InkPhysics

QUESTION WORKBOOK

Antimatter and photons

Particles · Year 12

AQA 3.2.1.3 · CIE 11.1.8 · OCR A 6.4.2(a), 6.4.2(b), 6.4.4(c)

19 questions · 57 marks

NAVY SCREEN EDITION

SECTION A · Warm-up

A1 Compare a particle and its antiparticle in terms of mass and charge. [2]

A2 A photon has a frequency of 1.0×10^{15} Hz. Calculate its energy ($h = 6.63 \times 10^{-34}$ J s). [2]

A3 Describe what happens in annihilation. [2]

A4 State what is meant by the rest energy of a particle, and give the rest energy of the electron in MeV. [2]

A5 Name the antiparticle of each of the following: the electron, the proton, the electron neutrino. [2]

A6 Explain why the annihilation of an electron–positron pair produces two photons rather than one. [2]

SECTION B · Standard

B1 Calculate the energy of a photon of wavelength 500 nm ($c = 3.0 \times 10^8$ m s^{-1}). [2]

B2 Calculate the minimum energy, and hence the minimum photon frequency, needed for pair production of an electron and a positron ($m_e = 9.11 \times 10^{-31}$ kg, $c = 3.0 \times 10^8$ m s^{-1}). [4]

B3 An electron and a positron, effectively at rest, annihilate to produce two identical photons. Calculate the energy and frequency of each photon. [3]

B4 A photon has an energy of 6.63×10^{-19} J. Calculate the photon energy in electronvolts ($e = 1.60 \times 10^{-19}$ C). [2]

B5 A dental X-ray set produces photons of energy 60 keV. Calculate the wavelength of these photons ($h = 6.63 \times 10^{-34}$ J s, $c = 3.0 \times 10^{8}$ m s^{-1}, $e = 1.60 \times 10^{-19}$ C). [3]

B6 A laser pointer emits light of wavelength 650 nm with a power of 1.5 mW. Calculate the number of photons it emits each second ($h = 6.63 \times 10^{-34}$ J s, $c = 3.0 \times 10^{8}$ m s^{-1}). [3]

B7 A gamma photon has a wavelength of 2.0×10^{-12} m. Show that the energy of the photon is about 0.6 MeV. Go on to deduce whether this photon could produce an electron–positron pair. The rest energy of the electron is 0.511 MeV ($h = 6.63 \times 10^{-34}$ J s, $c = 3.0 \times 10^{8}$ m s^{-1}, $e = 1.60 \times 10^{-19}$ C). [4]

SECTION C · Stretch

C1 A photon of energy 2.0 MeV passes close to a heavy nucleus and produces an electron–positron pair. The nucleus recoils, taking up momentum but a negligible share of the energy. Given that the rest energy of each particle is 0.511 MeV, calculate the total kinetic energy shared by the two particles, in joules, and state why the nucleus has to be there. [4]

C2 Calculate the maximum wavelength of a photon that can create an electron–positron pair beside a nucleus (rest energy of the pair = 1.022 MeV). [4]

C3 Explain why pair production normally occurs in the presence of a nearby nucleus. [3]

C4 A gamma photon of energy 200 MeV passes close to a nucleus. Deduce which, if any, of the following pairs it could create: an electron–positron pair, a muon–antimuon pair, a proton–antiproton pair. Rest energies: electron 0.511 MeV, muon 105.7 MeV, proton 938.3 MeV. [4]

C5 A positron with 0.35 MeV of kinetic energy annihilates with an electron that is effectively at rest. Calculate the total energy of the photons produced, in joules. The rest energy of the electron is 0.511 MeV ($e = 1.60 \times 10^{-19}$ C). [3]

C6 A student states that mass is always conserved. Discuss this statement with reference to annihilation and to pair production. In your answer you should describe both processes and give the minimum energies involved for an electron–positron pair (rest energy of the electron = 0.511 MeV). [6]