InkPhysics

ANSWER BOOK

Particle interactions and exchange particles

Particles · Year 12

AQA 3.2.1.4 · OCR A 6.4.2(h), 6.4.2(k)

19 questions · 53 marks

NAVY EDITION

inkphysics.co.uk

SECTION A · Warm-up

A1 The strong (nuclear) interaction and the weak (nuclear) interaction (1); the electromagnetic interaction and gravity (1). [2]

A2 The (virtual) photon (1). [1]

A3 The W^+ and W^- bosons (1). The Z boson (1). [2]

A4 (a) An electron antineutrino (1). (b) An electron neutrino (1). [2]

A5 The weak interaction, the only one that changes quark flavour (1). [1]

A6 The wavy line is the exchange particle (for example a virtual photon or a W boson) (1). Charge must balance at each junction: the total charge entering equals the total charge leaving (1). [2]

SECTION B · Standard

B1 Strong: gluons (pions between nucleons) (1). Electromagnetic: virtual photons; weak: W and Z bosons (1). Gravity: the graviton, and this is the one that is not established (1). The first three belong to the Standard Model and are tested to high precision; there is no accepted quantum theory of gravity and no graviton has ever been detected, so that entry is conjecture rather than established physics. [3]

B2 An exchange particle (a virtual particle) is emitted by one particle and absorbed by another (1). In transferring energy and momentum between them (1) it produces the effect we observe as a force; the type of exchange particle determines the interaction (1). [3]

B3 A neutron changes into a proton (1), emitting a W^- boson (1). The W^- then decays into an electron and an electron antineutrino (1). So $n \rightarrow p + W^-$, then $W^- \rightarrow e^- +$ anti-ν_e (1). [4]

B4 A proton changes into a neutron (1), emitting a W^+ boson (1), which decays into a positron and an electron neutrino: $p \rightarrow n + W^+$, then $W^+ \rightarrow e^+ + \nu_e$ (1). [3]

B5 The W^- boson (1). The electron (-1) becomes a neutrino (0), so one unit of negative charge must leave that junction with the exchange particle (1). The proton (+1) absorbs the W^- to become the neutral neutron, +1 - 1 = 0, so charge balances at both junctions (1). [3]

B6 The electromagnetic interaction (1), carried by a virtual photon (1). No quark or lepton changes flavour in this event, and flavour change is what marks out the weak interaction (1). [3]

B7 Similarity: the same overall change, a proton and an electron becoming a neutron and an electron neutrino (1). Difference: in electron capture the proton absorbs one of the atom's own inner (orbital) electrons, whereas in the collision a free, fast-moving electron strikes the proton (1). Electron capture is mediated by a W^+, emitted by the proton (1); the electron–proton collision is mediated by a W^- (1). [4]

B8 It exists only for the brief duration of the exchange (1) and it can never be observed or detected directly (1). [2]

SECTION C · Stretch

C1 The interaction is mediated by a W^+ boson (1) (a proton emits a W^+ and becomes a neutron (1); the W^+ is absorbed by the electron (1)). Overall: $p + e^- \rightarrow n + \nu_e$ (1). [4]

C2 The range of an interaction is linked to the mass of its exchange particle (1). The W and Z bosons are very massive, so they can only exist as virtual particles for an extremely short time (1) and travel a tiny distance, giving the weak force its very short range (1). The photon is massless, so the electromagnetic force has, in principle, infinite range (1). [4]

C3 Similarity: both are mediated by exchange particles (bosons) (1). Difference: the electromagnetic force uses the massless photon (long range) (1), whereas the weak force uses the massive W and Z bosons (very short range) (1). [3]

C4 Event 1: a lepton changes flavour (a muon becomes an electron), which only the weak interaction can do (1); the exchange particle is a W boson (1). Event 2: no flavour changes and two charged particles deflect one another, so the interaction is electromagnetic (1); the exchange particle is a virtual photon (1). [4]

C5 First stage: $+1 \rightarrow 0 + (+1) = +1$ ✓ (1). Second stage: $+1 \rightarrow +1 + 0 = +1$ ✓ (1). Overall, $p \rightarrow n + e^+ + \nu_e$ conserves charge: $+1 \rightarrow 0 + 1 + 0 = +1$ (1). [3]