3.8 Nuclear Physics: 30-minute Pack

AQA 7408 · Calculator allowed · about 30 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 This question tests core definitions in nuclear physics.

(a) Define the decay constant of a radioactive isotope. **(1)**

(b) State the equation linking the activity A of a source, its decay constant λ, and the number of undecayed nuclei N. **(1)**

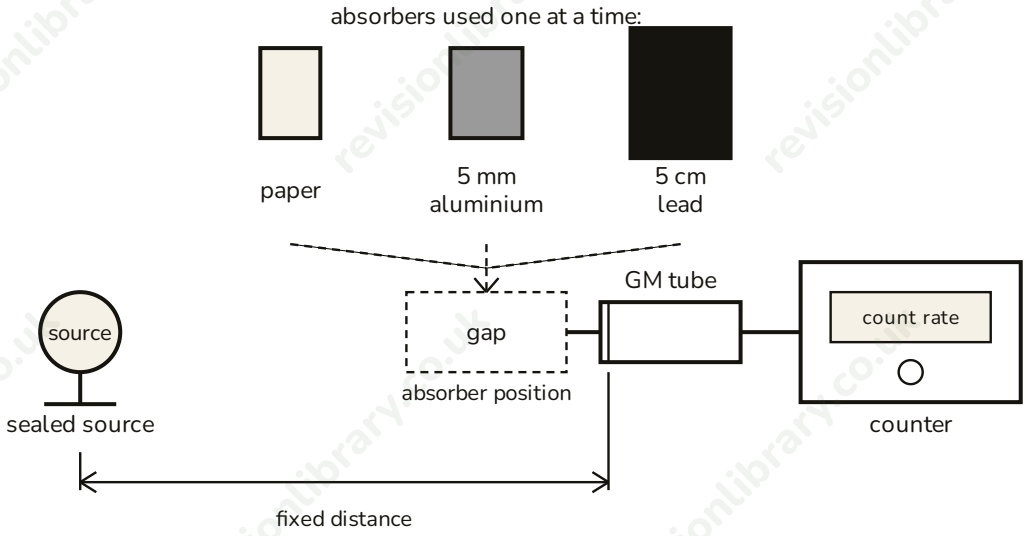
(c) State two properties of the strong nuclear force. **(1)**

(Total for Question 1 is 3 marks)

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2 Required practical: a student uses a GM tube and counter to investigate the absorption of radiation from a sealed, unknown radioactive source, placing different absorbers between the source and the tube at a fixed distance. The background count rate, measured with no source present, is 22 counts per minute. The student's results are shown below.

Absorber used	Measured count rate / counts per minute
None	850
Paper	845
5 mm aluminium	210
5 cm lead	26



(a) Explain why the student should measure the background count rate before the experiment, and explain how this measurement should be used with the readings in the table. **(2)**

(b) Determine the corrected count rate for each absorber, and use these values to identify the type(s) of radiation emitted by the source, justifying your answer using the data. **(4)**

(c) State one precaution, other than repeating readings, that the student should take to improve the reliability of each count rate measurement. **(1)**

(Total for Question 2 is 7 marks)

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3 An archaeological wood sample has a measured activity per unit mass of carbon of 6.9 disintegrations per minute per gram. Living wood has an activity per unit mass of carbon of 15.0 disintegrations per minute per gram. The half-life of carbon-14 is 5730 years. Use $A = A0 \exp(-\lambda t)$, where $\lambda = \ln 2 / (\text{half-life})$.

(a) Show that the decay constant of carbon-14 is about 1.21×10^{-4} per year. **(2)**

(b) Calculate the age of the wood sample. **(4)**

(c) The sample is later found to have been contaminated with a small amount of modern carbon during excavation. State and explain the effect this contamination would have on the calculated age of the sample compared with its true age. **(2)**

(Total for Question 3 is 8 marks)

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4 Mass of proton = 1.00728 u, mass of neutron = 1.00867 u, mass of a helium-4 nucleus = 4.00151 u. 1 u is equivalent to 931.5 MeV of energy.

(a) Show that the mass defect of a helium-4 nucleus is 0.0304 u. **(2)**

(b) Calculate the binding energy of the helium-4 nucleus in MeV, and hence the binding energy per nucleon. **(4)**

(c) State why binding energy per nucleon, rather than total binding energy, is used to compare the stability of different nuclides. **(1)**

(Total for Question 4 is 7 marks)

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Mark scheme · 3.8 Nuclear Physics: 30-minute Pack

Question 1

(a) the probability of decay of an individual nucleus per unit time oe **B1**

(a) Answer: The probability that an individual nucleus will decay per unit time.

(b) A = λ N cao **B1**

(b) Answer: A = λ N

(c) any two of: short range (acts only over a few femtometres); attractive at typical nucleon separations (and repulsive at very short range); acts equally between all nucleons regardless of charge (charge-independent) oe **B1**

(c) Answer: It has a very short range (a few femtometres) and it acts equally between all nucleons regardless of charge (charge-independent).

Question 2

(a) background radiation (e.g. from cosmic rays and rocks) is present at all times and would be added to (counted along with) the readings from the source, oe **B1**

(a) the background count rate (22 counts per minute) must be subtracted from each measured reading to give the corrected count rate due to the source alone, oe **B1**

(a) Answer: Background radiation adds to every reading, so 22 counts per minute must be subtracted from each measured value to find the count rate due to the source alone.

(b) corrected count rates calculated: none = 828, paper = 823, aluminium = 188, lead = 4 (counts per minute) **B1**

(b) no detectable α component, since the count rate barely changes when paper is added (828 to 823); α emission cannot be ruled out because the sealed source casing or intervening air could absorb α particles, oe **B1**

(b) β radiation is emitted, since the count rate falls greatly when aluminium is added (823 to 188), showing β particles are being absorbed, oe **B1**

(b) γ radiation is emitted, since the count rate only falls to (near) background level once thick lead is added (188 to 4), showing γ radiation was passing through the paper and aluminium but is absorbed by lead, oe **B1**

(b) Answer: Corrected count rates: 828, 823, 188, 4 counts per minute. The source emits β and γ radiation, with no detectable α component; α emission cannot be ruled out.

(c) count for a long time period (e.g. several minutes) at each absorber, to reduce the percentage (statistical) uncertainty caused by the random nature of radioactive decay, oe **B1**

(c) Answer: Count for a long time period at each setting, to reduce the statistical uncertainty in the count rate.

Question 3

(a) λ = ln2 / 5730 correctly substituted **M1**

(a) $\lambda = 1.21 \times 10^{-4}$ per year (cso, answer given) **A1**

(a) Answer: $\lambda = 1.21 \times 10^{-4}$ per year

(b) equation rearranged: ln(A0 / A) = λ t, oe **M1**

(b) correct substitution: ln(15.0 / 6.9) = 0.777 (or ln(6.9/15.0) = -0.777) **M1**

(b) $t = 0.777 / (1.21 \times 10^{-4})$, ft from (a) **A1**

(b) $t = 6.4 \times 10^{3}$ years (awrt, allow 6300 to 6500 years) **A1**

(b) Answer: About 6.4×10^{3} years (6400 years)

(c) the calculated age would be an underestimate (too young), oe **B1**

(c) because the modern carbon has a much higher carbon-14 activity than the old sample, it increases the measured activity above the true value for the sample's actual age, making it appear to have decayed less (and so be younger) than it really is, oe **B1**

(c) Answer: The calculated age would be too young (an underestimate), because the modern carbon raises the measured activity above the true value for the sample's real age.

Question 4

(a) total mass of separate nucleons = 2(1.00728) + 2(1.00867) = 4.0319 u **M1**

(a) mass defect = 4.0319 - 4.00151 = 0.0304 u (cso, answer given) **A1**

(a) Answer: Mass defect = 0.0304 u

(b) binding energy = mass defect x 931.5 MeV/u, ft from (a) **M1**

(b) binding energy = 28.3 MeV (awrt) **A1**

(b) binding energy per nucleon = total binding energy / 4 **M1**

(b) binding energy per nucleon = 7.08 MeV (awrt 7.1) **A1**

(b) Answer: Binding energy = 28.3 MeV; binding energy per nucleon = 7.08 MeV

(c) it allows nuclei of different sizes (different numbers of nucleons) to be compared fairly, since it represents the average energy needed to remove one nucleon, oe **B1**

(c) Answer: It gives a fair, size-independent measure of stability, as it is the average energy needed to remove one nucleon.

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