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Class: 12
Subject: Physics
Topic: Atoms and Nuclei
No. of Questions: 30

1. Explain the significance of negative energy of electron in an orbit.

Sol.

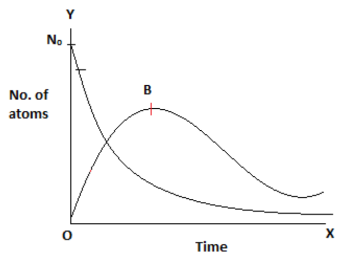
The energy of an electron in the orbits of an atom is negative. It shows that electron is bound to the nucleus. Greater is the value of negative energy, more tightly the electron is bound to the nucleus. Since the negative energy of electron is maximum in first orbit of an atom, therefore, the electron is more tightly bound to the nucleus in the innermost orbit. With the increase in the number of quantised orbit, the negative energy of electron decreases and hence binding of nucleus on the electron decreases. This shows that the electrons in the outermost orbits of and atom are least bound to the nucleus.

2. Consider a radioactive nucleus A which decays to a stable nucleus C through the following sequence:

$$B\rightarrow B \rightarrow C$$

Here, B is an intermediate nucleus which is also radioactive. Considering that there are N_o atoms of A initially, plot the graph showing the variation of number of atoms of A and B versus time.

Sol.



The given sequence of radioactive decay is

$$B\rightarrow B \rightarrow C$$

C is stable.

At t = 0, $N_a = N_0$ and N_B=0.

As time passes on, t increases. N_A falls off exponentially to zero at $t = \infty$. The number of atoms of B goes on increasing with time, becomes maximum and finally decays to zero (at t =∞) following exponential decay law. The variation of the number of atoms of A and B versus time is shown in Fig. 8(EP).4.

3. A positronium atom is a bound state of an electron (e^-) and its antiparticle, the positron (e^+) revolving round their centre of mass. In which part of the em spectrum does the system radiate when it de-excites from its first excited state to the ground state?

Sol. In an ordinary atom, as a first approximation, we ignore the motion of the nucleus, being too heavy. In a positronium atom, a positron replaces proton of hydrogen atom. As electron and positron masses are equal, the motion of the positron cannot be ignored.

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We consider motion of electron and positron about their centre of mass. A detailed analysis (beyond the scope of this book) shows that formulae of Bohr model apply to positronium atom provided that we replace m_e by what I known as reduced mass of the electon. For positronium, the reduced mass is $m_e/2$. In the transition n = 2 to n = 1m the wavelength fo radiation emitted is double than that of the corresponding radiation emitted for a similar transition in hydrogen atom, which has a wavelength of 1217 Å ; and hence is equal to 2 x 1217 = 2434 Å. This radiation lies in the ultra-violet part of the electromagnetic spectrum.

4. A nuclear reactor is a powerful device, wherein nuclear energy is utilized for peaceful purposes. It is based upon controlled nuclear chain reaction. The nuclear chain reaction is controlled by the use of control rods (of boron or cadmium) and moderators like heavy water, graphite, etc.
The whole reactor is protected with concrete walls 2 to 2.5 metre thick, so that radiations emitted during nuclear reactions may not produce harmful effects.
Read the above passage and answer the following questions:
(i) Give any two merits of nuclear reactors.
(ii) What is radioactive waste?
(iii) Why do people often oppose the location site of a nuclear reactor? What do you suggest?

Sol.

(i) Nuclear reactors are used in electric power generation. They are also used to produce radioactive isotopes–which have applications in medicine, industry and agriculture.
(ii) Radioactive waste consists of fission products and transuranic elements such as plutonium and americium. This waste is extremely hazardous to all forms of life on earth.
(iii) People often oppose the location site of a nuclear reactor because any leakage of nuclear radiations can affect adversely miles of area surrounding it. Elaborate safety measures are needed not only for reactor operations, but also for handling and disposal of radioactive waste.
I would suggest that Government must take stringent safety measures and assure people of safeguards in the event of nuclear accidents. At the same time, people must also be educated accordingly.

5. Einstein was the first to establish the equivalence between mass and energy. According to him, whenever a certain mass (Δm) disappears in some process, the amount of energy released is $E = (\Delta m)\, c^2$, where c is velocity of light in vacuum (=3 x 10^8m/s). The revers is also true, i.e., whenever energy E disappears, and equivalent mass $(\Delta m) = E/c^2$ appers.
Read the above passage and answer the following questions:
(i) What is the energy released when 1 a.m.u. of mass disappears in a nuclear reaction?
(ii) Doy you know any phenomenon in which energy materialises?
(iii) What values of life do you learn from this famous relation?

Sol.

(i) Here, $(\Delta m = 1$ a.m.u. $= 1.66 \times 10^{-27}$ kg
$E = (\Delta m)\, c^2 = 1.66 \times 10^{-27}\, (3 \times 10^8) = 1.49 \times 10^{-10}$ J.

(ii) Yes, in the phenomenon of pair production. Under suitable canditions, a photon materializes into an electron and a position:

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$$\gamma = e^{-1} + e^{+1}$$

(iii) Einstein's relation, E = (Δm) c^2emphasises that when certain mass disappears, and equivalent amount of energy appears. The reverse is also true. It implies that to gain something, you have to lose another in equivalent amount. No one can have all gains together or all losses together. It also implies that nothing comes for free. You have to pay the price in one form and acqure something in the desired form.

6. Poonam's mother is diagnosed cancer. The attending physician told her that she has to undergo radiotherapy. While telling her the side effects of the treatment, the doctor told that her beautiful hair may fall and she may become bald. Poonam's mother refuses to get the treatment.
Read the above passage and answer the following questions:
(i) What would you do if you were in Poonam's place?
(ii) What values of lip are associated with your attitude?

Sol.

(i) If I were in Poonam's place, I would tell my mother that treatment of cancer is a must. Hair fall is a temporary effect and the hair would grow slowly after the therapy. Convincing my mother to get the treatment, using all sorts of reasoning will be my top priority.
(ii) Concern for my mother's health is of utmost importance. I will no mind taking help from specialists to convince my mother for getting the reatment.

7. Four nuclei of an element fuse together to form a heavier nucleus. If the process is accompanied by release of energy, which of the tow – the parent or the daughter nucleus would have higher binding energy per nucleon?

Sol.

As lighter nuclei are less stable than the intermediate nuclei, therefore, BE/nucleon of daughter nucleus will be higher than the BE/nucleon of parent nucleus. The difference in the masses of parent nucleus and daughter is the mass defect, which is released in the form of energy.

8. Explain the concept of nuclear energy with reference to binding energy curve.

Sol.

Nuclear energy is the energy released during a nuclear reaction.

The curve of average binding energy per nucleon $(\overline{B})$ against mass number, Fig. 8(b).1 shows a long flat region from about A = 30 to A = 170. In this region, $\bar{B}$ is almost constant. However, for nuclei with A < 30 and A > 170, vaule of $\bar{B}$ is less than the plateau value. Clearly, nuclei with mass numbers in the range 30 $\leq A \geq$ 170 are more tightly bound than the nuclei with A < 30 and nuclei with A > 170. Hence when we transmute less tightly bound nuclei into more tightly bound nuclei through nuclear reactions, the nuclear energy may be released.

The nuclear reactions which can be practical sources of energy are broadly of two types.

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1. Nuclear fission, in which can be practical sources of energy are broadly of two types.
2. Nuclear fusion, in which lighter nuclei fuse into a heavier one.

In both the cases, energy released is estimated from mass defect (Δm) from Einstein's mass energy relation E $= (\Delta m)$ c^2.

9. What are delayed neutrons? Discuss their role.

Sol.

Some neutrons produced in fission are delayed by some time as they are produced in subsequent decays of the initial fission fragments. These are called delayed neutrons. This situation is crucial to mechanical control of the reactor. If all the fission neutrons were produced instantly in fission, these would be no time for the minute adjustment required in a reactor to keep it critical.

10. Give reasons for

A. Lighter elements are better moderators for a nuclear reactor than heavier elements.
B. In a natural uranium reactor, heavy water is a preferred moderator to ordinary water.
C. Cadmium rods are provided in a reactor.
D. Very high temperatures as those obtained in the interior of the sun are required for fusion reaction to take place.

Sol.

A. A good moderator has two properties. It slows down neutrons by elastic collision and it does not remove them from the core by absorbing them. That is why lighter elements are better moderators.
B. Heavy water is used in reactors using natural uranium as fuel. This is because it has lesser absorption probability of neutrons than ordinary water.
C. Cadmium rods have a high cross section for neutron absorption. They are used for controlling the nuclear chain reaction responsible for producing nuclear energy.
D. For fusion reactions, very their mutual electrostatic repulsion and come closer than the range of nuclear forces of attraction.

11. After two hours, $1/16^{th}$ of the initial amount of a certain radioactive isotope remains undecayed. The half-life of the isotope is

A. 15 minutes
B. 30 minutes
C. 45 minutes
D. 1 hour

Right Answer Explanation:

Since $\frac{1}{16} = \frac{1}{2^4}$, it follows that 2 hours = 4 half lives.

or 1 half-life = $\frac{2}{4} = \frac{1}{2}$ hour = 30 minutes

12. The half life of Pa-218 is 3 minutes. What mass of a 16 g sample of Pa - 218 will remain after 15 minutes?

A. 3.2 g
B. 2.0 g
C. 1.6 g
D. 0.5 g

Right Answer Explanation:

Since 15 minutes = 5 $\times$ 3 minutes = 5 half lives, the number of nuclei left after 15 minutes = $\frac{1}{2^5} = \frac{1}{32}$ of the original number.

Therefore, the mass of 16 g sample left after 15 minutes = $\frac{16}{32}$ = 0.5 g.
Hence, the correct choice is (4).

13. During a negative beta decay

A. an atomic electron is ejected
B. an electron which is already present within the nucleus is ejected
C. a neutron in the nucleus decays emitting an electron
D. a part of the binding energy of the nucleus is converted into an electron

Right Answer Explanation:
Negative β decay is expressed by the equation:
$n \longrightarrow p + e^- + \bar{\nu}$; $\bar{\nu}$ stands for antineutrino
Hence the correct choice is (3).

14. The decay constant of a radioactive sample is λ. The half-life and mean-life of the sample are (respectively) given by

A. 1/ λ and (ln 2)/ λ
B. (ln 2)/ λ and 1/ λ
C. 1/ λ and λ(ln 2)
D. λ(ln 2) and 1/ λ

Right Answer Explanation:
For a radioactive material of disintegration constant λ,

Half-life = $T_{1/2} = \frac{\ln 2}{\lambda}$, and

Mean-life = $\tau = \frac{1}{\lambda}$.
Hence the correct choice is (2).

15. A radioactive element X has atomic number Z and atomic mass number A. It decays by the emission of an alpha particle and a gamma ray. The new element is
   A.
   B. $^{A-2}_{Z-1}Y$
   C. $^{A-4}_{Z-2}Y$
   D. $^{A+1}_{Z}Y$
   E. $^{A+4}_{Z+2}Y$

Right Answer Explanation:
Alpha particle has mass number 4 and atomic number 2. Thus A decreases to A – 4 and Z decreases to Z – 2.
Hence the correct choice is (2).

16. The half-life of a radioactive substance depends upon

   A. its temperature
   B. the external pressure on it
   C. the mass of the substance
   D. the strength of the nuclear force between the nucleons of its atoms

Right Answer Explanation:
The correct choice is (4).

17. A uranium nucleus (atomic number 92, mass number 238) emits an alpha particle and the resultant nucleus emits a β particle. The atomic and mass numbers, respectively of the final nucleus are

   A. 90, 240
   B. 90, 236
   C. 91, 234
   D. 92, 232

Right Answer Explanation:
The emission of an α - particle decreases the mass number by 4 and atomic number by 2.
The emission of a β - particle increases the atomic number by 1.
Hence the final nucleus has a mass number = 238 – 4 = 234 and atomic number = 92 – 1 + 1 = 91.
Hence the correct choice is (3).

18. The equation $4{}_1^1H^+ \rightarrow {}_2^4He^+ + 2e^+ + 26\,MeV$ represents

A. β - decay
B. γ - decay
C. fusion
D. fission

Right Answer Explanation:

The correct choice is (3). It represents a fusion of four ${}_1^1H$ nuclei with the emission of a huge amount of energy.

19. The binding energy per nucleon of C-12 is 7.68 MeV and of C-13 is 7.48 MeV. The energy (in MeV) required to remove the extra neutron from C-13 is nearly equal to

A. 0.2
B. 3.7
C. 3.9
D. 5

Right Answer Explanation:
Energy required = (7.48 $\times$ 13 – 12 $\times$ 7.68) MeV = 5.08 MeV
Hence, the correct choice is (4).

20. A gamma ray photon creates an electron-positron pair. If the total kinetic energy of the electron-positron pair is 0.78 MeV, the energy of the gamma ray photon is (given the rest mass energy of electron = 0.51 MeV)

A. 0.27 MeV
B. 0.78 MeV
C. 1.29 MeV
D. 1.80 MeV

Right Answer Explanation:
E = 0.51 + 0.51 + 0.78 = 1.80 MeV. Hence the correct choice is (4).

21. The transition from state n = 4 to n = 3 in a hydrogen-like atom results in an ultraviolet radiation. Infrared radiation will be obtained in the transition

A. 2 $\rightarrow$ 1
B. 3 $\rightarrow$ 2
C. 4 $\rightarrow$ 2
D. 5 $\rightarrow$ 4

Right Answer Explanation:
The frequency of infrared radiation is less than that of ultraviolet radiation. Hence, infrared radiation has higher energy than ultraviolet radiation. Therefore, infrared radiation will be obtained in the transition n = 5 to n = 4, which is choice (4).

22. The mass number of a nucleus is

A. always less than its atomic number
B. always more than its atomic number
C. always equal to its atomic number
D. sometimes more and sometimes equal to its atomic number

Right Answer Explanation:
Mass number *Z* is greater than atomic number *A* for all nuclei; the single exception being the hydrogen nucleus for which *A* = *Z*. Hence the correct choice is (4).

23. A star initially has 10^{40} deuterons. It produces energy via the processes $^2_1H + ^2_1H \rightarrow ^3_1H + p$ and $^2_1H + ^3_1H \rightarrow ^4_2He + n$ where the masses of the nuclei are: m(^{2}H) = 2.014 u, m(p) = 1.007 u, m(n) = 1.008 u and m(^{4}He) = 4.001 u. If the average power radiated by the star is 10^{16} W, the deuteron supply of the star will get exhausted in a time of the order of

A. 10^6 s
B. 10^8 s
C. 10^{12} s
D. 10^{16} s

Right Answer Explanation:

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Let the mass of ${}_1^3\text{H}$ be x amu. Then the mass defect in the first process is

$$(\Delta m)_1 = m({}_1^2\text{H}) + m({}_1^2\text{H}) - m({}_1^3\text{H}) - m(p)$$
$$= 2.014 + 2.014 - x - 1.007 = (3.021 - x)\text{ u}$$

Mass defect in the second process will be

$$(\Delta m)_2 = m({}_1^2\text{H}) + m({}_1^3\text{H}) - m({}_2^4\text{H}) - m(n)$$
$$= 2.014 + x - 4.001 - 1.008 = (x - 2.995)\text{ u}$$

$\therefore$ Total mass defect is

$$\Delta m = (\Delta m)_1 + (\Delta m)_2 = (3.021 - x) + (x - 2.995)$$
$$= 0.026\text{ u}$$

Now 1 amu = 931 MeV = $931 \times 10^6 \times 1.6 \times 10^{-19}$ J.
Hence, energy released is given by

$$E = 0.026 \times 931 \times 10^6 \times 1.6 \times 10^{-19}$$
$$= 3.87 \times 10^{-12}\text{ J}$$

Now power $P = 10^{16}$ W. Therefore, the number of deutrons per second is $\dfrac{10^{16}}{3.87 \times 10^{-12}} = 2.58 \times 10^{27}$ per second

$\therefore$ Deutron supply will exhaust in $\dfrac{10^{40}}{2.58 \times 10^{27}} =$ 3.87×10^{12} seconds

Hence the correct choice is (3).

24. Masses of two isobars ${}_{29}^{64}\text{Cu}$ and ${}_{30}^{64}\text{Zn}$ are 63.9298 u and 63.9292 u respectively. It can be concluded from the given information that

A. both the isobars are stable
B. ^{64}Zn is radioactive, decaying to ^{64}Cu through β-decay
C. ^{64}Cu is radioactive, decaying to ^{64}Zn through γ-decay
D. ^{64}Cu is radioactive, decaying to ^{64}Zn through β-decay.

Right Answer Explanation:

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The atomic mass of stable Cu is smaller than that of Zn. Since the given mass of Cu is greater than that of Zn, ^{64}Cu will be unstable. In β-decay, the atomic number is increased by one while the mass number remains unchanged. Thus $^{64}_{29}\text{Cu} \xrightarrow{\beta\text{-decay}} {}^{64}_{30}\text{Zn} + {}^{0}_{-1}e$

Hence the correct choice is (4).

25. The order of magnitude of density of uranium nucleus is, ($m_p = 1.67 \times 10^{-27}$ kg)

A. 10^{20} kg m^{-3}
B. 10^{17} kg m^{-3}
C. 10^{14} kg m^{-3}
D. 10^{11} kg m^{-3}

Right Answer Explanation:

If A is the atomic number, the mass of uranium nucleus is

$$m = (1.67 \times 10^{-27}) A \text{ kg and its volume is}$$

$$V = \frac{4}{3}\pi r^3 = \frac{4\pi}{3} \times \{1.25 \times 10^{-15} \text{m} A^{1/3}]^3$$

$$\simeq 8.2 \times 10^{-45} A \text{ m}^3$$

$$(\because r = r_0 A^{1/3}; r_0 = 1.25 \times 10^{-15} \text{ m})$$

$$\therefore \quad \text{Density} = \frac{m}{V} = \frac{1.67 \times 10^{-27} A \text{ kg}}{8.2 \times 10^{-45} A \text{ m}^3}$$

$$\simeq 2 \times 10^{17} \text{ kg m}^{-3}$$

Hence the correct choice is (2).

26. The electron emitted in beta radiation originates from

A. inner orbits of atoms
B. free electrons existing in the nucleus
C. decay of a neutron in the nucleus
D. a photon escaping from the nucleus

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Right Answer Explanation:
Beta particle is an electron which is emitted from a nucleus when a neutron decays into a proton and an electron within the nucleus. Hence, the correct choice is (3).

27. Which of the following processes represents a gamma-decay?

A. ${}^{A}_{Z}X + \gamma \rightarrow {}^{A}_{Z-1}X + a + b$
B. ${}^{A}_{Z}X + {}^{1}_{0}n \rightarrow {}^{A-3}_{Z-2}X + c$
C. ${}^{A}_{Z}X \rightarrow {}^{A}_{Z}X + f$
D. ${}^{A}_{Z}X + {}_{-1}e \rightarrow {}^{A}_{Z-1}X + g$

Right Answer Explanation:
During the emission of a gamma radiation, both the mass number and atomic number remain the same. Hence the correct choice is (3).

28. A nucleus of mass number 220, initially at rest, emits an α - particle. If the Q value of the reaction is 5.5 MeV, the energy of the emitted α - particle will be

A. 4.8 MeV
B. 5.4 MeV
C. 6.0 MeV
D. 6.8 MeV

Right Answer Explanation:

$$\text{Kinetic energy} = \frac{(\text{momentum})^2}{2 \times \text{mass}}$$

Mass number of α-particle $(m) = 4$ units. Mass number of daughter nucleus $(M) = 220 - 4 = 216$ units. If P and p denote the momenta of the daughter nucleus and the α-particle respectively, then

$$Q = \frac{P^2}{2M} + \frac{p^2}{2m}$$

Since momentum is conserved, $P = p$. Hence

$$Q = \frac{p^2}{2}\left(\frac{1}{M} + \frac{1}{m}\right) = \frac{p^2}{2m}\left(\frac{m}{M} + 1\right)$$

Now $\frac{p^2}{2m}$ = KE of α-particle $= E_\alpha$. Thus,

$$Q = E_\alpha \left(\frac{m + M}{M}\right)$$

or $$E_\alpha = \frac{QM}{(m + M)} = \frac{5.5 \text{ MeV} \times 216}{(4 + 216)}$$

$$= 5.4 \text{ MeV}$$

Hence the correct choice is (2).

29. A nucleus at rest splits into two nuclear parts having radii in the ratio 1 : 2. Their velocities are in the ratio

A. 8 : 1
B. 6 : 1
C. 4 : 1
D. 2 : 1

Right Answer Explanation:

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Let A_1 and A_2 be the mass numbers of the two nuclear parts. Their radii are given by

$$R_1 = R_0 (A_1)^{1/3} \text{ and } R_2 = R_0 (A_2)^{1/3}$$

Dividing, we get

$$\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} \text{ or}$$

$$\frac{A_1}{A_2} = \left(\frac{R_1}{R_2}\right)^3 = \left(\frac{1}{2}\right)^3 = \frac{1}{8}$$

Hence the ratio of their masses is

$$\frac{m_1}{m_2} = \frac{1}{8}$$

From the principle of conservation of momentum, the magnitude of p_1 = magnitude of p_2 or $m_1 v_1 = m_2 v_2$, which gives

$$\frac{v_1}{v_2} = \frac{m_2}{m_1} = \frac{8}{1}, \text{ which is choice (1).}$$

30. Which of the following statements is incorrect?

A. Nuclei having an odd number of protons and an odd number of neutrons are generally unstable.
B. The mass number of a nucleus is equal to its atomic number only for the nucleus ^1_1H.
C. A radioactive element of half-life 1.5 years completely disintegrates in 4.5 years.
D. The mass per nucleon in an oxygen atom is slightly less than that in a hydrogen atom.

Right Answer Explanation:

Statement (1) is correct. $^{14}_{7}N$ which has 7 protons and 7 neutrons is an exception. The statement (2) is also correct. Statement (3) is incorrect. After 4.5 years (i.e. 3 half-lives), only $\frac{1}{2^3}$ of the radioactive element is left.

Statement (4) is correct. The energy released during the formation of nuclei of different atoms from their constituent nuclei is different. Hence the mass per nucleon is dependent upon the atom considered. The oxygen nucleus, being particularly stable, has a much larger value of the binding energy per nucleon. Hence the mass per nucleon in an oxygen atom is slightly less than the mass per nucleon in a hydrogen atom.