Class 12 Physics · Chapter 13: Nuclei

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. The radius of a nucleus is about 10^{-4} times the radius of its atom. The fraction of the atom's volume occupied by the nucleus is about [1]

(a) 10^{-12} (b) 10^{-16}
(c) 10^{-4} (d) 10^{-8}

Answer: (a) Volume $\propto r^3$, so the fraction is $(10^{-4})^3 = 10^{-12}$: the atom is almost empty, though the nucleus holds more than 99.9% of its mass.

2. The binding energy of the ${}^{4}_{2}\mathrm{He}$ nucleus is 28.3 MeV. Its mass defect is (take 1 u = 931.5 MeV/c^2) [1]

(a) 0.304 u (b) 0.0304 u
(c) 0.0152 u (d) 0.0076 u

Answer: (b) $E_b = \Delta M c^2$, so ΔM = 28.3 MeV ÷ 931.5 MeV/u = 0.0304 u. 0.0076 u is the mass defect per nucleon (÷ 4); 0.0152 u divides by 2; 0.304 u slips a decimal.

3. When beryllium was bombarded with α-particles, it gave out a neutral radiation that could knock protons out of light nuclei. Chadwick concluded that this radiation was not made of photons because [1]

(a) photons able to do this would need far more energy than the bombardment could supply (b) photons are always absorbed by protons without ejecting them
(c) photons cannot travel through beryllium (d) photons carry electric charge

Answer: (a) To knock protons out, photons would have needed far more energy than the α-bombardment could provide. Chadwick therefore proposed new neutral particles, neutrons, of mass very nearly that of the proton, which can transfer energy to protons efficiently in collisions.

4. Of the following nuclei, the one in which a nucleon is, on average, most tightly bound is [1]

(a) ${}^{4}_{2}\mathrm{He}$ (b) ${}^{12}_{6}\mathrm{C}$
(c) ${}^{238}_{92}\mathrm{U}$ (d) ${}^{56}_{26}\mathrm{Fe}$

Answer: (d) The binding energy per nucleon has its maximum, about 8.75 MeV, near A = 56; it is lower for light nuclei (^{4}He about 7.1 MeV, ^{12}C about 7.7 MeV) and for heavy ones (^{238}U about 7.6 MeV).

5. Which of the following nuclides is an isotone of ${}^{14}_{6}\mathrm{C}$? [1]

(a) ${}^{13}_{6}\mathrm{C}$ (b) ${}^{14}_{7}\mathrm{N}$
(c) ${}^{15}_{8}\mathrm{O}$ (d) ${}^{16}_{8}\mathrm{O}$

Answer: (d) Isotones have the same neutron number N = A − Z. For ${}^{14}_{6}\mathrm{C}$, N = 8; for ${}^{16}_{8}\mathrm{O}$, N = 8. ${}^{14}_{7}\mathrm{N}$ (N = 7) is an isobar of ${}^{14}_{6}\mathrm{C}$, ${}^{13}_{6}\mathrm{C}$ (N = 7) an isotope, and ${}^{15}_{8}\mathrm{O}$ has N = 7.

6. State whether each pair is a pair of isotopes, isobars or isotones: (i) ${}^{40}_{18}\mathrm{Ar}$ and ${}^{40}_{20}\mathrm{Ca}$ (ii) ${}^{13}_{6}\mathrm{C}$ and ${}^{14}_{7}\mathrm{N}$ (iii) ${}^{35}_{17}\mathrm{Cl}$ and ${}^{37}_{17}\mathrm{Cl}$ (iv) ^{2}H and ^{3}H. [2]

(i) Same A = 40, different Z: isobars. (ii) N = 13 − 6 = 7 and N = 14 − 7 = 7, different Z: isotones. (iii) Same Z = 17, different A: isotopes. (iv) Both have Z = 1 (deuterium and tritium), different A: isotopes.

- (i) isobars (0.5)
- (ii) isotones, with N = 7 for both (0.5)
- (iii) isotopes (0.5)
- (iv) isotopes (0.5)

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7. How much energy is needed to remove one neutron from a $^{13}_{6}C$ nucleus, leaving $^{12}_{6}C$? Given the atomic masses m($^{13}_{6}C$) = 13.003355 u, m($^{12}_{6}C$) = 12.000000 u, m_n = 1.008665 u and 1 u = 931.5 MeV/c^2. [2]

$^{13}_{6}C \rightarrow {}^{12}_{6}C + {}^{1}_{0}n$. Mass after − mass before = 12.000000 + 1.008665 − 13.003355 = 0.005310 u (the electron masses are the same on both sides). Energy needed = 0.005310 × 931.5 MeV = 4.95 MeV.

- mass difference 0.005310 u, final minus initial (1)
- energy needed = 4.95 MeV (1)

8. The fission of 1 kg of uranium gives about 10^{14} J, and burning 1 kg of coal gives about 10^7 J. What mass of coal must be burnt to give the energy released by the fission of 1 g of uranium? What does the comparison show about nuclear and chemical energies? [2]

1 g of uranium gives $10^{14} \times 10^{-3} = 10^{11}$ J. Mass of coal = $10^{11}/10^7 = 10^4$ kg (10 tonnes). Chemical energies are of the order of eV per atom and nuclear energies of the order of MeV, so for the same quantity of matter nuclear sources give vastly more energy.

- 10^{11} J from 1 g and 10^4 kg of coal (1)
- nuclear (MeV) against chemical (eV) energies per reaction (1)

9. The binding energies of $^{7}_{3}Li$, $^{4}_{2}He$ and $^{3}_{1}H$ are 39.25 MeV, 28.30 MeV and 8.48 MeV. (a) Find the minimum energy needed to split a $^{7}_{3}Li$ nucleus into a $^{4}_{2}He$ nucleus and a $^{3}_{1}H$ nucleus. (b) Find the binding energy per nucleon of $^{7}_{3}Li$ and of $^{4}_{2}He$. (c) Why does $^{7}_{3}Li$, though heavier, have a lower binding energy per nucleon than $^{4}_{2}He$? [3]

(a) Protons and neutrons are conserved, so the energy to be supplied is the loss in total binding energy: 39.25 − (28.30 + 8.48) = 2.47 MeV. (b) ^{7}Li: 39.25/7 = 5.61 MeV; ^{4}He: 28.30/4 = 7.08 MeV. (c) The binding energy curve is not smooth for light nuclei: it shows a peak at ^{4}He, which is unusually tightly bound, taken as evidence of shell structure in nuclei; ^{7}Li does not sit on such a peak.

- 2.47 MeV from the difference in total binding energy (1)
- E_{bn}: ^{7}Li ≈ 5.61 MeV, ^{4}He ≈ 7.08 MeV (1)
- ^{4}He sits on a peak of the curve (shell structure) (1)

10. A nuclear reactor produces heat at 500 MW from the fission of $^{235}_{92}U$, each fission giving 200 MeV. Find (a) the number of fissions per second, and (b) the mass of ^{235}U used up in one day. Take 1 MeV = 1.6 × 10^{-13} J and N_A = 6.02 × 10^{23} mol^{-1}. [3]

(a) Energy per fission = 200 × 1.6 × 10^{-13} = 3.2 × 10^{-11} J. Fissions per second = 5.0 × 10^8/3.2 × 10^{-11} = 1.56 × 10^{19} s^{-1}. (b) In one day (86 400 s): 1.56 × 10^{19} × 86 400 = 1.35 × 10^{24} nuclei = 1.35 × 10^{24}/6.02 × 10^{23} = 2.24 mol; mass = 2.24 × 235 g ≈ 527 g, about 0.53 kg.

- energy per fission in joules (0.5)
- fissions per second ≈ 1.6 × 10^{19} (1)
- nuclei per day ≈ 1.35 × 10^{24} (0.5)
- mass ≈ 0.53 kg (1)

11. A $^{238}_{92}U$ nucleus emits an α-particle, and the product then emits two β^- particles, one after the other. Write the three steps, and state how the final nucleus is related to the original. [3]

$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$; $^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + e^- + \bar{\nu}$; $^{234}_{91}Pa \rightarrow {}^{234}_{92}U + e^- + \bar{\nu}$. Each β^- decay raises Z by 1 and leaves A unchanged. The final nucleus has the same Z (92) and A = 234: it is an isotope of the original, $^{234}_{92}U$.

- α step: A − 4, Z − 2 (1)
- two β^- steps: Z + 1 each, A unchanged (1)
- final $^{234}_{92}U$, an isotope of the parent (1)

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