

AQA AS Antiparticles, Annihilation and Fundamental Interactions worksheet

35-40 minutes independent practice + 15-20 minutes review | 40 marks

Specification points covered

- 3.2.1.3(a-c) Relate particles to antiparticles by mass, charge and rest energy, and identify common antiparticles.
- 3.2.1.3(d-e) Use the photon model and $E = hf = hc/\lambda$.
- 3.2.1.3(f) Describe annihilation and pair production and calculate the energies involved from supplied data.
- 3.2.1.4(a-c) Name the four fundamental interactions and describe exchange particles, including virtual photons.
- 3.2.1.4(d-f) Describe weak processes, identify W^+ and W^- bosons, and draw or interpret simple particle-interaction diagrams.

Antimatter and neutrino detector commissioning

A facility is checking an antihydrogen trap, pair-production detector, weak-interaction records and PET timing electronics. Conserve charge, energy, momentum, baryon number and lepton number explicitly; label exchange particles only after checking each vertex.

1. Antiparticles and rest energy

1. State what is meant by an antiparticle. Give two properties in your answer. [2 marks]

2. Name the antiparticle of the electron, proton, neutron and electron neutrino. For each pair, state one property that changes sign. [4 marks]

3. The rest energy of an electron or positron is 0.511 MeV. Calculate the minimum photon energy needed to create an electron-positron pair, first in MeV and then in joules. [3 marks]

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2. Annihilation, photons and pair production

4. An electron and positron annihilate from rest. Explain why two gamma photons are produced in opposite directions and state the energy of each photon. [3 marks]

5. Calculate the frequency and wavelength of a 0.511 MeV photon. Use $h = 6.63 \times 10^{-34} \text{ J s}$, $c = 3.00 \times 10^8 \text{ m s}^{-1}$ and $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$. [3 marks]

6. A gamma photon of energy 1.40 MeV produces an electron-positron pair. Calculate the total kinetic energy after creation and the kinetic energy of each particle if it is shared equally. [2 marks]

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3. Fundamental interactions

7. Four observations are made: a test mass falls; two electrons repel; neighbouring nucleons bind; a neutron undergoes beta-minus decay. Identify the fundamental interaction responsible for each observation. [2 marks]

8. State the exchange particle associated with: (a) the electromagnetic interaction; (b) the strong nuclear interaction between nucleons; (c) the weak interaction. [3 marks]

9. Explain why a single photon cannot produce an electron-positron pair in empty space, and state the role of a nearby nucleus. [2 marks]

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4. Weak-interaction diagrams

10. Draw a simple particle-interaction diagram for beta-minus decay at quark level. Show the incoming and outgoing quarks, the W boson, the electron and the electron antineutrino. [4 marks]

Particle-interaction diagram space

11. In electron capture, an electron and a proton produce a neutron and an electron neutrino. Describe the quark change and explain how a charged W boson transfers charge between the two vertices. [4 marks]

12. A detector records $e^- + p \rightarrow \nu_e + n$. Show that charge, baryon number and electron-lepton number are conserved, and identify the fundamental interaction. [4 marks]

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5. Unfamiliar application

13. In a PET scanner, an electron and positron annihilate inside a head of diameter 0.240 m. Explain why detectors on opposite sides are triggered. Calculate the greatest possible difference in arrival times at two opposite detectors, assuming the annihilation lies on their diameter and gamma photons travel at $3.00 \times 10^8 \text{ m s}^{-1}$. [4 marks]

Review and improve

- ☐ I distinguish same rest mass from opposite charge or quantum number.
- ☐ I apply energy and momentum conservation to annihilation and pair production.
- ☐ I check charge and particle numbers at each interaction vertex.

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