3.2 Particles and Radiation: Test Pack

AQA 7408 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 This question tests core definitions used when classifying particles and applying conservation laws.

(a) State the baryon number of a meson and the baryon number of a baryon. **(1)**

(b) State the lepton number assigned to an electron antineutrino, and the lepton number assigned to a positron. **(1)**

(c) In the nuclide notation $^{A}_{Z}X$, state what the symbols A and Z represent. **(1)**

(Total for Question 1 is 3 marks)

---

2 This question concerns the exchange particles and ranges of the fundamental forces.

(a) State the name of the exchange (gauge boson) particle associated with the strong nuclear force between quarks. **(1)**

(b) According to theory, state the name of the (as yet unobserved) exchange particle predicted to be associated with the gravitational force. **(1)**

(c) Two protons inside a nucleus are separated by a distance of about 1×10^{-15} m (1 fm), while two protons in neighbouring atoms are typically separated by distances of order 1×10^{-10} m (0.1 nm) or more. Explain why the strong nuclear force must dominate over the electromagnetic repulsion between the two protons inside the nucleus, but has no significant effect on the structure of atoms at this larger atomic scale. **(3)**

(Total for Question 2 is 5 marks)

© Revision Library | revisionlibrary.co.uk

3 Radioactive decay must obey conservation laws. Nuclide notation $^{A}_{Z}X$ is used throughout, where A is the mass (nucleon) number and Z is the atomic (proton) number.

(a) A nucleus of uranium-238, ^238_92 U, decays by α emission to form a nucleus of thorium. State the mass number and the atomic (proton) number of the thorium nuclide produced. **(2)**

(b) Carbon-14, ^14_6 C, undergoes β-minus decay to form nitrogen-14. Write a balanced nuclear equation for this decay, including correct nuclide notation for the nitrogen nucleus, the β particle and the antineutrino produced. **(3)**

(c) State two conservation laws, other than conservation of charge and conservation of nucleon (mass) number, that must be obeyed in this β-minus decay. **(2)**

(Total for Question 3 is 7 marks)

---

4 A clean zinc surface has a work function of 6.90×10^{-19} J. Take $h = 6.63 \times 10^{-34}$ Js, $c = 3.00 \times 10^{8}$ m/s and $e = 1.60 \times 10^{-19}$ C.

(a) State what is meant by the work function of a metal surface. **(1)**

(b) Calculate the threshold frequency for photoemission from zinc, using E = hf. **(2)**

(c) Calculate the threshold wavelength corresponding to this frequency, and explain why visible light (wavelength range approximately 400-700 nm) cannot cause photoemission from zinc. **(2)**

(d) Ultraviolet light of wavelength 200 nm is now shone onto the zinc surface. Calculate the maximum kinetic energy of the emitted photoelectrons, in J. **(3)**

(e) Calculate the stopping potential needed to stop the fastest photoelectrons emitted in part (d) from reaching the collector. **(2)**

(Total for Question 4 is 10 marks)

© Revision Library | revisionlibrary.co.uk

5 Jamal investigates the photoelectric effect using a clean sodium surface. The work function of sodium is 3.65×10^{-19} J. Use the Physics Equations Sheet for E = hf. h = 6.63×10^{-34} Js.

(a) State what is meant by the threshold frequency of a metal surface in the photoelectric effect. **(1)**

(b) Calculate the threshold frequency of sodium, using E = hf. **(2)**

(c) Light of frequency 8.00×10^{14} Hz is incident on the sodium surface. Calculate the maximum kinetic energy of the emitted photoelectrons, using $E_{k(max)} = hf - \varphi$. **(3)**

(d) The observation that no photoelectrons are emitted below the threshold frequency, however intense the light, cannot be explained by the wave theory of light. Explain why this observation supports the photon (particle) model of electromagnetic radiation instead. **(3)**

(Total for Question 5 is 9 marks)

---

6 Radium-226 decays by α emission to radon-222: Ra-226 -> Rn-222 + α. The atomic masses are: radium-226 = 226.0254 u, radon-222 = 222.0175 u, α particle = 4.0026 u. Take 1 u = 1.66×10^{-27} kg and c = 3.00×10^{8} m/s. 1 MeV = 1.60×10^{-13} J.

(a) State what is meant by the mass defect of a nuclear decay. **(1)**

(b) Calculate the mass defect of this decay, in kg. **(3)**

(c) Use $E = mc^2$ to calculate the total energy released in this decay, in MeV. **(3)**

(d) This energy is shared as kinetic energy between the α particle and the recoiling radon-222 nucleus, with no other particles emitted. Explain, using conservation of momentum, why the α particle gains most of this kinetic energy. **(2)**

(Total for Question 6 is 9 marks)

© Revision Library | revisionlibrary.co.uk

Mark scheme · 3.2 Particles and Radiation: Test Pack

Question 1

(a) meson baryon number = 0 and baryon baryon number = +1 (both required) oe **B1**

(a) Answer: Meson baryon number = 0; baryon baryon number = +1

(b) electron antineutrino lepton number = -1 and positron lepton number = -1 (both required) oe **B1**

(b) Answer: Electron antineutrino lepton number = -1; positron lepton number = -1

(c) A = nucleon (mass) number, total number of protons and neutrons; Z = proton (atomic) number, number of protons (both required) oe **B1**

(c) Answer: A = nucleon (mass) number; Z = proton (atomic) number

Question 2

(a) gluon **B1**

(a) Answer: Gluon

(b) graviton **B1**

(b) Answer: Graviton

(c) at nuclear separations (about 1 fm) the strong nuclear force between the protons is attractive and stronger than their electromagnetic (Coulomb) repulsion, which is why the nucleus stays bound rather than flying apart **M1**

(c) the strong nuclear force has a very short range (of the order of a few fm) and falls to a negligible size beyond this range **M1**

(c) at atomic separations (about 0.1 nm, roughly 100000 times larger than a fm) the strong force has fallen to essentially zero, so only the long-range electromagnetic force acts, meaning atomic structure is governed by the electromagnetic force, not the strong force **A1**

(c) Answer: The strong force is short-range and dominates only at nuclear separations; at atomic separations it is negligible and only the electromagnetic force acts

Question 3

(a) mass number = 234 **B1**

(a) atomic number = 90 **B1**

(a) Answer: Mass number 234, atomic number 90 (thorium-234, ^234_90 Th).

(b) correct nitrogen nuclide: ^14_7 N **B1**

(b) correct β particle notation: ^0_-1 e (an electron) **B1**

(b) correct inclusion of an electron antineutrino on the right-hand side (symbol for antineutrino$_e$, with mass and charge number both zero) **B1**

(b) Answer: ^14_6 C -> ^14_7 N + ^0_-1 e + antineutrino$_e$

(c) conservation of lepton number **B1**

(c) conservation of energy (and momentum) oe **B1**

(c) Answer: Conservation of lepton number; conservation of energy and momentum.

Question 4

(a) the minimum energy needed to remove an electron from the surface of the metal, giving it zero kinetic energy just outside the surface oe **B1**

(a) Answer: The minimum energy needed to remove an electron from the metal surface

(b) correct substitution into f0 = φ / h **M1**

(b) 1.04 x 10^{15} Hz, cao **A1**

(b) Answer: 1.04 x 10^{15} Hz

(c) lambda0 = c / f0, ft from (b), giving 2.88 x 10^{-7} m (288 nm) **M1**

(c) this wavelength lies in the ultraviolet, shorter than the visible range, so visible photons have less energy than the threshold energy and cannot release photoelectrons however intense the light oe **A1**

(c) Answer: 2.88 x 10^{-7} m (288 nm), which is in the ultraviolet

(d) calculate f = c / λ = 1.50 x 10^{15} Hz **M1**

(d) substitute into Ek(max) = hf - φ **M1**

(d) 3.05 x 10^{-19} J (accept 3.0-3.1 x 10^{-19} J), awrt **A1**

(d) Answer: 3.05 x 10^{-19} J

(e) substitute into Vs = Ek(max) / e, ft from (d) **M1**

(e) 1.90 V (ft), cao **A1**

(e) Answer: 1.90 V

© Revision Library | revisionlibrary.co.uk

Question 5

(a) the minimum frequency of incident electromagnetic radiation that will just cause photoelectrons to be emitted from the surface oe **B1**

(a) Answer: The minimum frequency of light needed to release photoelectrons from the surface.

(b) rearranges and substitutes: $f0 = \varphi/h = 3.65 \times 10^{-19} / 6.63 \times 10^{-34}$ **M1**

(b) 5.51×10^{14} Hz (awrt, cao) **A1**

(b) Answer: 5.51×10^{14} Hz

(c) $hf = 6.63 \times 10^{-34} \times 8.00 \times 10^{14} = 5.304 \times 10^{-19}$ J **M1**

(c) $Ek(max) = 5.304 \times 10^{-19} - 3.65 \times 10^{-19}$ **M1**

(c) 1.65×10^{-19} J (awrt, cao) **A1**

(c) Answer: 1.65×10^{-19} J

(d) wave theory predicts that energy is spread continuously across the wavefront, and that increasing the intensity delivers more energy per second regardless of frequency, so given enough time or intensity any frequency should eventually release electrons **B1**

(d) experimentally, no electrons are emitted below the threshold frequency no matter how intense the light or how long the surface is exposed **B1**

(d) the photon model explains this because each photon carries a fixed, discrete energy hf, and a single electron absorbs the energy of a single photon; if hf is less than the work function, no individual photon can ever release an electron, regardless of the number of photons (intensity) **B1**

(d) Answer: Wave theory predicts electrons should eventually be released at any frequency given enough intensity or time, but experimentally none are emitted below f0. The photon model explains this because each photon delivers a fixed energy hf to one electron; if hf < φ, no photon can release an electron no matter how many arrive.

Question 6

(a) the difference between the total mass of the parent nucleus and the total mass of the decay products, which is converted into the energy released in the decay oe **B1**

(a) Answer: The difference between the mass of the parent nucleus and the total mass of the products

(b) mass defect in u = 226.0254 - 222.0175 - 4.0026 = 0.0053 u **M1**

(b) convert to kg using $1 u = 1.66 \times 10^{-27}$ kg **M1**

(b) 8.80×10^{-30} kg, cao **A1**

(b) Answer: 8.80×10^{-30} kg

(c) substitute mass defect from (b) into $E = mc^2$, ft **M1**

(c) compute E in J: $8.80 \times 10^{-30} \times (3.00 \times 10^8)^2 = 7.92 \times 10^{-13}$ J **M1**

(c) convert to MeV using $1 MeV = 1.60 \times 10^{-13}$ J to give 4.95 MeV (accept 4.9-5.0 MeV), ft **A1**

(c) Answer: 4.95 MeV

(d) the radium nucleus starts at rest, so total momentum after decay is zero; the α particle and the radon-222 nucleus must therefore recoil with equal and opposite momenta **B1**

(d) since kinetic energy = $p^2 / (2m)$ for a given magnitude of momentum, the much lighter α particle has a correspondingly much greater kinetic energy than the far more massive radon-222 nucleus oe **B1**

(d) Answer: Equal and opposite momenta mean the lighter α particle carries far more kinetic energy than the heavy recoiling nucleus

© Revision Library | revisionlibrary.co.uk