CLASS XII – PHYSICS (042)
STEP-BY-STEP SOLUTIONS AND MARKING SCHEME

Chapter 13: Nuclei – Practice Paper (35 Marks)

Answer key – Section A

Q.	1	2	3	4	5	6	7	8	9
Ans.	(a)	(c)	(b)	(d)	(c)	(b)	(a)	(b)	(d)

Marks are shown in square brackets. Equivalent correct methods are acceptable. Key relations: $R = R_0A^{1/3}$; $\Delta M = Zm_p + (A - Z)m_n - M$; $E_b = \Delta M\, c^2$; $Q = (\Sigma m_{initial} - \Sigma m_{final})c^2$; 1 u = 931 MeV/$c^2$.

SECTION A

Q.1 (a)

Y ($A \approx 56$) has the highest binding energy per nucleon, so it is the most stable. X is a light nucleus with a low value, so when it fuses with another nucleus the product (higher binding energy per nucleon) is more tightly bound and energy is released. Z is a heavy nucleus with a lower value than medium-mass nuclei, so on splitting into two medium-mass nuclei the nucleons become more tightly bound and energy is released. **[1]**

Q.2 (c)

The potential energy has its minimum at $r_0 = 0.8$ fm (point B), where the force (the negative slope of the curve) is zero. For $r < r_0$ (point A) the energy falls steeply as r increases, so the force is repulsive. For $r > r_0$ (point C) the energy rises with r, so the force is attractive. **[1]**

Q.3 (b)

Isobars have the same mass number A. Q (^{238}U) and S (^{238}Np) both have A = 238. (P and Q are isotopes, and R and S are isotones, with N = 145 each.) **[1]**

Q.4 (d)

$R \propto A^{1/3}$, so $R_Y/R_X = (125/27)^{1/3} = 5/3$. Nuclear density is the same for all nuclei (mass $\propto$ A, volume $\propto R^3 \propto$ A), so the ratio of densities is 1. **[1]**

Q.5 (c)

Mass of constituents = 8(1.007 + 1.009) = 16.128 u. Mass defect = 16.128 − 15.990 = 0.138 u. $E_b = 0.138 \times 931 \approx 128.5$ MeV. **[1]**

Q.6 (b)

Mass number: 1 + 235 = 140 + 94 + x, so x = 2. (The atomic numbers balance: 92 = 54 + 38.) **[1]**

Q.7 (a)

When the spheres touch, the distance between centres = 2 × 2.0 = 4.0 fm. $U = (e^2/4\pi\varepsilon_0)/r$ = 1.44 MeV fm/4.0 fm = 0.36 MeV = 360 keV. **[1]**

Q.8 (b)

Both statements are true. In fission a heavy nucleus splits into medium-mass nuclei having greater binding energy per nucleon, so energy is released. R, the instability of a free neutron, has no bearing on this, so it does not explain A. **[1]**

Q.9 (d)

A is false: strictly, mass–energy interconversion also occurs in chemical reactions, because chemical binding energy also contributes a mass defect. R is true, which is why the effect is not noticed. **[1]**

SECTION B

Q.10

(a) From the graph, the binding energy per nucleon of ^{2}H is 1.0 MeV, so $E_b = 1.0 \times 2 = 2$ MeV. For ^{4}He it is 7.0 MeV, so $E_b = 7.0 \times 4 = 28$ MeV. **[1]**

(b) Energy released = E_b(final) − E_b(initial) = 28 − 2 × 2 = 24 MeV. **[1]**

Q.11

(a) $R = R_0A^{1/3}$: $A^{1/3} = 3.6/1.2 = 3$, so A = 27. **[1]**

(b) The nucleus is $^{27}_{13}$Al. The number of neutrons N = A − Z = 27 − 13 = 14. **[1]**

Q.12

(A) A nucleon feels the nuclear force only from nucleons within its range (a few fm). Nucleon S, deep inside, has a fixed number of neighbours within the dashed circle, and this number does not grow when more nucleons are added to the nucleus; this is the saturation of the nuclear force. **[1]**

Hence the binding energy of an interior nucleon is the same (about pk, for p neighbours) whatever the size of the nucleus, so the binding energy per nucleon is nearly constant for medium and heavy nuclei. (T, near the surface, has fewer neighbours and is less tightly bound, but surface nucleons are a small fraction.) **[1]**

OR (B) Mass defect is the difference between the total mass of the separate nucleons and the mass of the nucleus: $\Delta M = Zm_p + (A - Z)m_n - M$. Binding energy is the energy needed to separate the nucleus into its nucleons. **[1]**

The two are related by $E_b = \Delta M\, c^2$. **[1]**

Q.13

$Q = (2 \times 2.0141 - 3.0160 - 1.0087)\ u \times c^2 = (4.0282 - 4.0247)\ u\ c^2 = 0.0035\ u\ c^2$. Q = 0.0035 × 931 ≈ 3.26 MeV. **[1]**

Q is positive (the initial mass is greater than the final mass), so energy is released: the reaction is exothermic. **[1]**

SECTION C

Q.14

(a) The nucleus near A = 56 (iron) has the greatest binding energy per nucleon, about 8.8 MeV. **[1]**

(b) For light nuclei the binding energy per nucleon is low. The fused nucleus has a larger binding energy per nucleon, i.e. it is more tightly bound, so the extra binding energy is released. **[1]**

(c) For P (A = 240) the binding energy per nucleon ≈ 7.5 MeV; for Q (A = 120) it is ≈ 8.5 MeV. Gain per nucleon = 1.0 MeV, so the energy released ≈ 240 × 1.0 = 240 MeV. **[1]**

Q.15

(A) (a) Reaction (iv) needs two ^{3}He nuclei. Each ^{3}He is made by reaction (iii), which needs a deuteron from reaction (i) (and an e^+ that is annihilated in (ii)). So (i), (ii) and (iii) must each occur twice. **[1]**

(b) Net energy = 2(0.42) + 2(1.02) + 2(5.49) + 12.86 = 0.84 + 2.04 + 10.98 + 12.86 = 26.72 ≈ 26.7 MeV. **[1]**

(c) The nuclei are positively charged and repel each other. They must have enough kinetic energy to overcome this Coulomb barrier and come within the range of the nuclear force, which needs a very high temperature (thermonuclear fusion). **[1]**

OR (B) For a heavy nucleus (A ≈ 240) the binding energy per nucleon (≈ 7.6 MeV) is lower than for medium nuclei (≈ 8.5 MeV). When it splits into two medium-mass fragments, the nucleons are more tightly bound and the difference in binding energy is released as energy. **[1]**

For light nuclei the binding energy per nucleon is lower than that of heavier nuclei. When they fuse, the product is more tightly bound and energy is released. **[1]**

Example of fission: $^1_0n + {}^{235}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3\ {}^1_0n$ (any correct reaction). **[1]**

Q.16

(a) Number of nuclei $N = (1000\ g/240\ g\ mol^{-1}) \times 6 \times 10^{23} = 4.17 \times 6 \times 10^{23} = 2.5 \times 10^{24}$. **[1]**

(b) $E = 2.5 \times 10^{24} \times 200\ MeV = 5 \times 10^{26}\ MeV = 5 \times 10^{26} \times 1.6 \times 10^{-13}\ J = 8 \times 10^{13}\ J$. **[1]**

(c) Ratio = $8 \times 10^{13}/10^7 = 8 \times 10^6$. Nuclear fuel gives about 8 million times as much energy as coal. **[1]**

SECTION D

Q.17

(i) (c). Mass of 3 protons + 4 neutrons = 3(1.007) + 4(1.009) = 3.021 + 4.036 = 7.057 u. **[1]**

(ii) (a). $\Delta M = 7.057 - 7.014 = 0.043$ u. **[1]**

(iii) (d). $E_b = \Delta M \times 931 = 0.043 \times 931 \approx 40$ MeV. **[1]**

(iv) (b). $E_b/A = 40/7 \approx 5.7$ MeV. **[1]**

OR (iv) (b). The binding energy per nucleon of ^{7}Li (5.7 MeV) is less than that of ^{4}He (7.0 MeV), so ^{7}Li is less tightly bound. **[1]**

SECTION E

Q.18

(A) (a) Feature 1: for 30 < A < 170 the binding energy per nucleon is nearly constant (about 8 MeV). This shows that the nuclear force is short-ranged and saturates: a nucleon is bound only to its near neighbours. **[1]**

Feature 2: the curve peaks at about 8.8 MeV near A = 56 and falls for A < 30 and A > 170. The nuclear force is strong, since the binding energy is a few MeV per nucleon, and the nucleons of medium-mass nuclei are the most tightly bound. **[1]**

Consequence: energy is released when a heavy nucleus splits (fission) or when light nuclei join (fusion), since in both the nucleons move to a more tightly bound state. **[1]**

(b) Mass of 2 protons + 2 neutrons = 2(1.007 + 1.009) = 4.032 u. $\Delta M = 4.032 - 4.002 = 0.030$ u. $E_b = 0.030 \times 931 \approx 27.9$ MeV. **[1]**

Binding energy per nucleon = 27.9/4 ≈ 7.0 MeV. **[1]**

OR (B) (a) The volume of the nucleus $V = (4/3)\pi R^3 = (4/3)\pi R_0{}^3 A$. **[1]**

The mass of the nucleus is about A u, with u the atomic mass unit. **[1]**

Density $\rho = A\,u/[(4/3)\pi R_0{}^3 A] = 3u/(4\pi R_0{}^3)$, in which A has cancelled, so the density is the same for all nuclei. **[1]**

(b) $\rho = (3 \times 1.66 \times 10^{-27})/(4 \times 3.14 \times 1.73 \times 10^{-45}) = 4.98 \times 10^{-27}/(21.7 \times 10^{-45}) \approx 2.3 \times 10^{17}$ kg m^{-3}. **[1]**

Mass of 1 cm^3 = 10^{-6} m^3 × 2.3×10^{17} kg m^{-3} = 2.3×10^{11} kg. **[1]**

— End of Solutions —