InkPhysics

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


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## 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 $\pi^-$ 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)
= +3/3 = +1e (1) [2]

**B2** Charge = (+2/3) + (-1/3) + (-1/3) (1)
= 0 (1) [2]

**B3** Charge = (+2/3) + (+1/3) (1)
= +1e (the anti-down quark has charge +1/3) (1)
Baryon number = (+1/3) + (-1/3) (1)
= 0, confirming it is a meson (1) [4]

**B4** An antiproton is anti-up, anti-up, anti-down (1)
Charge = (-2/3) + (-2/3) + (+1/3) (1)
= -3/3 = -1e (1) [3]

**B5** Baryon number +1 means three quarks (1). With strangeness 0, only up (+2/3) and down (-1/3) are available, and the only trio whose charges sum to +2 is three up quarks (1). Check: 3 × (+2/3) = +2e, so the composition is uuu (1). [3]

**B6** Before: the down quark has charge -1/3. After: up (+2/3) + $W^-$ (-1) (1). (+2/3) + (-1) = -1/3, equal to the charge before, so charge is conserved (1). [2]

**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)
Charge = +1e (1)
Strangeness = 0 (up) + (+1) (anti-strange) = +1 (1) [3]

**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). 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). [4]

**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 × (+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]