NUCLEAR PHYSICS
3.NUCLEAR REACTIONS

POINTS TO REMEMBER

1. **Nuclear Fission :**
   - **a)** It is the splitting up of a heavy nucleus into two or more lighter nuclei with the emission of energy. $_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + {}_0^3n^1 + 200\text{ MeV}$
   - **b)** The average number of neutrons emitted will be 2.5 The velocity of neutrons can be controlled by moderators.E.g. Graphite, heavy water, beryllium oxide, hydrocarbon plastics.
   - **c)** The number of neutrons can be controlled by control rods.E.g. Boron, cadmium, steel.
   - **d)** Neutron multiplication factor (K) = $\dfrac{\text{No of neutrons is second generation}}{\text{No of neutrons in the first generation}}$

   - If K < 1, the reaction is not self sustained.
   - It is called sub- critical state.
   - If K = 1, then its is called a controlled chain reaction called critical state.
   - If K>>1, the reaction is self sustained. It is called super critical state (principle of atom bomb).
   - Nuclear fission this phenomenon was first observed by Strassmann and Hann. It was explained by Neils Bohr and J.A. Wheeler on the basis of liquid drop model of the nucleus.
   - Power of a nuclear reactor, $P = \left(\dfrac{n}{t}\right)$ Energy liberated per fission.

2. **Nuclear Fusion is** in which two or more lighter nuclei combine to form a heavy nucleus with the emission of energy. $4\,{}_1H^1 \rightarrow {}_2He^4 + 2\,{}_{+1}e^1 + 25.71\text{MeV}$

3. **Carbon-Nitrogen Cycle:**

Bothe (1938) proposed a set of reactions taking place in the central part of the sun and stars in which carbon and nitrogen act as catalysts.

$^1_1H + {}^{12}_6C \rightarrow {}^{13}_7N + Q_1$

$^{13}_7N \rightarrow {}^{13}_6C + {}^0_1e$

$^1_1H + {}^{13}_6C \rightarrow {}^{14}_7N + Q_2$

$^1_1H + {}^{14}_7N \rightarrow {}^{15}_8O + Q_3$

$^{15}_8O \rightarrow {}^{15}_7N + {}^0_1e + Q_4$

$^1_1H + {}^{15}_7N \rightarrow {}^{12}_6C + {}^4_2He$

All the above reactions are added to give the following net nuclear reaction.

$4{}^1_1H \rightarrow {}^4_2He + 2{}^0_1e + Q$ Energy released is about 25.71MeV.

4. **Proton-Proton Cycle :**

$^1_1H + {}^1_1H \rightarrow {}^2_1H + {}^0_1e + Q_1$

$^1_1H + {}^2_1H \rightarrow {}^3_2He + Q_2$

$^{1}_{1}H + ^{3}_{2}He \to ^{4}_{2}He + ^{0}_{1}e + Q_3$

on adding $4^{1}_{1}H \to ^{4}_{2}He + 2^{0}_{1}e + Q$

Energy released in this cycle is 24.6 MeV.

5. **Fundamental particles**

- The particles inside the atom are called elementary particles.
- Basing on spin, elementary particles are classified into two types
  1) Bosons 2)Fermions
- Basing on interactions, elementary particle are classified as
  - Gravitons – gravitational interactions
  - Photons – electromagnetic interactions
  - Leptons – weak interactions
  - Hadrons – strong interactions.

Long Answer Questions

1. **Explain the principle and working of a nuclear reactor with the help of labeled diagram?(March2011,March2010,March2009)**

Ans: **Nuclear Reactor:** Nuclear reactor or atomic pile is used to produce a large amount of nuclear energy through a controlled nuclear fission process.

i) Nuclear Fuel: The fissionable material used in the reactor is called nuclear fuel. The Uranium isotopes $_{92}U^{235}$ and $_{92}U^{238}$, Plutonium Pu and thorium $_{99}th^{232}$ are commonly used fuels in the reactors. The rods of these fuels are tightly sealed in aluminium cylinders.

ii) Moderators: These are used to slow down the fast moving neutrons produced in the fission process. The materials used as moderators are heavy water, carbon in the form of pure graphite, ordinary water, hydrocarbon plastics etc.

iii) Control rods: These are the materials that can absorb the neutrons and control the nuclear chain reaction. Cadmium or Beryllium rods are generally used for this purpose. When the control rods are completely inserted into the carbon blocks, they absorb neutrons and the chain reaction completely stopped.

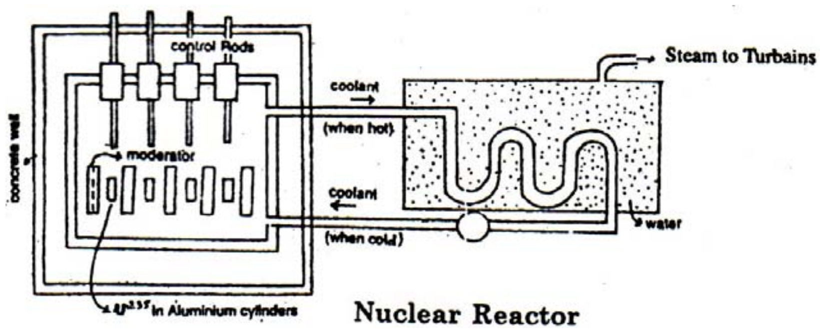
iv) Safety rods: These are used to reduce the neutron reproduction rate to less than one abruptly to stop the chain reaction whenever required.

v) Protective shielding: It is used to prevent the spreading of the radioactive effect to the space around the nuclear reactor. For this purpose lead blocks, concrete walls of thickness 10m are used.

vi) Coolant: The material used to absorb the heat generated in the reactor is called coolant. The coolant release the heat energy to the water and the water is thus converted into steam, which is used to run the turbines. These turbines in turn generate the power.

Working: The schematic diagram of a nuclear power reactor is shown in the figure. This helps to understand the working of a reactor. Uranium fuels are placed in the aluminium cylinders which are separated by some distance. The graphite moderator in the form of pure carbon blocks is placed in between the fuel cylinders. To control the number of neutrons, a number of control rods of cadmium or beryllium or boron are placed in the holes of graphite block.

When a ^{235}U nuclei undergo fission fast neutrons are liberated. These neutrons pass through the surrounding graphite moderator and loose their kinetic energy to become thermal neutrons. These thermal neutrons are captured by ^{235}U which carries out the fission reaction.



Nuclear Reactor

By raising and lowering the control rods the fission process can be controlled. The heat generated in this process is used for heating suitable coolant which in turn heat water and produce steam. This steam is made to rotate steam turbine and thereby drive a generator for production of electric power.

2. Explain the source of stellar energy. Explain the carbon-nitrogen cycle and proto-proton cycle occurring in stars.

Ans: A fusion reaction is a powerful source of energy. The emission of energy by sun and stars can be explained based on nuclear fusion. Depending upon the temperature, the energy released may be through carbon nitrogen cycle or proton-proton cycle.

<u>Carbon –Nitrogen Cycle</u>

Bothe (1938) proposed a set of reactions taking place in the central parts of the sun and stars in which carbon and nitrogen act as catalysts.

$${}_6C^{12} + {}_1H^1 \rightarrow {}_7N^{13} + \gamma$$

$${}_7N^{13} \rightarrow {}_6C^{13} + {}_1e^0 + \upsilon$$

$${}_6C^{13} + {}_1H^1 \rightarrow {}_7N^{14} + \gamma$$

$${}_7N^{14} + {}_1H^1 \rightarrow {}_8O^{15} + \gamma$$

$${}_8O^{15} \rightarrow {}_7N^{15} + {}_1e^0 + \upsilon$$

$_{7}N^{15} + _{1}H^{1} \rightarrow _{6}C^{12} + _{2}He^{4}$

The net result of the above processes can be written as

$$4 _{1}H^{1} \rightarrow _{2}He^{4} + 2 _{+1}e^{0} + 2\upsilon + \gamma$$

The energy released during this process $\gamma = 25.71Mev$

In this process four protons are fused to form one Helium nuclei and two positron releasing energy of about 25.71MeV and two anti neutrino.

Proton – Proton cycle:

Bothe and his co-workers suggested the following fusion reactions possible in a star.

$$_{1}H^{1} +_{1} H^{1} \rightarrow_{1} H^{2} + _{+1}e^{0} + \upsilon ....(a)$$

$$_{1}H^{1} +_{1} H^{2} \rightarrow _{2}H^{3} + energy ....(b)$$

The above fusion reactions (a) and (b) must occur twice to yield two $_{2}He^{3}$ nuclei. Therefore the next reaction can be written as

$$_{2}He^{3} +_{2} He^{3} \rightarrow _{2}He^{4} + 2 _{1}H^{1} + energy$$

The net result of the above reaction is that 4 protons are fused to produce an α-particle and a few other particles and release of a total energy 25.71MeV

$$4 _{1}H^{1} \rightarrow _{2}He^{4} + 2 _{+1}e^{0} + 2v + 2\gamma$$

The proton –proton cycle is an important source of energy in the sum and in stars of comparatively lower temperatures (red dwarfs).

SHORT ANSWER QUESTIONS

1. Uranium $^{238}_{92}U$ is not suitable for chain reaction. Why?

Ans: $_{92}U^{238}$ undergoes fission with fast neutrons whose kinetic energies are greater than 1MeV where as $^{235}_{92}U$ undergoes fission when bombarded with slow neutrons or thermal neutrons whose kinetic energies are ne3aly l0.02MeV.Hence $^{238}_{92}U$ is not suitable for chain reaction.

2. What is nuclear fission? Give an example to illustrate it. Find the energy liberated in the nuclear fission of $^{235}_{92}U$.

Ans: The splitting up of a heavy nucleus into two or more lighter nuclei with the emission of energy is called nuclear fission

Ex: $_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} + E$

Where Q is the energy released in the fission of $_{92}U^{235}$

E = [Total mass of reactants – Total mass of products] C^2

$$= [\,Mass\ of\ {}_{92}U^{235} + Mass\ of\ {}_{0}n^{1}\,] - [\,Mass\ of_{56}Ba^{141} + Mass\ of\ {}_{36}Kr^{92} + Mass\ of\ three\ neutorns\,]C^2$$

$$= [\,Mass\ of\ {}_{92}U^{235} - Mass\ of\ {}_{56}Ba^{141} - Mass\ of_{36}Ba^{92} - Mass\ of\ two\ neutrons\,] \times C^2$$

$= [235.04393 - 140.91770 - 91.89540 - 2 \times 1.008665]C^2$ = 0.2135 x 931.5 = 198.9 MeV

3. Explain the terms. Chain reaction and multiplication factor. How is a chain reaction sustained ?

Ans: **<u>Chain Reaction:</u>** In a nuclear fission reaction three neutrons are released. Each of these neutrons causes further fission in three more Uranium nuclei resulting in release of nine neutrons. These neutrons split nine more nuclei and release 27 neutrons. As this process continues the number of neutrons released increases in geometric progression and this process is called chain reaction.

<u>Neutron multiplication factor</u> The ratio of second generation neutrons to the first generation neutrons is called neutron multiplication factor.

Neutron multiplication factor (K) = $\dfrac{\text{No of neutrons is second generation}}{\text{No of neutrons in the first generation}}$

- **a)** If K < 1, the reaction is not self sustained.
- **b)** It is called sub- critical state.
- **c)** If K = 1, then it is called a controlled chain reaction called critical state.
- **d)** If K>>1, the reaction is self sustained. It is called super critical state (principle of atom bomb).

To sustain the chain reaction the mass of Uranium should be equal to or more than a particular amount of mass called ‘critical mass’**.**

4. In a nuclear reactor, what is the function of (i) moderator, (ii) the control rods, (iii) the coolant and (iv) protective shielding.

Ans: **<u>i) Moderator:</u>** The average energy of neutrons released in the fission process is 2MeV. These are to be slowed down to thermal energies 0.025MeV in moderator material. E.g. Graphite, heavy water, beryllium oxide, hydrocarbon plastics.

<u>ii) Control rods :</u> These are made of nuclear absorbing materials like Cadmium, boron etc. When the control rods are completely inserted into the carbon blocks, they absorb neutrons and the chain reaction completely stopped.

<u>iii) Coolant:</u> The heat generated in the nuclear reactor is removed by using a suitable coolant to flow around them.

iv) Protective shielding : Suitable shielding such as steel, lead, concrete etc, are provided around the reactor to absorb and reduce the intensity of radiations to such low levels that do not harm the operating personnel.

5. Write a note on 'Breeder reactor'

Ans: **Breeder Reactor :** Non-fissionable material such as ^{238}U A can be converted into fissionable material and the reactor produces or 'Breeds' more fuel than it consumes. Such a nuclear reactor is called a breeder reactor.

When ^{238}U is bombarded with fast neutrons the following reaction takes place

$$_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} + \gamma$$

$$_{92}U^{239} \rightarrow {}_{93}NP^{239} + {}_{-1}e^0$$

$$_{93}NP^{239} \rightarrow {}_{94}Pu^{239} + {}_{-1}e^0$$

Thus a non-fissionable U^{238} is converted into fissionable isotope plutonium -239.

6. Write a note on 'Power reactor'

Ans: **Power Reactors:** In the core of a nuclear reactor a large amount of heat energy is liberated. This heat is absorbed by the water present in the cooling system and there by steam is produced. This steam in turn is used to operate the steam turbines which ultimately generate electric power. These reactors are called power reactors.

The power of a nuclear reactor is $P = \left(\frac{n}{t}\right) \times Energy\ released\ per\ fission$

Where $\left(\frac{n}{t}\right)$ is the number of fissions per second

7. Distinguish between 'Nuclear fission' and 'nuclear fusion'

Ans:

Nuclear fission	**Nuclear fusion**
1. The splitting up of a heavy nucleus into two or more lighter nuclei with the emission of energy is called Nuclear fission	**1.** The process in which two or more lighter nuclei combine to form a heavy nucleus with the emission of energy is called Nuclear fusion.
2. 0.09% of mass is converted into energy.	**2.** 0.66% of mass is converted into energy.
3. Energy of 200 MeV is released for each fission	**3.** . Energy of about 28MeV is liberated per fusion

4. It takes place at ordinary temperature	**4.** It require very high temperature of the order if $10^7 K$
5 Less energy per nucleon is released $\left[\frac{200MeV}{235}\ for\, U^{235}\right]$	**5.** More energy per nucleon is released (during fusion of deuteron $\frac{28}{4} MeV$)

8. Explain the source of energy in the Sun.

Ans: A fusion reaction is a powerful source of energy. The emission of energy by sun and stars can be explained based on nuclear fusion. Depending upon the temperature, the energy released may be through carbon nitrogen cycle or proton-proton cycle.

Carbon –Nitrogen Cycle

Bothe (1938) proposed a set of reactions taking place in the central parts of the sun and stars in which carbon and nitrogen act as catalysts.

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$${}_8O^{15} \rightarrow {}_7N^{15} + {}_1e^0 + \upsilon$$

$${}_7N^{15} + {}_1H^1 \rightarrow {}_6C^{12} + {}_2He^4$$

The net result of the above processes can be written as

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The energy released during this process $\gamma = 25.71 Mev$

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The above fusion reactions (a) and (b) must occur twice to yield two $_2He^3$ nuclei. Therefore the next reaction can be written as

$$_2He^3 +_2 He^3 \rightarrow {}_2He^4 + 2_1H^1 + energy$$

The net result of the above reaction is that 4 protons are fused to produce an α-particle and a few other particles and release of a total energy 25.71MeV

$$4_1H^1 \rightarrow {}_2He^4 + 2\ {}_{+1}e^0 + 2v + 2\gamma$$

The proton –proton cycle is an important source of energy in the sum and in stars of comparatively lower temperatures (red dwarfs).

9. What are elementary particles? How are they classified?

Ans: Elementary particle is a particle not known to have substructure (i.e.) it is not known to be made of still smaller particles. It is the basic particles of the universe from which other particles are made.

Elementary particles can be grouped into three families namely photons, leptons and hadrons.

Photons interact only with charged particles and the interaction is electromagnetic. The leptons consist of particles that interact by means of weak nuclear force.

The hardons contains the particles that interact by means of both the strong and weak nuclear forces.

10. What are quarks? How can you express mesons and baryons is terms of quarks?

Ans: Quarks are the elementary particles of hadrons family. Photons and leptons are considered to be elementary particles and they are not composed quarks.

According to quark theory, every meson consists of a quark and its anti-quark. But each Baryon consists of three quarks.

VERY SHORT ANSWER QUESTIONS

1. What are delayed neutrons? What is its importance?

Ans: In nuclear fission process, few neutrons (around 1%) are emitted over a period of time. These neutrons are called delayed neutrons.

Importance : These neutrons play an important role in the working of nuclear reactorby accelerating the fission process.

2. What is a thermal neutron? What is its importance?

Ans: If fast moving neutrons pass through substances like heavy water, paraffin wax, graphite etc., they are slowed down to thermal energy levels. These neutrons are called thermal neutrons. They are used in nuclear fission reactions.

3. What is the role of moderator in a nuclear reactor?

Ans: The moderator is used in the nuclear reactor to slow down the fast moving neutrons produced in the nuclear fission process.

Heavy water, carbon in the form of pure graphite, ordinary water, and beryllium are used as moderators.

4. What is the value of neutron multiplication factor in a controlled chain reaction and in an uncontrolled chain reaction?

Ans: The ratio of second generation neutrons to the first generation neutrons is called neutron multiplication factor.

$$\text{Neutron multiplication factor (K)} = \frac{\text{No of neutrons is second generation}}{\text{No of neutrons in the first generation}}$$

If $K < 1$, the reaction is not self sustained.It is called sub- critical state.
If $K = 1$, then its is called a controlled chain reaction called critical state.
If $K >> 1$, the reaction is self sustained. It is called super critical state (principle of atom bomb).

5. What is the role of control rods in a nuclear reactor?(May2009)

Ans: **C**ontrol rods are the neutron absorbing materials like cadmium, boron etc. which absorbs the neutrons and there by controls the nuclear fission process.

6. Why are nuclear fusion reactions called thermonuclear reactions?

Ans: As nuclear fusion reactions occur at very high temperature, the fusion reactions are called as thermonuclear reactions. Energy of the Sun and Stars is due to nuclear fusion.

7. State the conditions necessary for nuclear fusion.

Ans: Nuclear fusion takes place only at high temperature of about $10^6 K$ and at a high pressure.

8. What is annihilation of matter? Give an example?

Ans: **Annihilation of matter:** The process in which a material particle and its anti particle combine to produce γ-particle is called annihilation of matter.

Ex ; ${}_{-1}e^0 + {}_{+1}e^0 \rightarrow \gamma + \gamma$

When an electron and a positron annihilate, two γ-particles are released. In this process rest mass energy of electron and positron is 0.51MeV.

9. Distinguish between a particle and an antiparticle?

Ans: An antiparticle is a form of matter that has the same mass as that of the particle but carries an opposite charge and/or a magnetic moment that is oriented in opposite direction relative to the spin.

SOLVED PROBLEMS

1. A slow neutron strikes a nucleus of $^{235}_{92}U$ splitting it into lighter nuclei of $^{141}_{56}Ba$ and $^{92}_{36}Kr$ along with three neutrons. Calculate the energy released in this reaction. The mass of uranium, barium and krypton of this reaction are 235.043933, 140.917700 and 91.895400u respectively. The mass of neutron is 1.008665u.

Sol: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + Q$

Where Q is the energy released. Q = (Total mass of reactants – total mass of products) c^2

$$= \left[(mass\,of\ ^{235}_{92}U + mass\,of\ ^{1}_{0}n) - (mass\,of\ ^{141}_{56}Ba + mass\,of\ ^{92}_{36}Kr + mass\,of\ three\,neutrons\right] c^2$$

$$= \left[(mass\,of\ ^{235}_{92}U - mass\,of\ ^{141}_{56}Ba + mass\,of\ ^{92}_{36}Kr - mass\,of\ two\,neutrons\right] c^2$$

$$= (235.043933 - 140.917700 - 91.895400 - 2\times1.008665)u\times c^2$$

= 0.2135 x 931.5MeV = 198.9MeV.

2. A nuclear power reactor generates electric power of 100 MW. How many number of fissions occur per second if nuclear fuel used is the reactor is uranium?

Sol: Power of a reactor $P = \left(\frac{n}{t}\right)\times 200\times10^{6}\times1.6\times10^{-19}\,J$

$$100\times10^{6} = \left(\frac{n}{t}\right)\times200\times1.6\times10^{-13} \quad \Rightarrow \quad \frac{n}{t} = 3.125\times10^{18}\,/\,s.$$

3. Find the kinetic energy of the α-particle emitted in the decay $^{238}_{94}Pu \rightarrow ^{234}_{92}U + ^{4}_{2}He$ .The atomic masses of ^{238}Pu ¸ ^{234}U and α-particle are 238.04955u, 234.04095u and 4.002603u respectively. Neglect any recoil of the nucleus.

Sol: Q = [Total mass of the reactants – Total mass of the products] c^2

$$= [Mass\,of\ ^{238}Pu - (mass\,of\ ^{234}U + Mass\,of\ ^{4}_{2}He]c^2$$

= [238.04955 – (234.04095 + 4.002603)] $u\times c^2$

= (0.0060030) 931.5MeV = 5.592MeV.

This is converted as kinetic energy of the α-particle.

4. **Find the energy released during the most probable fission of ^{235}U. $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$. Average binding energy per nucleon of ^{235}U, ^{141}Ba and ^{92}Kr are 7.61MeV, 8.32MeV and 8.80MeV respectively.**

Sol: Q = Binding energy of ^{141}Ba + Binding energy of ^{92}Kr -Binding energy of ^{235}U

= 141 x 8.32 + 92 x 8.8 – 235 x 7.61 = 194.37MeV

5. **How much ^{235}U is consumed in a day in an atomic power house operating at 400 MW, provided the whole of mass ^{235}U is converted into energy?(March2011)**

Sol: Power = 400 MW = ^{235}U ; time = 1 day = 86,400s

Energy E = power x time = $400 \times 10^6 \times 86,400 = 3.456 \times 10^{13} J$.

$$E = Mc^2 \quad \Rightarrow M = \frac{E}{c^2} = \frac{3.456 \times 10^{13}}{(3 \times 10^8)^2} = 0.384g$$

6. **Calculate the energy released by the fission of 1g of ^{235}U joule, given that the energy released per fission is 200 MeV. (Avogadro's number =** 6.023×10^{23})

Sol: The number of atoms in 1g of $^{235}U = \frac{\text{Avogadro's number}}{\text{mass number}} = \frac{6.023 \times 10^{23}}{235} = 2.563 \times 10^{21}$

Energy released per fission = 200 MeV = 200 x $10^6 \times 1.6 \times 10^{-19} = 32 \times 10^{-11} J$

Energy released by 1g of ^{235}U = Number of atoms x Energy released per fission

$$= 2.563 \times 10^{21} \times 3.2 \times 10^{-11} J = 8.202 \times 10^{10} J$$

7. **The binding energies per nucleon for deuteron $\left(^{2}_{1}H\right)$ and helium $\left(^{4}_{2}He\right)$ are 1.1MeV and 7.0MeV respectively. Calculate the energy released, when two deuterons fuse to form a helium nucleus**

Sol: The fusion reaction is $2\left(^{2}_{1}H\right) \rightarrow ^{4}_{2}He + Q$

Q = Total binding energy of the product $^{4}_{2}He$ - Total binding energy of reactant

= 4 x 7.0 – 4 x 1.1 = 28.0 – 4.4 = 23.6MeV.

UNSOLVED PROBLEMS

1. **An explosion of atomic bomb releases an energy of $7.6\times10^{13} J$. If 200 MeV energy is released on fission of one U^{235} atom. Calculate (i) the number of uranium atoms undergoing fission (ii) the mass of uranium used in the bomb.**

Sol: 1) Number of atoms $= \dfrac{\text{Total energy}}{\text{Energy released fission of each atom}}$

$$N = \frac{7.6\times10^{13} J}{200\times10^{6}\times1.6\times10^{-19} J} = 2.375\times10^{24}$$

2) Mass of uranium $= \dfrac{2.375\times10^{24}}{6.023\times10^{23}}\times235 = 926.66\, gms$

2. **If one microgram of ${}_{92}U^{235}$ is completely destroyed in an atom bomb, how much energy will be released?(March2010)**

Sol: Mass = 1 microgram $=10^{-9} kg$

Energy $E = mc^2 = 10^{-9}\times(3\times10^{8})^2 = 9\times10^{7} J$

3. **Calculate the energy released by fission from 2gm of ${}_{92}U^{235}\ m$ kwh. Given that the energy released per fission is 200MeV.**

Sol: For one 'U' atom, energy released is 200MeV = $200\times10^{6}\times1.6\times10^{-19} J$

Number of atoms in 2 gm of ${}_{92}U^{235}$ = $\dfrac{2}{235}\times6.023\times10^{23}$

Energy released by 2gm of U^{235} = $\dfrac{2}{235}\times6.023\times10^{23}\times200\times10^{6}\times1.6\times10^{-19} J$

$$= \frac{16.40\times10^{20}}{3.6\times10^{6}} = 4.54\times10^{4}\, kwh$$

4. **200MeV energy is released when one nucleus of U^{235} undergoes fission. Find the number of fissions per second required for producing a power of 1 megawatt.**

Sol: $1Mw = 10^{6} J/s$, Number of atoms = $\dfrac{10^{6}}{200\times10^{6}\times1.6\times10^{-19}}$

$$N = \frac{10^{19}}{200\times1.6} = \frac{10\times10^{16}}{2\times1.6} = 3.125\times10^{16}\, atoms$$

5. **If uranium -238 disintegrates into ${}_{90}Th^{234}$ and an alpha particle ${}_{2}He^{4}$, calculate the total energy released during the fission. Given that mass of ${}_{90}Th^{234}$ = 234.11650 amu mass of ${}_{2}He^{4}$ = 4.00387 amu.**

Sol: $_{92}U^{235} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$

$E = \Delta m\ c^2$; Q = [238.12492 – 234.11650 – 4.00387] x 931.5; Q = 4.237MeV

ASSESS YOUR SELF

1. **Why is a nucleus compared with a liquid drop?**

A. Because nucleus has properties like short range and saturation nature of nuclear force which are ` similar to that of the forces in a liquid drop.

2. **Even if some of the γ - rays and X-rays have same wavelength, how can they be distinguished?**

A. X-ray emission is an atomic phenomenon γ-ray emission is a nuclear phenomenon

3. **When a nucleus undergoes β-decay an electron is emitted. Does this mean that a nucleus consists of electron also?**

A. No. When a neutron inside a nucleus converts into a proton an electron is emitted.

4. **Which types of decay does not change the parent element and why?**

A. γ-decay, because γ-rays have no charge and no mass.

5. **The rate of radioactive decay is independent of the external physical conditions like temperature, pressure. Why?**

A. Because the radioactive decay is a nuclear phenomenon.

6. **Why doesn't do the nucleus collapse despite the strong attractive forces between the nucleons?**

A. Because when two nucleons are within a distance of about 0.4 fm, the nuclear force becomes repulsive.

7. Which is the best projectile for a nuclear reaction?

A. Neutron, since it is electrically neutral.

8. Does nuclear fission occur in nature spontaneously in a mass of uranium?

A. yes, since there are always some stray neutrons in any mass of uranium produced by cosmic rays and they produce nuclear fission in U – 235.

9. Does chain reaction occur in nature in a mass of uranium?

A. No, since the chain reaction is prevented by the presence of the 140 times more abundant uranium -238.

10. **It is said what the ratio of rate of escape of neutrons to the rate of their production varies inversely as the radius of the spherical mass of a fissile material. Why?**

A. Escape of neutron is a surface effect and is proportional to the square of the radius where as the production of neutrons is due to fission which is a volume effect proportional to the cube of the radius

11. **Is it possible to divide a uranium nucleus into two equal parts in a fission process?**

A. Yes, but only rarely.

12. **What conservation principle is obeyed by fission products?**

A. Principles of conservation of momentum and energy are obeyed.

13. **When uranium nucleus breaks into two pieces of unequal masses which of the two (heavier or lighter) has greater kinetic energy and greater linear momentum?**

A. Principles of conservation of momentum and energy are obeyed.

14. **Can fission be induced by bombarding with particles other than neutrons?**

A. Yes, high speed protons, deuterons and α-particles.

15. **Why do the breeder reactors is more compact than ordinary reactors?**

A. Because, breeder reactors do not use moderators.

16. **Can fusion occur in nature on the earth?**

A. No. since the required temperature are not available on the earth.

17. **Which releases greater energy per nucleon – fission or fusion?**

A. Fusion releases greater energy per nucleon since fusion releases energy of about 6.5MeV per nucleon where as fission releases an energy of about 0.9MeV per nucleon.

18. **If it is possible to convert matter completely into energy when electron and position combine, is it possible to produce an electron and positron pair by means of γ-radiation ?**

A. Yes, when a γ-radiation of minimum energy of 1.02MeV goes into the electric field outside the nucleus an electron and a positron pair is created. This phenomenon is called pair production.