ATOMS AND NUCLEI

(AIPMT)

2012

1. Electron in hydrogen atom first jumps from third excited state to second excited state to second excited state and then from second excited to the first excited state. The ratio of the wavelengths $\lambda_1 : \lambda_2$ emitted in the two cases is
a) $\frac{7}{5}$ b) $\frac{27}{20}$ c) $\frac{27}{5}$ d) $\frac{20}{7}$
2. If the nuclear radius of ^{27}Al is 3.6 fermi the approximate nuclear radius of ^{64}Cu in Fermi is
a) 2.4 b) 1.2 c) 4.8 d) 3.6
3. A mixture consists of two radioactive materials A_1 and A_2 with half lives of 20s and 10s respectively. Initially the mixture has 40g of A_1 and 160 g of A_2. The amount of the two in the mixture will become equal after
a) 60s b) 80 s c) 20 s d) 40 s
4. An electron of a stationary hydrogen atom passes from the fifth energy level to the ground level. The velocity that the atom acquired as a result of photon emission will be
a) $\frac{24hR}{25m}$ b) $\frac{25hR}{24m}$ c) $\frac{25m}{24hR}$ d) $\frac{24m}{25hR}$
(m is the mass of the electron, R, Rydberg constant and h Planck's constant)

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5. The wavelength of the first line of Lyman series for hydrogen atom is equal to that of the second line of Balmer series for hydrogen like ion. The atomic number Z of hydrogen like ion is
a) 3 b) 4 c) 1 d) 2
6. The half life of a radioactive isotope X is 50 years. It decays to another element Y which is stable. The two elements X and Y were found to be in the ratio of 1:15 in a sample of a given rock. The age of the rock was estimated to be
a) 150 years b) 200 years c) 250 years d) 100 years
7. The power obtained in a reactor using U^{235} disintegration in 100kW. The mass decay of U^{235} per hour is
a) 10 microgram b) 20 microgram c) 40 microgram d) 1 microgram
8. A radioactive nucleus of mass M emits a photon of frequency υ and the nucleus recoils. The recoil energy will be
a) $Mc^2-h\upsilon$ b) $h^2\upsilon^2/2MC^2$ c) zero d) $h\upsilon$
9. A nucleus $^{m}_{n}X$ emits one α particle and two β-particles. The resulting nucleus is
a) $^{m-6}_{n-4}X$ b) $^{m-6}_{n}X$ c) $^{m-4}_{n}X$ d) $^{m-4}_{n-2}Y$
10. Fusion reaction takes place at high temperature because
a) nuclei break up at high temperature b) atoms get ionized at high temperature
c) kinetic energy is high enough to overcome the coulomb repulsion between nuclei
d) molecules break up at high temperature
11. An electron in the hydrogen atom jumps from excited state n to the ground state. The wavelength so emitted illuminates a photosensitive material having work function 2.75 eV. If the stopping potential of the photoelectron is 10 V, then the value of n is
a) 2 b) 3 c) 4 d) 5

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12. The mass of a $^{7}_{3}Li$ nucleus is 0.042 u less than the sum of the masses of all its nucleons. The binding energy per nucleon of $^{7}_{3}Li$ nucleus is nearly.

a) 46 MeV b) 5.6 MeV c) 3.9 MeV d) 23 MeV

13. The activity of a radioactive sample is measured as N_0 counts per minute at t = 0 and N_0/e counts per minute at t = 5 minutes. The time (in minutes) at which the activity reduces to half its value is

a) $\log_e \frac{2}{5}$ b) $\frac{5}{\log_e 2}$ c) 5 $\log_{10}2$ d) $5\log_e 2$

14. The energy of a hydrogen atom in the ground state is -13.6 eV. The energy of a He^+ ion in the first excited state will be

a) -13.6 eV b) -27.2 eV c) -54.4 eV d) -6.8 eV

15. An alpha nucleus of energy $\frac{1}{2}mv^2$ bombards heavy nuclear target of charge Ze. Then the distance of closest approach for the alpha nucleus will be proportional to

a) $\frac{1}{Ze}$ b) v^2 c) $\frac{1}{m}$ d) $\frac{1}{v^4}$

16. The decay constant of a radio isotope is λ. If A_1 and A_2 are its activities at times t_1 and t_2 respectively, the number of nuclei which have decayed during the time (t_1-t_2)

a) $A_1t_1 = A_2t_2$ b) $A_1 - A_2$ c) $(A_1 - A_2)/\lambda$ d) $\lambda(A_1 - A_2)$

17. The binding energy per nucleon in deuterium and helium nuclei are 1.1 MeV and 7.0 MeV, respectively. When two deuterium nuclei fuse to form a helium nucleus the energy released in the fusion is

a) 23.6 MeV b) 2.2 MeV c) 28.0 MeV d) 30.2 MeV

KEY

1. d	**2. c**	**3.d**	**4.a**	**5.d**	**6.b**	**7.c**
8. b	**9.c**	**10.c**	**11.c**	**12.b**	**13.d**	**14.a**
15.c	**16.c**	**17.a**				

SOLUTIONS

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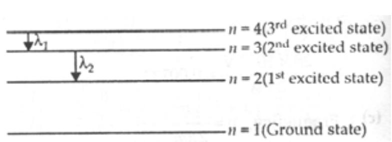
1. (d)



According to Rydberg formula

$$\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

In first case, $n_f = 3$, $n_i = 4$

$$\therefore \frac{1}{\lambda_1} = R\left[\frac{1}{3^2} - \frac{1}{4^2}\right] = R\left[\frac{1}{9} - \frac{1}{16}\right] = \frac{7}{144}R \quad \text{.......(i)}$$

In second case, $n_f = 2$, $n_i = 3$

$$\therefore \frac{1}{\lambda_2} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5}{36}R \qquad \text{.......(ii)}$$

Divide (ii) by (i), we get

$$\frac{\lambda_1}{\lambda_2} = \frac{5}{36} \times \frac{144}{7} = \frac{20}{7}$$

2. (c)

Nuclear radius, $R = R_0 A^{1/3}$ where R_0 is a constant and A is the mass number

$$\therefore \frac{R_{Al}}{R_{Cu}} = \frac{(27)^{1/3}}{(64)^{1/3}} = \frac{3}{4}$$

Or $R_{Cu} = \frac{4}{3} \times R_{Al} = \frac{4}{3} \times 3.6$ Fermi = 4.8 fermi

3. (d)

Let after t s amount of the A_1 and A_2 will become equal in the mixture

As $N = N_0 \left(\frac{1}{2}\right)^n$

Where n is the number of half-lives

For A_1, $N_1 = N_{01}\left(\frac{1}{2}\right)^{t/20}$

For A_2, $N_2 = N_{02}\left(\frac{1}{2}\right)^{t/10}$

According to question, $N_1 = N_2$

$$\frac{40}{2^{t/20}} = \frac{160}{2^{t/10}}$$

$$2^{t/10} = 4\left(2^{t/20}\right) \text{ or } 2^{t/10} = 2^2 2^{t/20}$$

$$2^{t/10} = 2^{\left(\frac{t}{20}+2\right)}$$

$$\frac{t}{10} = \frac{t}{20} + 2 \text{ or } \frac{t}{10} - \frac{t}{20} = 2$$

Or $\frac{t}{20} = 2$ or t = 40 s

4. (a)

According to Rydberg formula

$$\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

Here, $n_f = 1$, $n_i = 5$

$$\therefore \frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{5^2}\right] = R\left[\frac{1}{1} - \frac{1}{25}\right] = \frac{24}{25}R$$

According to conservation of linear momentum, we get

Momentum of photon = Momentum of atom

$$\frac{h}{\lambda} = m\upsilon \text{ or } \upsilon = \frac{h}{m\lambda} = \frac{h}{m}\left(\frac{24R}{25}\right) = \frac{24hR}{25m}$$

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5. (d) The wavelength of the first line of Lyman series for hydrogen atom is

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right]$$

The wavelength of the second line of Balmer series for hydrogen like ion is

$$\frac{1}{\lambda} = Z^2 R\left[\frac{1}{2^2} - \frac{1}{4^2}\right]$$

Or $\frac{3}{4} = \frac{3Z^2}{16}$ or $Z^2 = 4$ or Z = 2

6. (b) $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$

Where n is number of half lives

$\therefore \frac{1}{16} = \left(\frac{1}{2}\right)^n$ or $\left(\frac{1}{2}\right)^4 = \left(\frac{1}{2}\right)^n$ or n = 4

Let the age of rock be t years,.

$\because n = \frac{t}{T_{1/2}}$

Or t = $nT_{1/2}$ = 4 x 50 years = 200 years

7. (c) According to Einstein's mass energy relation

$E = mc^2$ or $m = \frac{E}{c^2}$

Mass decay per second

$$\frac{\Delta m}{\Delta t} = \frac{1}{c^2}\frac{\Delta E}{\Delta t} = \frac{P}{c^2} = \frac{1000 \times 10^3 W}{\left(3 \times 10^8 m/s\right)^2}$$

$$= \frac{10^6}{9 \times 10^{16}} \text{ kg/s}$$

Mass decay per hour

$$= \frac{\Delta m}{\Delta t} \times 60 \times 60 = \left(\frac{10^6}{9 \times 10^{16}} kg/s\right)(3600\, s)$$

$$= 4 \times 10^{-8} kg = 40 \times 10^{-6} g = 40 \mu g$$

8. (b) Momentum of emitted photon

$$= p_{photon} = \frac{h\upsilon}{c}$$

From the law of conservation of linear momentum, Momentum of recoil nucleus

$$= P_{nucleus} = P_{photon}$$

$\therefore \qquad M\upsilon = \frac{h\upsilon}{c}$

Where υ is the recoil speed of the nucleus

Or $\upsilon = \frac{h\upsilon}{Mc}$

The recoil energy of the nucleus

$= \frac{1}{2}M\upsilon^2 = \frac{1}{2}M\left(\frac{h\upsilon}{Mc}\right)^2 = \frac{h^2\upsilon^2}{2Mc^2}$ (Using (i))

9. (c) When an alpha particle $\left({}_2^4He\right)$ is emitted, the mass number and the atomic number of the daughter nucleus decreases by four and two respectively, When a beta particles $\left(\beta^-\right)$ is emitted, the atomic number of the daughter nucleus increases by one but the mass number remains the same.

$${}_n^mX \xrightarrow{\alpha} {}_{n-2}^{m-4}Y \xrightarrow{2\beta^-} {}_n^{m-4}X$$

10. (c) Extremely high temperature needed for fusion make kinetic energy large enough to overcome coulomb repulsion between nuclei. Because of this they are called as thermonuclear reactions.

11 (c) Here, Stopping potential, V0= 10 V

Work function, W = 2.75 eV

According to Einstein's photoelectric equation

$eV_0 = h\upsilon - W$

Or $h\upsilon = eV_0 + W$

= 10 eV + 2.75 eV = 12.75 eV …. (i)

When an electron in the hydrogen atom makes a transition from excited state n to the ground state (n=1), then the frequency (υ) of the emitted photon is given by

$h\upsilon = E_n - E_1$

$h\upsilon = -\frac{13.6}{n^2} - \left(-\frac{13.6}{1^2}\right)$

[$\because$ For hydrogen atom, $E_n = -\frac{13.6}{n^2}eV$]

According to given problem

$-\frac{13.6}{n^2} + 13.6 = 12.75$

$\frac{13.6}{n^2} = 0.85 \Rightarrow n^2 = \frac{13.6}{0.85} = 16$

Or n = 4

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12 (b) For ${}_3^7Li$ nucleus,

Mass defect, $\Delta M = 0.042u$

$\because$ 1 u = 931.5 MeV/c^2

$\therefore \Delta M$ = 0.042 x 931.5 MeV/c^2

= 39.1 MeV/c^2

Binding energy, $E_b = \Delta Mc^2$

$$= \left(39.1\frac{MeV}{c^2}\right)c^2$$

= 39.1 MeV

Binding energy per nucleon, $= \frac{39.1MeV}{7}$ = 5.6 MeV

13 (d) According to Radio activity law $R = R_0 e^{-\lambda t}$ ……………….(i)

Where,

R_0 = initial activity at t = 0

R = activity at time t

λ = decay constant

According to given problem,

$R_0 = N_0$ counts per minute

$R = \frac{N_0}{e}$ Counts per minute

t = 5 minutes

Substituting these values in equation (i), we get

$$\frac{N_0}{e} = N_0 e^{-5\lambda}$$

$$e^{-1} = e^{-5\lambda}$$

$5\lambda = 1$ or $\lambda = \frac{1}{5}$ per minute

At t = $T_{1/2}$, the activity R reduces to $\frac{R_0}{2}$.

Where $T_{1/2}$ = half life of a radioactive sample

From equation (i), we get

$$\frac{R_0}{2} = R_0 e^{-\lambda T_{1/2}}$$

$$e^{-\lambda T_{1/2}} = 2$$

Taking natural logarithms of both sides of above equation, we get

$$\lambda T_{1/2} = \log_e 2$$

Or $T_{1/2} = \frac{\log_e 2}{\lambda}$ = 5$\log_e$2 minutes

14. (a) Energy of an hydrogen like atom like He^+ in an n^{th} orbit is given by

$$E_n = -\frac{13.6Z^2}{n^2}eV$$

For hydrogen atom, Z= 1

$\therefore \quad E_n = -\frac{13.6}{n^2}eV$

For ground state, n = 1

$\therefore \quad E_1 = -\frac{13.6}{1^2}eV = -13.6eV$

For He+ ion, Z=2

$$E_n = -\frac{4(13.6)}{n^2} eV$$

For first excited state, n = 2

$$\therefore \quad E_2 = -\frac{4(13.6)}{(2)^2} eV = -13.6\, eV$$

Hence, the energy in He^+ ion in first excited state is same that of energy of the hydrogen atom in grounds state i.e. -13.6 eV.

15. (c) At the distance of closest approach d, Kinetic energy = Potential energy

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{(2e)(ze)}{d}$$

Where,

Ze = charge of target nucleus

2e = charge of alpha nucleus

$\frac{1}{2}mv^2$ = kinetic energy of alpha nucleus of mass m moving with velocity υ

Or $$d = \frac{2Ze^2}{4\pi\varepsilon_0\left(\frac{1}{2}m\upsilon^2\right)} \therefore d \propto \frac{1}{m}$$

16 (c) : $A_1 = \lambda N_1$ at time t_1

$A_2 = \lambda N_2$ at time t_2

Therefore, number of nuclei decayed during time interval (t_1-t_2) is

$$N_1 - N_2 = \frac{[A_1 - A_2]}{\lambda}$$

17. (a) : ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + \Delta E$

The binding energy per nucleon of a deuteron = 1.1 MeV

$\therefore$ Total binding energy = 2 x 1.1 = 2.2 MeV

The binding energy per nucleon of a helium nuclei = 7 MeV

$\therefore$ Total binding energy = 4 x 7 = 28 MeV

AIIMS QUESTIONS

1. Assertion: Mass defect in nuclear reactions is less than 1%
   Reason: In nuclear reaction, change in BE/N is generally less than 1%
2. Assertion: It is desirable to slow down fast moving neutrons to sustain controlled chain reactions
   Reason: Slow moving neutrons efficiently collide with U^{235}.
3. Half life of a radio-active element is 8 years, how much amount will be present after 32 years?
   a) $\frac{1}{4}$ b) $\frac{1}{8}$ c) $\frac{1}{16}$ d) $\frac{1}{32}$
4. The nucleus ${}_n^mX$ emits one α particle and 2β-particles. The resulting nucleus is
   a) ${}_{n-2}^{m-4}Y$ b) ${}_{n-4}^{m-6}Z$ c) ${}_{n}^{m-6}Z$ d) ${}_{n}^{m-4}X$
5. Assertion: At rest, radium is decayed into Radon and an α-particle. They both moves back to back of each other
   Reason: Splitting of radioactive particle is based on conservation of linear momentum

6. Assertion: More energy is released in fusion than fission
Reason: More number of nucleons take part in fission

7. Assertion: γ-radiation emission occurs after α and β decay
Reason: Energy levels occur in nucleus

SOLUTIONS:

1.
Sol: (a)

2.
Sol: (c)
The average energy of a neutron produced in fission of U235 is 2 MeV. These neutrons unless slowed down will escape from the reactor without interacting with uranium nuclei, unless a large amount of fissionable material is used for sustaining the chain reaction. What we needs to do is to slow down the fast neutrons by elastic scattering with light nuclei. Chadwick's experiment showed that in an elastic collision with hydrogen neutron almost come to rest.

3.
Sol: (c)
Here, $T_{1/2}$ = 8 years
T = 32 years

Using, N = $N_0\left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}}$

$$\left(\frac{N}{N_0}\right)=\left(\frac{1}{2}\right)^{\frac{32}{8}}=\left(\frac{1}{2}\right)^4$$

$$\left(\frac{N}{N_0}\right)=\frac{1}{16}$$

4.
Sol: (d)
Emission of α-particle decreases the mass number, the atomic number by 4 and 2 respectively.
Emission of β-particle increases the atomic number by 1 while the mass number remains unchanged.
After the emission of the one α-particle and two β-particles
Decreases in mass number = 4-0 = 4
Decreases in atomic number = 2-2=0
$\therefore$ The resulting the nucleus is ${}^{m-4}X$

5.
Sol: (a)
6.
Sol: (b)
7..
Sol: (a)