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Atoms and Nuclei — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · PHYSICS · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Take the ground-state energy of hydrogen as −13.6 eV, hc = 1240 eV nm, $1/(4\pi\varepsilon_0) = 9 \times 10^9$ N m²/C², e = 1.6×10^{-19} C and c = 3×10^8 m/s unless stated otherwise. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Alpha-particle scattering and Rutherford's model · Bohr model and energy levels · Hydrogen spectrum · Composition and size of the nucleus · Atomic masses · Mass–energy relation and mass defect · Binding energy per nucleon · Nuclear fission and fusion

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. An alpha particle of kinetic energy 5 MeV moves head-on towards a gold nucleus (Z = 79). Its distance of closest approach is about

(1) 4.6×10^{-12} m

(2) 2.3×10^{-14} m

(3) 9.1×10^{-14} m

(4) 4.6×10^{-14} m

2. In the alpha-particle scattering experiment, a very small fraction of the alpha particles were turned back through angles greater than 90°. From this Rutherford concluded that

(1) the electrons are spread evenly through the atom

(2) the positive charge and almost all the mass of the atom are concentrated in a tiny nucleus

(3) the atom is mostly empty space and contains no nucleus

(4) alpha particles are strongly attracted by electrons

3. The energy needed to remove the electron from a He^{+} ion in its first excited state is

(1) 54.4 eV

(2) 3.4 eV

(3) 13.6 eV

(4) 40.8 eV

4. The ratio of the speed of the electron in the third Bohr orbit of Li^{2+} to its speed in the ground state of hydrogen is

(1) 1

(2) 3

(3) 1/3

(4) 9

5. A large number of hydrogen atoms are excited to the n = 5 level. The number of different wavelengths that can appear in their emission spectrum as they return to the ground state is

(1) 4

(2) 5

(3) 10

(4) 15

6. The ratio of the wavelength of the first line of the Lyman series of hydrogen to that of the first line of the Balmer series is

(1) 5 : 27

(2) 27 : 5

(3) 3 : 4

(4) 4 : 9

7. The shortest wavelength in the Balmer series of hydrogen is about

(1) 656 nm

(2) 365 nm

(3) 122 nm

(4) 91 nm

8. In the Bohr model, the change in the angular momentum of the electron when a hydrogen atom goes from the n = 4 state to the n = 2 state is

(1) h/(2π)

(2) 2h

(3) h/(4π)

(4) h/π

9. A hydrogen atom in its ground state absorbs a photon of energy 12.75 eV. It is raised to

(1) the n = 4 level

(2) the n = 3 level

(3) the n = 5 level

(4) the continuum: the atom is ionised

10. The ratio of the radius of the nucleus ^{125}Te to that of the nucleus ^{27}Al is

(1) 125 : 27

(2) 25 : 9

(3) 5 : 3

(4) √5 : √3

11. The ratio of the density of the nucleus ^{238}U to that of the nucleus ^{4}He is about

(1) 238 : 4

(2) (238/4)^(1/3)

(3) 4 : 238

(4) 1 : 1

12. The energy equivalent of a mass of 1 mg is

(1) 9×10^{13} J

(2) $9 \times 10^{1^{\circ}}$ J

(3) 3×10^{5} J

(4) 9×10^{7} J

13. Given the atomic masses m(^{1}H) = 1.007825 u, m(^{2}H) = 2.014102 u and the neutron mass 1.008665 u, the binding energy per nucleon of the deuteron is about (1 u = 931.5 MeV/c^2)

(1) 1.11 MeV

(2) 2.22 MeV

(3) 0.56 MeV

(4) 4.44 MeV

14. Energy is released when a heavy nucleus such as ^{235}U splits into two middle-sized nuclei because

(1) the products have a smaller binding energy per nucleon

(2) the products have a larger binding energy per nucleon

(3) the total number of nucleons decreases

(4) mass is created in the process

15. Each fission of a ^{235}U nucleus releases about 200 MeV. The energy released by the complete fission of 1 g of ^{235}U is about (Avogadro number 6.02×10^{23} per mole)

(1) 8.2×10^{13} J

(2) 2.0×10^{8} J

(3) 8.2×10^{7} J

(4) 8.2×10^{10} J

16. In the fusion reaction $^{2}H + {}^{2}H \rightarrow {}^{3}He + n$, the atomic masses are $m(^{2}H) = 2.014102$ u and $m(^{3}He) = 3.016029$ u, and the neutron mass is 1.008665 u. The energy released is about ($1\ u = 931.5\ MeV/c^2$)

(1) 4.03 MeV

(2) 2.22 MeV

(3) 3.27 MeV

(4) 17.6 MeV

17. The atomic mass unit is 1/12 of the mass of a ^{12}C atom, 1.6605×10^{-27} kg. Its energy equivalent is about

(1) 9.31 MeV

(2) 931.5 MeV

(3) 1.49×10^{-10} MeV

(4) 0.511 MeV

18. Which of the following nuclei has the largest binding energy per nucleon?

(1) ^{56}Fe

(2) ^{238}U

(3) ^{4}He

(4) ^{2}H

19. The first line of the Balmer series of hydrogen has a wavelength of 656 nm. The corresponding line ($n = 3 \rightarrow n = 2$) of the He^{+} ion has a wavelength of about

(1) 656 nm

(2) 328 nm

(3) 1312 nm

(4) 164 nm

20. In the Bohr model, the kinetic energy and the potential energy of the electron in the n = 2 state of hydrogen are

(1) 3.4 eV and −3.4 eV

(2) −3.4 eV and 6.8 eV

(3) 3.4 eV and −6.8 eV

(4) 6.8 eV and −3.4 eV

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

21. The ionisation energy (in eV) of the Li^{2+} ion in its ground state is _____ (to the nearest integer).

Answer: _____

22. The wavelength (in nm) of the photon emitted when a hydrogen atom goes from the n = 3 level to the n = 2 level is _____ (to the nearest integer).

Answer: _____

23. Taking R_0 = 1.2 fm in R = R_0A^(1/3), the radius (in fm) of the nucleus ^{125}Te is _____.

Answer: _____

24. Given the atomic masses m(^{1}H) = 1.007825 u and m(^{4}He) = 4.002603 u, and the neutron mass 1.008665 u, the binding energy (in MeV) of the ^{4}He nucleus is _____ (to the nearest integer; 1 u = 931.5 MeV/c^2).

Answer: _____

25. A nuclear reactor produces 320 MW from the fission of ^{235}U, each fission releasing 200 MeV. The number of fissions per second is x × 10^{18}. The value of x is _____.

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(4)	(2)	(3)	(1)	(3)	(1)	(2)	(4)	(1)	(3)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(4)	(2)	(1)	(2)	(4)	(3)	(2)	(1)	(4)	(3)

Q21	Q22	Q23	Q24	Q25
122	656	6	28	10

WORKED SOLUTIONS

Q1. Answer (4). At closest approach all the kinetic energy has become electric potential energy: K = k(2e)(79e)/d. d = $9 \times 10^{9} \times 158 \times (1.6 \times 10^{-19})^2/(5 \times 1.6 \times 10^{-13}) \approx 4.6 \times 10^{-14}$ m, an upper limit on the size of the nucleus.

Q2. Answer (2). A light electron cannot turn back a heavy alpha particle, and positive charge spread through the whole atom would only deflect it slightly. Turning one back needs a very strong repulsion from a small, massive, positive centre: the nucleus. (That most alpha particles pass almost straight through shows the atom is mostly empty.)

Q3. Answer (3). For a hydrogen-like ion $E_n = -13.6\ Z^2/n^2$ eV. For He^+ (Z = 2) in n = 2: $E = -13.6 \times 4/4 = -13.6$ eV, so 13.6 eV is needed. (54.4 eV would ionise it from the ground state.)

Q4. Answer (1). In the Bohr model $v = Ze^2/(2\varepsilon_0 hn) \propto Z/n$. Li^{2+} (Z = 3) in n = 3 gives 3/3 = 1: the same as hydrogen in n = 1 (about 2.2×10^6 m/s).

Q5. Answer (3). Any downward jump between two of the five levels gives a line: $^5C_2 = 5 \times 4/2 = 10$. (One atom on its own can give at most 4 lines, one per step.)

Q6. Answer (1). $1/\lambda = R(1/n_1^2 - 1/n_2^2)$. Lyman first line (2 → 1): R × 3/4. Balmer first line (3 → 2): R × 5/36. λ_L/λ_B = (5/36)/(3/4) = 5/27.

Q7. Answer (2). The series limit (∞ → 2): $1/\lambda = R/4$, $\lambda = 4/R = 4/(1.097 \times 10^7)$ m ≈ 365 nm. (656 nm is the longest Balmer line, 122 nm and 91 nm belong to the Lyman series.)

Q8. Answer (4). $L = nh/(2\pi)$. From n = 4 to n = 2 it changes by $2h/(2\pi) = h/\pi$.

Q9. Answer (1). $E_n = -13.6/n^2$ eV. −13.6 + 12.75 = −0.85 eV = −13.6/16, so n = 4.

Q10. Answer (3). $R = R_0 A^{\wedge}(1/3)$, so $R_T e/R_A l = (125/27)^{\wedge}(1/3) = 5/3$.

Q11. Answer (4). Nuclear mass ≈ A u and volume = $(4/3)\pi R_0^3 A$, so the density $A\ u/((4/3)\pi R_0^3 A)$ does not depend on A: all nuclei have about the same density, about 2.3×10^{17} kg/m³.

Q12. Answer (2). $E = mc^2 = 10^{-6}$ kg × $(3 \times 10^8$ m/s$)^2 = 9 \times 10^{10}$ J. (9×10^{13} J would be 1 g.)

Q13. Answer (1). Mass defect Δm = 1.007825 + 1.008665 − 2.014102 = 0.002388 u (atomic masses: the electron masses cancel). Binding energy 0.002388 × 931.5 = 2.22 MeV, shared by 2 nucleons: 1.11 MeV each.

Q14. Answer (2). The binding energy per nucleon is about 7.6 MeV for uranium but about 8.5 MeV for nuclei near the middle of the table. The products are more tightly bound, so their total mass is smaller and the difference appears as energy (about 200 MeV). The number of nucleons stays the same.

Q15. Answer (4). N = $6.02 \times 10^{23}/235 = 2.56 \times 10^{21}$ nuclei. E = $2.56 \times 10^{21} \times 200 \times 1.6 \times 10^{-13}$ J ≈ 8.2×10^{10} J.

Q16. Answer (3). $\Delta m = 2 \times 2.014102 - (3.016029 + 1.008665) = 4.028204 - 4.024694 = 0.003510$ u. $Q = 0.003510 \times 931.5 \approx 3.27$ MeV.

Q17. Answer (2). $E = mc^2 = 1.6605 \times 10^{-27} \times (2.998 \times 10^8)^2 = 1.4924 \times 10^{-10}$ J. Dividing by 1.602×10^{-13} J/MeV gives about 931.5 MeV. (1.49×10^{-10} is the value in joules; 0.511 MeV is the electron's rest energy.)

Q18. Answer (1). Binding energy per nucleon: ^{2}H about 1.1 MeV, ^{4}He about 7.1 MeV, ^{238}U about 7.6 MeV and ^{56}Fe about 8.8 MeV, near the peak of the curve. Nuclei near iron are the most tightly bound.

Q19. Answer (4). For a hydrogen-like ion $1/\lambda = RZ^2(1/n_1^2 - 1/n_2^2)$. With Z = 2 the same transition has four times the photon energy, so $\lambda = 656/4 = 164$ nm.

Q20. Answer (3). For a circular orbit under an inverse-square force, K = −E and U = 2E. With $E_2 = -13.6/4 = -3.4$ eV: K = 3.4 eV and U = −6.8 eV.

Q21. Answer 122. $E_1 = -13.6Z^2$ eV $= -13.6 \times 9 = -122.4$ eV, so the ionisation energy is 122.4 eV, i.e. 122.

Q22. Answer 656. $\Delta E = 13.6(1/4 - 1/9) = 1.889$ eV. $\lambda = hc/\Delta E = 1240/1.889 \approx 656$ nm (the red Hα line).

Q23. Answer 6. $R = 1.2 \times 125\text{^}(1/3) = 1.2 \times 5 = 6$ fm.

Q24. Answer 28. $\Delta m = 2 \times 1.007825 + 2 \times 1.008665 - 4.002603 = 0.030377$ u. Binding energy $0.030377 \times 931.5 \approx 28.3$ MeV, i.e. 28.

Q25. Answer 10. Energy per fission $200 \times 1.6 \times 10^{-13} = 3.2 \times 10^{-11}$ J. $N = 3.2 \times 10^8 / 3.2 \times 10^{-11} = 10^{19} = 10 \times 10^{18}$ per second.

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: Bohr orbits were found numerically from the force and angular-momentum conditions with SI constants, the alpha particle's approach was integrated step by step, and nuclear energies were computed from the atomic masses.