CONCEPTUAL QUESTIONS

Q1. Why does the alpha particle not make physical contact with nucleus, when an alpha particle is headed directly toward the nucleus of an atom.

Ans. Alpha particle is double positively charged helium atom and nucleus is also positively charged as it contains protons. Both the positively charged bodies repel due to Columbic force of repulsion. Magnitude of this force depends upon the charges as well as the distance between the charges. As the alpha particle comes closer to the nucleus, repulsion increases. Hence alpha particle cannot make physical contact with nucleus.

Q2. Why do heavier elements require more neutrons in order to maintain stability?

Ans. Heavier elements have more neutrons and lesser protons because neutrons being neutral do not repel each other. On the other hand, strong nuclear force still exists between neutrons which binds the nucleus. Protons being positively charged particles, have two types of forces between them, strong nuclear force which is attractive and Columbic force which is repulsive. So more the neutrons and lesser the protons, small Columbic repulsive force will exist between protons and this is Columbic repulsive force which makes the nucleus unstable. Therefore, due to small number of protons, less repulsive force will arise and nucleus will remain stable.

Q3. An alpha particle has twice the charge of a beta particle. Why does the former deflect less than the later when passing between electrically charged plates, assuming they both have the same speed?

Ans. When a charged particle passes perpendicularly between electrically charged plates, Columbic force provides centripetal force. Therefore;

$$F_C = F_E$$

$$\Rightarrow \quad \frac{mv^2}{r} = qE$$

$$\Rightarrow \quad r = \frac{mv^2}{qE} \qquad (1)$$

Where r is the radius of curved path.

Since electric field between the plates and speed of the particle is same, so from Eq.1

$$\Rightarrow \quad r \propto \frac{1}{q/m}$$

Since the charge to mass ratio of beta particle is;

$$\frac{q}{m} = 1.75 \times 10^{11}\ C/kg$$

And the charge to mass ratio of alpha particle is;

$$\frac{q}{m} = 4.8 \times 10^{7}\ C/kg$$

Therefore the alpha particle has greater radius of curvature which shows that alpha particle deflects less due to its high inertia.

Q4. Element X has several isotopes. What do these isotopes have in common? How do they differ?

Similarities

(1) The common thing that is found in all the isotopes of an element is the number of protons and number of electrons.

(2) Their chemical properties are same for all isotopes because chemical properties are determined by number of electrons. Electronic configuration is also same in all the isotopes.

Differences

(1) Difference in isotopes of an element arises due to the different number of neutrons.
(2) Secondly their physical properties are also different.
(3) All isotopes are neither stable nor unstable e.g, ${}_{11}Na^{23}$ is stable whereas ${}_{11}Na^{24}$ is radioactive although both are isotopes of sodium.

Q5. How many protons are there in the nucleus ${}_{86}Rn^{222}$? How many neutrons? How many electrons are there in the neutral atom?

Ans. General representation for a nucleus is ${}_{Z}X^{A}$.

Where Z shows number of protons &
A is sum of number of protons Z and neutrons N.

Now comparison shows that the given nucleus ${}_{86}Rn^{222}$ has 86 number of protons i.e., $Z = 86$ and $A = 222$.

As $Z + N = 222$

so $N = 222 - Z = 136$ neutrons

Since number of protons and electrons are always same in a neutral atom, so number of electrons are also 86.

Q6. Ra^{226} has half-life of 1600 years. (a) What fraction remains after 4800 years? (b) How many half-lives does it have in 9600 years?

Ans: (a) After 1600 years, $\frac{1}{2}$ are decayed and $\frac{1}{2}$ are left.

After 3200 years,

$(\frac{1}{2})(\frac{1}{2}) = \frac{1}{4}$ are left while $1 - \frac{1}{4} = \frac{3}{4}$ decayed.

After 4800 years, $\frac{4800}{1600} = 3$ three half-lives are passed and

hence $(\frac{1}{2})(\frac{1}{2})(\frac{1}{2}) = \frac{1}{8}$ are left and $1 - \frac{1}{8} = \frac{7}{8}$ decayed.

(b) Number of half-lives $n = \frac{9600\ years}{1600\ years} = 6$ half-lives.

Q7. Radium has a half–life of about 1600 years. If the universe was formed five billion or more years ago, why is there any radium left now?

Ans. Radium is continuously decaying into lead with a half-life of 1600 years and it should not be left if universe has observed five billion years of its existence but Uranium 238 (the most abundant isotope of uranium) which is a radioactive element and when it emits three alpha particles, the product formed due to this decay, is radium. The product or daughter nucleus formed, is also radioactive and final product is stable lead. Thus if on one side radium is decaying into lead, it is also being formed on the other hand by three alpha emissions of U^{238}. Half-life of U^{238} is 4.46 billion years.

Q8. Nuclear power plants use nuclear fission reactions to generate steam to run steam-turbine generator. How does the nuclear reaction produce heat?

Ans. A nuclear reactor uses nuclear fission reaction to generate heat and hence electricity. This fission reaction produces many small and moderate fragments each having very high kinetic energy. When these fragments strike with atoms of the moderators inside the reactor, their kinetic energy is converted into heat. This heat is so high that it evaporates the water passing through reactor by pipes. Thus steam is produced by this heat which runs the turbine to produce electrical energy. Thus kinetic energy of fragments, produced in fission reaction, appears as heat.

Q9. What factors make a fusion reaction difficult to achieve?

Ans: Fusion reaction requires a very large amount of energy to bring two positively charged nuclei closer together against the electrostatic force of repulsion between them. For this purpose, the nuclei should move towards each other with very high speed which is not attainable.

The fusion reaction takes place at tremendously high temperature that is about 10 million degree Celsius. Such a high temperature cannot be obtained easily. It means fusion reaction requires high temperature and high energy but both of them are difficult to achieve. In short following factors make it difficult.

- High enough temperature about 10^7 degrees Celsius.
- Containing the plasma at that temperature using electromagnetic fields.
- Stopping the plasma touching the container and losing it.

Q10. Discuss the similarities and differences between fission and fusion.

Similarities

- Both fission and fusion are nuclear reactions.
- Both reactions result in the production of energy as heat and radiation.
- Both reactions use the energy stored in atomic particles in the energy production process.

- Both fission and fusion are processes that aim to produce energy, which power plants can then turn into electrical energy.
- Both nuclear reactions are suitable for making nuclear bombs.
- Energy released in both reactions obeys Einstein's relation $E = mc^2$

Differences

- Fission is the splitting of an atom into two or more smaller ones while fusion is the fusing of two or more smaller nuclei into a larger one.
- Fission reaction does not normally occur in nature while fusion occurs in stars, such as the sun.
- Fission produces many highly radioactive particles but very few radioactive particles are produced by fusion reaction.
- It takes little energy to split two atoms in a fission reaction whereas extremely high energy is required to bring two or more protons close enough that nuclear forces overcome their electrostatic repulsion.
- Fusion reactors cannot sustain a chain reaction but fission reaction can sustain. Thus, if fusion reaction goes out of control, the reaction would stop automatically as it will cool down.

Q 11. In what Ways is time constant RC similar to and different from (a) radioactive decay constant λ (b) radioactive half-life?

Ans: (a)

Similarities

- Both capacitor and radioactive nucleus decay (change) at an exponential rate, relative high initial rate, progressively decreasing.
- Neither fully complete their decay (needing an infinite time).
- Both RC and λ are constant quantities.
- Relation between them is $RC = \frac{1}{\lambda}$.
- In equal time intervals the charge on the capacitor or the number of un-decayed nuclei change in the same ratio.

Differences

- Decay constant λ determines the rate of decay while capacitive time constant RC is the time in which charge of capacitor drops to $\frac{1}{e}$ of its maximum value.
- Radioactive decay is spontaneous and random process unlike the regular flow of charge off a capacitor.
- Radioactive decay results in a permanent change to the particles involved (nuclear change), whereas electrons are physically unchanged in capacitor.
- Radioactive decay rate of a given sample cannot be influenced by any means while the rate of decay for a capacitor (voltage drop or discharge current) is controllable by altering capacitance value and / or circuit resistance.

- Unit of capacitive time constant RC is that of time (sec) while the unit of radioactive decay constant λ is reciprocal of time (sec^{-1}).
- Larger the value of λ, greater the rate of decay whereas larger the value of RC, smaller the rate of discharge.

(b)

Similarities

- Both capacitive time constant RC and radioactive half-life $T_{1/2}$ have same dimension.
- Both RC and $T_{1/2}$ represent time for a particular process.
- Relation between both is $T_{1/2} = \ell n(2) \times RC$.

Differences

- Half-life of a radioactive substance cannot change by any means while changing the resistor or capacitance or both can change the time constant of capacitor.
- RC is used when dealing with charges in electrostatics while $T_{1/2}$ is used when dealing with radioactive nuclei in nuclear physics.
- Rate of discharge of a capacitor is called current while rate of decay of radioactive substance is called activity.

γ-rays

Q 12. What happens to atomic number of a nucleus that emits γ-ray photons? What happens to its mass?

Ans. γ-ray photons are neutral massless particles and they are emitted by an excited nucleus to get stability. As they have no charge and mass, so after the emission of γ-ray photons, there is neither any change in atomic number of the nucleus nor any change in the mass of nucleus.

Therefore, atomic number and mass remain same when an atom emits γ-ray photons.

Q 13. Explain why neutron activated nuclides tend to decay by β^- rather than β^+ ?

Ans. If we plot a graph between number of neutrons and protons for nuclei, we obtain a straight line for all stable nuclei. This line is called line of stability. Elements above and below this line are normally unstable. Those nuclei whose neutron to proton ratio (N/Z) is higher, lie above the line of stability and have more neutrons than required for a stable nucleus. They are relatively unstable and tend to decay by β^- emission because β^- emission transforms a neutron into proton, moving the nucleus closer to the line of stability by reducing neutron to proton ratio.

Since neutrons are added to the nucleus during neutron activation, so it has higher N/Z ratio and generally tends to decay by β^- emission.

As an example Te^{130} (n,γ)Te^{131} decays by β^- emission to form iodine I^{131}.

Q 14. Why are large nuclei unstable?

Ans. Larger nuclei are unstable due to Columbic effect. They contain large number of protons and neutrons. Although neutrons are neutral but protons being positively charged particles repel each other as they are very close to each other inside the nucleus (10^{-14}m). For large number of protons Columbic repulsive force tends to make the nucleus unstable and dominates over attractive strong nuclear force. Therefore, larger nuclei are generally unstable.

Q 15. What happens to atomic number and mass number of a nucleus that (a) emits an electron? (b) Undergoes electron capture? (c) Emits α-particle?

Ans. (a) Electrons are negatively charged beta (${}_{-1}\beta^{o}$) particles. When it is emitted from a nucleus, its atomic number Z increases by one while mass number A remains same before and after the emission. Mathematically we can represent the ${}_{-1}\beta^{o}$ emission by

$$ {}_{Z}X^{A} \longrightarrow {}_{Z+1}X^{A} + {}_{-1}\beta^{o} + \bar{\nu} $$

(b) When a nucleus captures an electron (${}_{-1}\beta^{o}$) then there occurs a decrease in its atomic number Z while atomic mass A remains same. Also this electron capture results in the emission of a neutrino by daughter nucleus. Mathematical equation can be written as

$$ {}_{Z}X^{A} + {}_{-1}\beta^{o} \longrightarrow {}_{Z-1}X^{A} + \nu $$

(c) Alpha particles are doubly ionized helium atoms (${}_{2}He^{4}$). When they are emitted from a nucleus, there occurs a decrease in atomic number Z as well as atomic mass A. Atomic number decreases by 2 while atomic mass decreases by 4. Mathematically we can represent the α-emission by

$$ {}_{Z}X^{A} \longrightarrow {}_{Z-2}X^{A-4} + {}_{2}He^{4} $$

Q 16. How many α-decays occur in the decay of ${}_{90}Th^{228}$ into ${}_{82}Pb^{212}$?

Ans. Alpha particles are doubly ionized helium atoms (${}_{2}He^{4}$). When they are emitted from a nucleus, atomic number decreases by 2 while mass number decreases by 4.

Now Pb has A = 212

While Th has A = 298.

Difference of mass number A gives;

$$ A = 228 - 212 = 16 $$

Similarly difference of Z number yields

$$ Z = 90 - 82 = 8 $$

Now a change of Z = 8 and A = 16 can occur when four alpha particles are emitted from Thorium. Hence ${}_{90}Th^{228}$ undergoes four α-decays in its conversion into ${}_{82}Pb^{212}$.

(Textbook needs correction in mass number of Thorium)

Q 17. What is color force?

Ans. Quarks have another property called color. This color is not color in visual sense rather it is just a label for something analogous to electric charge. Quarks are said to come in three colors red, green and blue. Anti-quarks have the properties anti-red, anti-green and anti-blue. The force that exists between them is given the name color force.

Just like strong nuclear force between nuclei, color force holds quarks. This force is analogous to electric force between two charges and it is carried by massless particles called gluons (exchange particles). Gluons that carry the color force have a color charge. Like colors repel while unlike colors attract.
