

4.7 Particles, antiparticles and conservation

Name: _____ Class: _____ Date: _____

Total: 30 marks

KEY WORDS quark–lepton model – • baryon • meson • lepton • antiparticle
 • Mass–energy equivalence • pair production • annihilation

Objective

Develop the methods for particles, antiparticles and conservation before the curated WPH14 questions. Use $g = 9.81 \text{ m s}^{-2}$ where needed. These are original training questions, not copied past-paper questions.

1 Key knowledge and worked examples

■ Families and antiparticles

In the **quark–lepton model** –, baryons and mesons contain quarks. Leptons are fundamental particles in the model.

- A **baryon** contains three quarks, for example a proton uud or neutron udd . An antibaryon contains three antiquarks.
- A **meson** contains one quark and one antiquark, for example a pion.
- A **lepton** is fundamental, for example an electron or neutrino. A positron is an antilepton, not a meson.
- A photon is the quantum of electromagnetic radiation; it is neither a baryon nor a lepton.

Up-type quarks have charge $+2e/3$ and down-type quarks $-e/3$. Antiquarks have opposite charges. For example, uud sums to $+e$ and udd to zero. The symmetry of the quark families predicted a top quark before it was observed. Classification models make testable predictions, not just lists of known particles.

An **antiparticle** has the same rest mass as its particle and opposite electric charge when charged. Other relevant additive quantum numbers also reverse. An electron has lepton number $+1$; its positron has -1 . Both have baryon number zero. A neutral antiparticle can differ in quantum numbers despite having no electric charge.

■ Check conserved totals

Assign baryon number +1 to a baryon, −1 to an antibaryon, and zero to mesons/leptons/photons. Quarks carry +1/3 and antiquarks −1/3. Assign lepton number +1 to a lepton and −1 to an antilepton. Compare total charge, baryon number and lepton number on both sides of a proposed reaction. Also check energy and momentum. Passing the listed conservation checks alone does not prove that an interaction will occur; it establishes that those laws do not forbid it.

Worked example. Test $n \rightarrow p + e^- + \bar{\nu}_e$.

Quantity	Before	After
Charge / e	0	$+1 - 1 + 0 = 0$
Baryon number	1	$1 + 0 + 0 = 1$
Lepton number	0	$0 + 1 - 1 = 0$

The antineutrino balances the electron's lepton number. Changing it to a neutrino would make the final total +2, so that proposed equation would fail this check. Preserve bars and charge signs when interpreting supplied particle symbols.

■ Rest energy, creation and annihilation

Mass–energy equivalence relates a rest-mass change to energy:

$$\Delta E = c^2 \Delta m$$

In **pair production**, energy creates a particle–antiparticle pair. The energy must at least supply both rest masses; extra energy can become kinetic energy or recoil. Momentum must also be conserved, so the surrounding interaction matters. In **annihilation**, particle and antiparticle can turn into photons. A pair initially at rest producing two photons gives equal photon energies and opposite momenta. Each photon carries one particle's rest energy for an equal-mass pair; the total is twice that value.

One electronvolt is e joules: $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$. MeV means 10^6 eV and GeV means 10^9 eV . A quoted mass in MeV/c^2 is a mass unit, not an energy unit. Multiply by c^2 to get its corresponding rest energy.

Worked example. Convert a mass of $140 \text{ MeV}/c^2$ to kilograms.

$$mc^2 = 140 \times 10^6 \times 1.60 \times 10^{-19} \text{ J} = 2.24 \times 10^{-11} \text{ J}$$

$$m = \frac{E}{c^2} = \frac{2.24 \times 10^{-11} \text{ J}}{(3.00 \times 10^8 \text{ m s}^{-1})^2} = 2.49 \times 10^{-28} \text{ kg}$$

Use the same units before comparing masses. Percentage difference from an accepted value is $100 \times |m_{\text{predicted}} - m_{\text{accepted}}| / m_{\text{accepted}}$. State the reference value. In threshold questions, distinguish rest-energy supply from kinetic energy; do not use $p = mv$ for a photon or a particle close to c .

2 Practice

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

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

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]

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

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

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


