

Exercise walk-through

4.7

Particles, antiparticles and conservation (statements 118–119, 121–124)

Pearson Edexcel · International A-Level · Physics

Scattering links observation to a model

Observation / symbol	Supported conclusion
Most pass nearly straight	Most atomic volume is empty
Rare large deflections	Tiny, dense, positive nucleus
A_ZX	Proton number Z ; nucleon number A ; neutrons $A - Z$

The quark–lepton model organises particles

Family	Constituents / example
Baryon	Three quarks; proton uud
Meson	Quark + antiquark; pion
Lepton / antilepton	Electron / positron
Photon	Electromagnetic quantum

Exercises 2.1·2.2

2.1 Classify a proton, pion, electron, positron and photon as baryon, meson, lepton/antilepton or neither. Give the quark content of the proton and explain its charge. [5]

proton / pion

electron / positron

photon

2.2 State two properties relating a charged particle and its antiparticle. Explain why “a neutral particle has no different antiparticle” is not a reliable rule. Describe how the quark model’s family pattern supported prediction of the top quark. [4]

particle

antiparticle

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proton / pion

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photon

2.1 Proton: baryon; pion: meson. Electron: lepton; positron: antilepton. Photon: neither baryon nor lepton. Proton is uud , whose charges sum $2/3 + 2/3 - 1/3 = +1$ in units of e .

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particle

antiparticle

2.2 Equal rest mass and opposite electric charge. A neutral antiparticle can have opposite additive quantum numbers, for example lepton number, despite both charges being zero. The pattern/symmetry of the established quark families suggested a missing partner with predicted properties, later tested experimentally as the top quark.

Exercise 2.3

2.3 Convert $135 \text{ MeV}/c^2$ to kilograms. A calculation predicts $2.35 \times 10^{-28} \text{ kg}$ for this particle. Calculate percentage difference relative to the converted mass. Use $c = 3.00 \times 10^8 \text{ m s}^{-1}$. [4]

$m = 135 \text{ MeV}/c^2$

3 Exam-style questions

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3 Exam-style questions

2.3 Convert MeV to joules then divide by c^2 .

$$m = \frac{E}{c^2} = \frac{135 \times 10^6 \times 1.60 \times 10^{-19} \text{ J}}{(3.00 \times 10^8 \text{ m s}^{-1})^2} = 2.40 \times 10^{-28} \text{ kg}$$

Mass. Compare to the specified reference value.

$$\% \text{ difference} = 100 \frac{|m_{\text{pred}} - m_{\text{ref}}|}{m_{\text{ref}}} = 100 \frac{|2.35 - 2.40| \times 10^{-28} \text{ kg}}{2.40 \times 10^{-28} \text{ kg}} = 2.08\%$$

Percentage difference.

Exercise 3.1

3.1 Test both $n \rightarrow p + e^- + \nu_e$ and $n \rightarrow p + e^- + \bar{\nu}_e$ against charge, baryon-number and lepton-number conservation. Identify the admissible equation under these checks and explain why conservation checks alone do not prove that any proposed interaction will occur. [5]

$n \rightarrow p + e^- + \nu_e \text{ or } n \rightarrow p + e^- + \bar{\nu}_e$

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3.1 Both equations conserve charge: $0 = +1 - 1 + 0$. Both conserve baryon number: $1 = 1 + 0 + 0$. With neutrino, final lepton number is $0 + 1 + 1 = 2$, unlike initial zero. With antineutrino, final total is $0 + 1 - 1 = 0$, so the second passes all three checks. These are necessary constraints; passing them alone does not establish the interaction mechanism or probability.

Exercise 3.2

3.2 An electron and positron annihilate with negligible initial kinetic energy and total momentum zero. Each has rest mass 9.11×10^{-31} kg. Calculate total photon energy and the energy of each photon if two are produced. Explain their directions and why a single photon cannot carry the initial total energy and momentum. [6]



initial total momentum zero

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initial total momentum zero

3.2 Both rest masses contribute.

$$E_{\text{total}} = 2m_e c^2 = 2 \times 9.11 \times 10^{-31} \text{ kg} \times (3.00 \times 10^8 \text{ m s}^{-1})^2 = 1.64 \times 10^{-13} \text{ J}$$

Total energy.

$$E_{\gamma} = \frac{E_{\text{total}}}{2} = \frac{1.6398 \times 10^{-13} \text{ J}}{2} = 8.20 \times 10^{-14} \text{ J}$$

Each energy. Photon momenta must be opposite and equal in magnitude for initial zero momentum, so energies are equal. One photon with nonzero energy has nonzero momentum and cannot alone balance initial zero momentum.

Exercise 3.3

3.3 A photon of energy 1.20 MeV creates an electron–positron pair near a nucleus. Calculate the minimum rest energy needed and the maximum energy available as kinetic energy of the pair if nuclear recoil energy is negligible. Explain the nucleus's role and why $p = mv$ cannot be used for the incident photon. State the baryon and lepton totals before and after pair creation. [6]

photon 1.20 MeV



nucleus

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photon 1.20 MeV



nucleus

3.3 Both rest masses are required.

$$E_{\min} = 2m_e c^2 = 2 \times 9.11 \times 10^{-31} \text{ kg} \times (3.00 \times 10^8 \text{ m s}^{-1})^2 = 1.64 \times 10^{-13} \text{ J}$$

$$E_{\min} = \frac{2m_e c^2}{1.60 \times 10^{-13} \text{ J per MeV}} = \frac{1.6398 \times 10^{-13} \text{ J}}{1.60 \times 10^{-13} \text{ J per MeV}} = 1.025 \text{ MeV}$$

Threshold approximately 1.02 MeV.

$$E_{k,\max} = E_\gamma - 2m_e c^2 = (1.20 - 1.024875) \text{ MeV} = 0.175 \text{ MeV}$$