3.8 Nuclear Physics: Test Pack

AQA 7408 · Calculator allowed · about 50 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Radioactive sources are described using nuclide notation and classified by the type of radiation they emit.

(a) State what is meant by an isotope. **(2)**

(b) An atom of radon has the notation ^222_86 Rn. State the number of protons, neutrons and electrons in a neutral atom of this isotope. **(3)**

(c) State the order of penetrating power of α, β-minus and γ radiation, from most to least penetrating, and state one material that will substantially stop each type. **(3)**

(d) A radium-226 nucleus (proton number 88) decays by α emission to form a nucleus of radon. Write a balanced nuclear equation for this decay, using correct nuclide notation. **(2)**

(Total for Question 1 is 10 marks)

2 A sample of technetium-99m used in medical imaging has a half-life of 6.0 hours. A hospital receives a sample with an initial activity of 6.4×10^{9} Bq. Use $A = \lambda N$ and $A = A_0 \exp(-\lambda t)$, where $\lambda = \ln 2 / (\text{half-life})$.

(a) Show that the decay constant of technetium-99m is 3.2×10^{-5} per second. **(3)**

(b) Calculate the number of technetium-99m nuclei present in the sample when it is received. **(2)**

(c) Calculate the activity of the sample 24 hours after it is received. **(3)**

(d) The random nature of radioactive decay means individual nuclear decays cannot be predicted. Explain what is meant by this, and why activity calculations such as part (c) can still give reliable predictions for a macroscopic sample. **(2)**

(Total for Question 2 is 10 marks)

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3 Radium-226 (proton number 88) decays by α emission to radon. Separately, sodium-22 (proton number 11) decays by β-plus (positron) emission to neon-22 (proton number 10).

(a) Complete the nuclear equation for the α decay of radium-226: (226,88)Ra -> (?,?)Rn + (4,2)He. State the nucleon number and proton number of the radon nucleus produced. **(2)**

(b) Complete the nuclear equation for the β-plus decay of sodium-22 to neon-22: (22,11)Na -> (22,10)Ne + positron + X. Identify particle X, and state why it must be included for the equation to balance. **(3)**

(c) Explain, in terms of the fundamental particles involved, what happens to a proton inside the nucleus during β-plus decay. **(2)**

(Total for Question 3 is 7 marks)

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4 A lithium-7 nucleus (3 protons, 4 neutrons) has a nuclear mass of 7.01435 u. The mass of a free proton is 1.00728 u and the mass of a free neutron is 1.00867 u. Take 1 u = 931.5 MeV/c^2.

(a) Calculate the total mass of the separate, unbound nucleons that make up a lithium-7 nucleus. **(2)**

(b) Calculate the mass defect of the lithium-7 nucleus. **(2)**

(c) Calculate the binding energy of the lithium-7 nucleus, in MeV. **(3)**

(d) Calculate the binding energy per nucleon of lithium-7. **(2)**

(Total for Question 4 is 9 marks)

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Mark scheme · 3.8 Nuclear Physics: Test Pack

Question 1

(a) atoms (nuclei) of the same element, with the same number of protons (same proton/atomic number), oe **B1**

(a) with different numbers of neutrons (different nucleon/mass numbers), oe **B1**

(a) Answer: Atoms of the same element (same number of protons) with different numbers of neutrons (different mass numbers).

(b) protons = 86 **B1**

(b) neutrons = 136 (222 - 86) **B1**

(b) electrons = 86 (equal to protons, since the atom is neutral) **B1**

(b) Answer: 86 protons, 136 neutrons, 86 electrons.

(c) correct order: γ most penetrating, then β, then α least penetrating **B1**

(c) α is stopped by a sheet of paper (or a few cm of air); β is stopped by a few mm of aluminium **B1**

(c) γ requires several cm of thick lead (or thick concrete) to substantially reduce its intensity, oe **B1**

(c) Answer: Gamma > β > α in penetrating power. Alpha stopped by paper; β stopped by a few mm of aluminium; γ needs thick lead (or concrete) to reduce it substantially.

(d) nucleon number and proton number balance correctly (226 = 222 + 4 and 88 = 86 + 2) **B1**

(d) correct nuclide symbols for the products: ^222_86 Rn and ^4_2 He **B1**

(d) Answer: ^226_88 Ra -> ^222_86 Rn + ^4_2 He

Question 2

(a) half-life converted to seconds: 6.0 x 3600 = 21600 s **M1**

(a) $\lambda = \ln 2 / 21600$ correctly substituted **M1**

(a) $\lambda = 3.2 \times 10^{-5}\ s^{-1}$ (cso, answer given) **A1**

(a) Answer: $\lambda = 3.2 \times 10^{-5}\ s^{-1}$

(b) N0 = A0 / λ correctly substituted, ft from (a) **M1**

(b) $N0 = 2.0 \times 10^{14}$ (awrt) **A1**

(b) Answer: 2.0×10^{14} nuclei

(c) t converted to seconds (86400 s) and substituted with λ into A = A0 exp(-λ t) **M1**

(c) exponent evaluated correctly: λ t = 2.77, giving exp(-2.77) = 0.0625 (equivalent to 4 half-lives, factor of 1/16) **M1**

(c) $A = 4.0 \times 10^{8}$ Bq (awrt, ft from (a)) **A1**

(c) Answer: 4.0×10^{8} Bq

(d) it is impossible to predict which nucleus, or when any particular (individual) nucleus, will decay; each nucleus has the same constant probability of decaying per unit time, oe **B1**

(d) because the sample contains a very large number of nuclei, the average (statistical) behaviour of the whole sample follows the exponential decay law reliably, even though individual decays are random, oe **B1**

(d) Answer: Individual nuclear decay is random and unpredictable, but with a very large number of nuclei the overall (average) decay rate is predictable and follows the exponential law reliably.

Question 3

(a) nucleon number conserved: 226 = A + 4, so A(Rn) = 222 **M1**

(a) proton number conserved: 88 = Z + 2, so Z(Rn) = 86 cao **A1**

(a) Answer: Radon-222 (nucleon number 222, proton number 86)

(b) X is an electron neutrino cao **B1**

(b) without X, energy (and momentum) would not be conserved between the different possible energies/directions of the emitted positron for a fixed total energy release oe **B1**

(b) including the (near massless, chargeless) neutrino also correctly conserves lepton number and charge in the decay oe **B1**

(b) Answer: X is an electron neutrino; it is needed so that energy, momentum and lepton number are all conserved in the decay (the positron alone is observed with a range of energies, which would violate conservation of energy without a third particle sharing the energy released).

(c) a proton (an up-up-down combination of quarks) is converted into a neutron (up-down-down) **B1**

(c) with the emission of a positron and an electron neutrino, i.e. p -> n + positron + electron neutrino oe **B1**

(c) Answer: A proton is converted into a neutron, with the emission of a positron and an electron neutrino: p -> n + positron + neutrino.

Question 4

(a) mass = (3 x 1.00728) + (4 x 1.00867) **M1**

(a) mass = 7.05652 u cao **A1**

(a) Answer: 7.05652 u

(b) mass defect = 7.05652 - 7.01435 **M1**

(b) mass defect = 0.04217 u cao **A1**

(b) Answer: 0.04217 u

(c) quote binding energy = mass defect x 931.5 MeV per u **M1**

(c) substitute BE = 0.04217 x 931.5 **M1**

(c) BE = 39.3 MeV cao **A1**

(c) Answer: 39.3 MeV

(d) BE per nucleon = 39.3 / 7 **M1**

(d) BE per nucleon = 5.61 MeV cao **A1**

(d) Answer: 5.61 MeV

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