anti-strange quark: strangeness $+1$ (1). [2]
- A5** The π^- is a down quark and an anti-up quark (1). Charge = $(-1/3) + (-2/3) = -1e$ (1). [2]
- A6** Charge (1); baryon number or strangeness (1). (Any two of the three.) [2]

SECTION B · Standard

- B1** Charge = $(+2/3) + (+2/3) + (-1/3)$ (1) [2]
= $+3/3 = +1e$ (1)
- B2** Charge = $(+2/3) + (-1/3) + (-1/3)$ (1) [2]
= 0 (1)
- B3** Charge = $(+2/3) + (+1/3)$ (1) [4]
= $+1e$ (the anti-down quark has charge $+1/3$) (1)
Baryon number = $(+1/3) + (-1/3)$ (1)
= 0 , confirming it is a meson (1)
- B4** An antiproton is anti-up, anti-up, anti-down (1) [3]
Charge = $(-2/3) + (-2/3) + (+1/3)$ (1)
= $-3/3 = -1e$ (1)
- B5** Baryon number $+1$ means three quarks (1). With strangeness 0 , only up ($+2/3$) [3]
and down ($-1/3$) are available, and the only trio whose charges sum to $+2$ is three up
quarks (1). Check: $3 \times (+2/3) = +2e$, so the composition is uuu (1).
- B6** Before: the down quark has charge $-1/3$. After: up ($+2/3$) + W^- (-1) (1). $(+2/3) +$ [2]
 $(-1) = -1/3$, equal to the charge before, so charge is conserved (1).

- B7** Each kaon contains exactly one strange or one anti-strange quark (1): an anti-strange quark gives the kaon strangeness +1 and a strange quark gives strangeness -1 (1). Pions are built only from up and down quarks and their antiquarks, all of which have strangeness 0 (1). [3]

SECTION C · Stretch

- C1** Inside the neutron (udd) one down quark changes into an up quark (1), turning it into a proton (uud) (1). The change emits a W^- boson (1), which becomes an electron and an electron antineutrino (1). [4]
- C2** Charge = $(+2/3) + (+1/3)$ (1) [3]
 Charge = $+1e$ (1)
 Strangeness = 0 (up) + $(+1)$ (anti-strange) = $+1$ (1)
- C3** The composition must give the neutron's zero charge (1). uud gives $+1e$ (the proton) (1), whereas udd gives $(+2/3) + (-1/3) + (-1/3) = 0$, matching the neutral neutron (1). [3]
- C4** A baryon is three quarks, with no antiquarks (baryon number +1) (1). [4]
 Strangeness -1 means exactly one strange quark, contributing charge $-1/3$ (1). The other two quarks must supply $+1/3$ between them, which one up $(+2/3)$ and one down $(-1/3)$ do (1). Composition: uds, with charge $(+2/3) + (-1/3) + (-1/3) = 0$ ✓ (1).
- C5** A baryon has baryon number +1, so it must contain three quarks and no antiquarks, since each antiquark contributes $-1/3$ (1). Among the up, down and strange quarks, only the strange quark carries strangeness, and its value is -1; the anti-strange quark (+1) is not available inside a baryon (1). A baryon's strangeness can therefore only be 0, -1, -2 or -3, never +1 (1). The claim is impossible: no such particle exists in the quark model (1). [4]
- C6** The up quark has the largest charge, $+2/3 e$ (1). A baryon is three quarks, so the maximum charge is that of uuu: $3 \times (+2/3) = +2e$ (1). Replacing any up with a down or a strange quark (both $-1/3 e$) lowers the total, so $+2e$ is the maximum (1). [3]