3.11 Physics: Nuclear and Particle Physics: 30-minute Pack

AQA 7408 · Calculator allowed · about 30 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 The radius R of a nucleus with nucleon (mass) number A can be modelled using $R = R0 \times A^{1/3}$, where $R0 = 1.05 \times 10^{-15}$ m. Take the mass of a nucleon to be approximately $u = 1.66 \times 10^{-27}$ kg, whatever the nuclide.

(a) Calculate the radius of a carbon-12 nucleus. Give your answer in metres to 3 significant figures. **(2)**

(b) Show that the radius of a uranium-238 nucleus is about 6.51×10^{-15} m. **(2)**

(c) By modelling each nucleus as a uniform sphere of volume $(4/3) \times \pi \times R^3$ and mass $A \times u$, calculate the density of a carbon-12 nucleus and the density of a uranium-238 nucleus, using your radii from parts (a) and (b). State what your two values show about nuclear density. **(5)**

(d) Explain how this approximately constant nuclear density supports the idea that the strong nuclear force has a very short range, acting only between neighbouring nucleons rather than between every pair of nucleons in the nucleus. **(2)**

(Total for Question 1 is 11 marks)

© Revision Library | revisionlibrary.co.uk

2 Mass of proton = 1.00728 u, mass of neutron = 1.00867 u, mass of an iron-56 nucleus = 55.9206 u. 1 u is equivalent to 931.5 MeV of energy.

(a) State what is meant by the binding energy of a nucleus. **(1)**

(b) Show that the mass defect of an iron-56 nucleus (26 protons, 30 neutrons) is about 0.529 u. **(3)**

(c) Calculate the binding energy per nucleon of iron-56, in MeV. **(2)**

(d) The graph of binding energy per nucleon against nucleon number A rises steeply from hydrogen, peaks close to iron/nickel (A about 56), then falls gradually towards the heaviest nuclides. Using this graph, explain why energy is released in both the fusion of light nuclei and the fission of heavy nuclei. **(4)**

(Total for Question 2 is 10 marks)

© Revision Library | revisionlibrary.co.uk

Mark scheme · 3.11 Physics: Nuclear and Particle Physics: 30-minute Pack

Question 1

(a) $12^{1/3} = 2.29$ (or 2.289) **M1**

(a) $R = 2.40 \times 10^{-15}$ m (awrt, cao) **A1**

(a) Answer: $R = 2.40 \times 10^{-15}$ m

(b) $238^{1/3} = 6.20$ (or 6.198) **M1**

(b) $R = 1.05 \times 10^{-15} \times 6.198 = 6.51 \times 10^{-15}$ m shown (cso, answer given) **A1**

(b) Answer: $R = 6.51 \times 10^{-15}$ m

(c) volume of carbon-12 nucleus = $(4/3) \times \pi \times (2.404 \times 10^{-15})^3 = 5.82 \times 10^{-44}$ m^3 (5.79×10^{-44} m^3 if the rounded R = 2.40×10^{-15} m is used; ecf from a) **M1**

(c) density of carbon-12 = $(12 \times 1.66 \times 10^{-27}) / 5.82 \times 10^{-44} = 3.42 \times 10^{17}$ kg/m^3 (awrt, ecf; accept 3.42 to 3.44 x 10^{17}) **A1**

(c) volume of uranium-238 nucleus = $(4/3) \times \pi \times (6.51 \times 10^{-15})^3 = 1.156 \times 10^{-42}$ m^3 (ecf from b) **M1**

(c) density of uranium-238 = $(238 \times 1.66 \times 10^{-27}) / 1.156 \times 10^{-42} = 3.42 \times 10^{17}$ kg/m^3 (awrt, ecf) **A1**

(c) the two densities are (almost) equal, showing that nuclear density is approximately independent of (constant regardless of) nucleon number A, oe **B1**

(c) Answer: Density of C-12 nucleus = density of U-238 nucleus = approximately 3.4 x 10^{17} kg/m^3, confirming nuclear density is roughly constant for all nuclides.

(d) a roughly constant density means each nucleon occupies about the same amount of volume, regardless of how many nucleons (A) are present, oe **B1**

(d) this is consistent with each nucleon being strongly attracted only to its nearest neighbours (a short-range, saturated force); if the strong force instead acted between every pair of nucleons at all separations, the nucleus would be pulled ever more tightly together as A increased, and density would rise with A rather than staying constant, oe **B1**

(d) Answer: Because density does not increase with A, each nucleon must be held by a force that only reaches its nearest neighbours (short range), not by a force acting on every nucleon in the whole nucleus.

Question 2

(a) the energy needed to completely separate all the nucleons of a nucleus to infinity (or the energy released when a nucleus is assembled from its separate nucleons), oe **B1**

(a) Answer: The energy needed to separate a nucleus into its individual, separate protons and neutrons.

(b) mass of the separate protons and neutrons found: 26 x 1.00728 = 26.189 u and 30 x 1.00867 = 30.260 u **M1**

(b) total mass of separate nucleons = 26.189 + 30.260 = 56.449 u, and the nucleus mass subtracted from it **M1**

(b) mass defect = 56.449 - 55.9206 = 0.529 u shown (cso, answer given) **A1**

(b) Answer: mass defect = 0.529 u

(c) binding energy = 0.529 x 931.5 = 493 MeV (492.6 MeV from the unrounded 0.5288 u) (ft from b), then divided by 56 **M1**

(c) binding energy per nucleon = 8.80 MeV (awrt 8.8; accept 8.79 to 8.80), ecf **A1**

(c) Answer: 8.80 MeV per nucleon

(d) binding energy per nucleon is greatest (a maximum) around A = 56, i.e. nuclei near iron/nickel are the most stable, oe **B1**

(d) in fusion, light nuclei combine to form a heavier nucleus with a greater binding energy per nucleon than the original (separate) light nuclei, oe **B1**

(d) in fission, a heavy nucleus splits into two lighter nuclei of greater binding energy per nucleon than the original heavy nucleus, oe **B1**

(d) in both cases the products are more tightly bound (higher total binding energy) than the reactants, and this increase in total binding energy is released as energy, oe **B1**

(d) Answer: Nuclei near A = 56 are most stable (highest BE per nucleon). Fusion and fission both move nuclei towards this region, increasing the total binding energy, and the increase is released as energy.

© Revision Library | revisionlibrary.co.uk