CHAPTER4: NUCLEAR STRUCTURE

The nucleus is the central positively charged part of an atom.
Nuclei contain protons and neutrons which are collectively referred to as **nucleons (nuclear number)**.

4.1.0: ATOMIC NUMBER Z, MASS NUMBER A AND ISOTOPES

Atomic number Z of an element is the number of protons in the nucleus of an atom of the element.
Mass number A of an atom is the number of nucleons in its nucleus.
Isotopes are atoms of the same element with the same atomic number but different mass numbers.
Isotopes of an element whose chemical symbol is represented by X can be distinguished by using the symbol $^{A}_{Z}X$
Where **A** is mass number and **Z** is atomic number
Example of isotopes
Isotopes of Lithium $^{7}_{3}Li$ and $^{6}_{3}Li$
Isotopes of uranium $^{235}_{92}U$ and $^{238}_{92}U$
Isotones are nuclei with the same number of neutrons
Isobars are nuclei with the same number of nucleons.

4.1.1: EINSTEIN'S MASS – ENERGY RELATION

Einstein showed from his theory of relativity that mass (m) and energy (E) can be changed from one form to another.
The energy Δ**E** produced by a change of mass Δ**M** is given by the relation.

$$\boxed{\Delta E = \Delta MC^2}$$

Where C is the speed of light (C= $3 \times 10^8 ms^{-1}$)

Example

The sun obtains energy from fusion process. The sun radiates $4.0x10^{23}kW$ at a constant rate and 0.7% of its mass is converted into a radiation during fusion. Determine the life of the sun in years

Solution

$$\Delta E = \Delta MC^2$$
$$pt = \Delta MC^2$$
$$4.0x10^{26}t = \frac{0.7}{100}x2.0x10^{30}x(3.0x10^8)^2$$
$$t = 3.15x10^{18} = \frac{3.15x10^{18}}{365x24x3600} = 9.99x10^{10}years$$

4.1.2: UNIFIED ATOMIC MASS UNIT [U]

It is defined as $^1/_{12}$ of the mass of carbon–12 atom.

6.02×10^{23} atoms has a mass of 12g of carbon -12

6.02×10^{23} atoms $= 12x10^{-3}kg$

1atom $= \frac{12\,x\,10^{-3}}{6.02x10^{23}}$

1unified atomic mass $= {}^1/_{12}\,x\,\frac{12\,x\,10^{-3}}{6.02x10^{23}}$

$= 1.661129568\,x\,10^{-27}kg$

$$\boxed{1U = 1.66\,x\,10^{-27}kg}$$

From Einstein's mass – energy relation

$\Delta E = MC^2$

$1U = 1.661129568\,x\,10^{-27}\,x\,(2.998\,x\,10^8)^2$

$1U = 1.49302392\,x\,10^{-10}J$

$1eV = 1.602x10^{-19}J$

$1U = \frac{1.49302392\,x\,10^{-10}}{1.602x10^{-19}}eV$

$1U = 931.97\,x\,10^6eV$

$$\boxed{1U = 931MeV}$$

MASS DEFECT AND BINDING ENERGY

a) MASS DEFECT

It is defined as the mass equivalence of the energy required to split the nucleus into its constituent particles.

OR

It is the difference in the mass of the constituent nucleons and the nucleus of an atom.

$$\boxed{Mass\ defect = (mass\ of\ nucleons\ and\ elctrons) - (mass\ of\ atom)}$$

Note

The reduction in mass arises because the act of combining the nucleons to form the nucleus causes some of their mass to be released as energy (in form of γ-rays).

Any attempt to separate the nucleons would involve them being given this same amount of energy; it is therefore called the **binding energy** of the nucleus.

b) BINDING ENERGY (B.E)

- Binding energy of the **nucleus** is the energy required to break up the nucleus into it's constituent nucleons
- Bind energy per nucleon is the ratio of the energy needed to split a nucleus into it's constituent nucleons to the mass number.

$$\boxed{\text{B.E per nucleon} = \frac{B\ E}{\text{Mass number}}}$$

Binding energy per nucleon is very useful in measure of the stability of the nucleus. The higher the binding energy per nucleon the more stable the nucleus is.

Binding energy (J) = mass defect (kg) x $C^2 (ms^{-1})^2$

Where 1U = 1.66×10^{-27}kg

OR

Binding energy (MeV) = mass defect (U) x 9.31 (MeV)

Where 1U = 931MeV

Example

1. Given atomic mass of $^{238}_{92}U$ = 238.05076U

   $mass\ of\ neutron = 1.00867U$

   $mass\ of\ proton = 1.00728U$

   $mass\ of\ electron = 0.00055U$

   1U = 931MeV

   Find; a) mass defect b) B.E per nucleon for $^{238}_{92}U$

Solution

Mass defect=(mass nucleons + electrons)−(mass of nucleus)

number of protons = 92

number of electrons = 92

number of neutrons = (238 − 92) =146

$$\text{Mass defect} = \begin{pmatrix} 146x1.00867 \\ + \\ 92x1.00728 \\ + \\ 92x0.00055 \end{pmatrix} - (238.05076)$$

$$= 239.98618 - 38.05076$$

$$\text{Mass defect} = 1.93542U$$

b) B.E per nucleon = $\frac{B\ E}{\text{Mass number}}$

B.E = mass defect x 931

= 1.93542 x 931

= 1801.87602MeV

B.E per nucleon = $\frac{1801.87602}{238}$

B.E per nucleon =7.571MeV

2. Given mass of proton = 1.0080U

   Mass of neutron= 1.0087U

Mass of alpha particle = 4.0026U

1U = 931MeV

Find:

a) mass defect in (i) U (ii) kg

b) Binding energy in (i) MeV (ii) J

c) Binding energy per nucleon in (i) MeV (ii) J

Solution

An alpha particle is a helium nuclei $^{4}_{2}He$

a) Mass defect = (mass of nucleons) - (mass of a tom)

number of protons = 2

number of neutrons = 2

i) mass defect = (2 x 1.0080 + 2 x 1.0087) – 4.006

= 0.0308U

ii) mass defect in kg

1U = 1.66 x 10^{-27}kg

Mass defect = 0.0308 x 1.66 x 10^{-27}kg

= 5.1128 x 10^{-29}kg

b)(i) Binding energy (MeV)=mass defect x 931MeV

=0.00308 x 931

=28.6748MeV

ii) Binding energy (J) =28.6748 x 10^{6} x 1.6 x 10^{-19}J

= 4.59 x10^{-12}J

Or Binding energy (J) = mass defect (kg) xC^2(ms^{-1})^2

=5.1128 x 10^{-29} x $(3x10^8)^2$

= 4.60 x 10^{-12}J

c)(i) Binding energy per nucleon = $\frac{B\ E}{\text{Mass number}}$

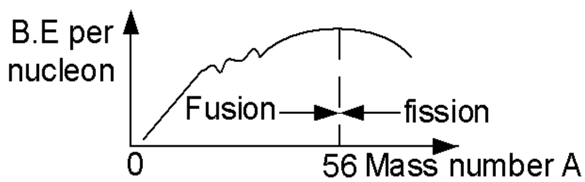
= $\frac{28.6748}{4}MeV$

= 7.17MeV

ii) Binding energy per nucleon =7.17 x 10^{6} x 1.6 x 10^{-19}

= 1.15 x 10^{-12}J

4.1.4: VARIATION OF B.E PER NUCLEON WITH MASS NUMBER



- Binding energy per nucleon for very small and large nuclides is small.
- A few peaks for low mass numbers are for lighter nuclei that are comparatively stable.
- The binding energy per nucleon increases sharply to a maximum at mass number 56
- For A> 56 binding energy per nucleon gradually decreases

NOTE

The low binding energy per nucleon value for small and high mass number nuclide implies that they are potential sources of nuclear energy because they easily undergo fusion and fission respectively.

4.1.5: Explanation of fusion and fission using the graph

- **During nuclear fusion** two light nuclei unite to form a heavier nucleus of a smaller mass but a higher binding energy per nucleon. The mass difference is accounted for by the energy released.
- **During Nuclear fission**, a heavy nucleus splits to form two lighter nuclei of smaller masses but a higher binding energy per nucleon. The mass difference is accounted for by the energy released

4.2.0: RADIO-ACTIVITY (RADIOACTIVE DECAY)

Radioactivityis the spontaneous disintegration of a radioactive atom into more stable nuclei with emission of radiations.

Heavy nuclides are generally unstable if there are too many neutrons or too many protons. This is because too many protons increases electrostatic repulsion between themselves. This force may not be counter balanced by the nuclear force. Hence nuclus becomes unstable

Radio-activity is said to be a random process because no particular pattern is followed.

Radioactive –isotopes

Are atoms of the same element with the same atomic number but different mass numbers

USES RADIOACTIVITY(radio-active isotopes)

- Treatment of cancer
- Used in carbon dating
- Detection of leaks in pipes
- Production of energy in nuclear reactors
- Measurement of thickness of metal sheet during manufacture
- Inautomobile industry to test the quality of steel in manufacture of cars
- Tracers to investigate flow of fluids in chemical plants
- In construction to gauge the density of the road surface

Health hazard

- Causes genetic Mutation (genetic changes)
- Causes Cancer
- Destroys eye sight
- Causes deep seated wounds in humans

Precautions

- Lead aprons should be worn when dealing with radiations
- Avoid unnecessary exposure to the radiations
- Delicate parts should not be exposed to the radiations
- Should be stored in thick walled containers

4.2.1: TYPES OF IONISING RADIATIONS

a) **Alpha particles** ($\propto$)

They have a mass of 4times that of hydrogen atom and a charge of +2e where e is the numerical charge on an electron hence they are Helium nuclei [^4_2He]

Properties

- They have the least penetrating power among the ionizing radiations.
- They are positively charged hence can be deflected by electric and magnetic field
- They are the best ionizers of gases
- They have the shortest range in air among the ionizing radiations
- When emitted, they are emitted with the same speed

Note

When a nucleus undergoes $\propto -$ decay it loses four nucleons, two of which are protons, therefore atomic number Z decreases by two.

Thus if a nucleus X becomes a nucleus Y as a result of $\propto$ −decay then.

$$^A_ZX \rightarrow \quad ^{A-4}_{Z-2}Y \quad + \quad ^4_2He$$

(Parent) (Daughter) ($\propto$ Particle)

$E.g$ Uranium − 238 decays by $\propto$ −emission to thorium 234 according to

$$^{238}_{92}U \longrightarrow \ ^{234}_{90}Th + ^4_2\propto$$

b) Beta particle (β)

It is an electron which is moving at a high speed. It is represented as [$_{-1}^{0}e$]

Properties

- It has a higher penetrating power than ∝particle
- It is negatively charged hence deflected by electric and magnetic field.
- It is a moderate ionizer of gases
- It has a moderate range in air
- β particles are emitted by nuclei with various speeds
- It is lighter than ∝ −particle

Note

β-particles are emitted by nuclei which have too many neutrons to be stable. To gain a stable state one of its neutrons should change into a proton and an electron, when this happens the electron is immediately emitted as a β-particle.

Thus when a nucleus undergoes β-decay, it's mass number A does not change and it's atomic number Z increases by one

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

(Parent) (Daughter) (β - Particle)

$E.g$ Carbon-14 decays by β-emission to nitrogen- 14 according to

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

c) Gamma rays (γ)

They are electromagnetic waves of very short wave length and they travel with a velocity of tight.

Properties

- They have the highest penetrating power
- They are electrically neutral hence they can't be deflected by electric or magnetic field
- They are the poorest ionizers of gases
- They can be diffracted and refracted

4.2.2: ENERGY OF DISINTEGRATION (Q-value)

If the total mass of reactant is greater than the total mass of products then the reaction is **exothermic** otherwise its **endothermic**

Example

1: ${}^{210}_{84}Po \rightarrow {}^{4}_{2}He + {}^{206}_{82}Pb$

Atomic mass of ${}^{206}_{82}Pb$ =205.969U

Atomic mass of ${}^{4}_{2}He$ = 4.003U

Atomic mass of ${}^{210}_{84}Po$ = 209.983U

i) State whether the disintegration is endothermic or exothermic and calculate the energy of disintegration.

ii) Calculate energy of the α −particle

Solution

Mass of reactant = 209.983U

Mass of product= 205.909U + 4.003U

= 209.972U

Since mass of reactant is greater than the total mass of products then its exothermic.

Therefore ${}^{210}_{84}Po \rightarrow {}^{4}_{2}He + {}^{206}_{82}Pb + Q$

Energy of disintegration = mass defect x 931MeV

= (209.983 – 209.972) x 931MeV

= 0.011 x 931MeV

= 10.24MeV

Note Q-value appears as the kinetic energy of the products

$K.e_{\alpha}= \frac{M}{M+m_{\alpha}}Q$ where

$m_{\alpha}$is the atomic mass of the α -particle

M is atomic mass of daughter atom

$K.e_{\alpha}$ = $\frac{206}{206+4}10.24$

$K.e_{\alpha}$ =10.05MeV

2. Consider the equation ${}^{206}_{82}Pb + Q \rightarrow {}^{4}_{2}He + {}^{202}_{80}Hg$

Atomic mass of Hg = 201.971U
Atomic mass of He = 4.003U
Atomic mass of Pb = 205.969

Calculate i) Q –value

ii) kinetic energy of the α-particle

Solution

i) Q = mass x 931MeV

Q = ((201.971 + 4.003) – 205.969) x 931MeV

0.005 x 931MeV

Q-value = 4.66MeV

ii) $K.e_{\alpha}=\frac{M}{M+m_{\alpha}}Q$

$K.e_{\alpha}$ = $\frac{202}{202+4}4.66$

$K.e_{\alpha}$ = 4.57MeV

Generally: A nucleus would tend to be unstable and emit an α-particle, if the sum of the atomic masses of the products are together less than that of the nucleus and it would be stable if the sum of the atomic masses of the possible reaction products are together greater than the atomic mass of the nucleus.

EXERCISE 10

1. $^{210}_{84}Po$ decays to Pb-206 by emission of alpha – particle of single energy
   (i) Write down the symbolic equation for the reaction
   (ii) Calculate the energy in MeV released in each disintegration
   (iii) Explain why this energy does not all appear as kinetic energy of the alpha particle.
   (iv) Calculate the kinetic energy of the alpha particle

   210Po = 209.93673U
   206Pb = 205.929421U
   4He = 4.001504U
   1U = 931MeV **An (5.40MeV, 5.3MeV)**

2. Consider the decay process represented by

   $^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn \quad + {}^{4}_{2}He$

   Calculate the kinetic energy of the alpha particle

   $^{226}_{88}Ra$ = 226.0254U
   $^{222}_{86}Rn$ = 222.0175U
   $^{4}_{2}He$ = 4.0026U **An (4.93MeV)**

4.2.3: ARTIFICIAL DISINTEGRATION (Nuclear reaction)

This is achieved by bombarding the nuclei with an energetic particle.

The bombarding particle acquires enough energy by being accelerated in a reasonable speed by use of electric fields except the neutron.

$$Eg\ {}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{2}O \quad + {}^{1}_{1}H$$

Beta particle as a bombarding particle

Advantage

- It can be accelerated at a high speed using electric field.

Disadvantages

- It experiences electrostatic repulsion with shell electrons
- It is light

Alpha particle as bombarding particle

Advantages

- It can be accelerated to high speed using electric field
- It is fairly heavy

Disadvantage

- It experiences electrostatic repulsion with positive nucleus

Neutron as a bombarding particle

- This is the best particle for study of nuclear reactions. Being electrically neutral it nether experiences electrostatic repulsion in the shell electrons nor the nucleus.
- However, it cannot be accelerated to high speeds using electric fields.

Energetic neutrons for nuclear reactions are obtained from nuclear reactants by the process of fusion.

4.2.4: NUCLEAR FISSION

Nuclear fission is the disintegration of a heavy nucleus into two lighter nuclei accompanied by release of energy..

Energy is released by the process because the average binding energy per nucleon of the fission products is greater than that of the parent.

$e.g \quad {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{148}_{57}La + {}^{85}_{35}Br + 3\,{}^{1}_{0}n + Q$

Example

Calculate the energy released by 1kg of ${}^{235}_{92}U$ under going fission according to

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{148}_{57}La + {}^{85}_{35}Br + 3\,{}^{1}_{0}n + Q$$

Mass 235U = 235.1U

Mass of 148La = 148.0U

Mass of ${}^{1}_{0}n$ = 1.009U

Mass of 85Br = 84.9U

Solution

Mass of reactants =235.1 + 1.009= 236.109U

Mass of products=(148.0 + 84.9 + (3 x 1.009))

= 235.927U

Energy released=mass defect x 931MeV

= (236.109 – 235.927) x 931MeV

=169.442MeV

Energy released =169.442 x 10^{6} x 1.6 x 10^{-19}J

= 2.71 x 10^{-11}J

Numbe of atoms = $\frac{m}{M} N_A$ atoms

1 kg contains = $\frac{1x6.02\ x\ 10^{23}}{235 \times 10^{-3}}$ = 2.562 x 10^{24} atoms

One atom released =2.71 x 10^{-11}J

2.562 x 10^{24} atoms =2.71 x 10^{11} x 2.562 x 10^{24}J

= 6.943 x 10^{13}J

Energy released by 1kg of uranium = 6.943 x 10^{13}J

Exercise: 57

1. Calculate the energy released when 10kg of ${}^{235}_{92}U$ undergoes fission according to;

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

(mass of 235U = 235.04U, of 41Ba = 140.91U, of 92Kr = 91.91U of 1n = 1.01U and 1U = 931MeV, N_A = 6.02 x 10^{23}mol^{-1})

An (7.36 x 10^{14}J or 4.77 x 10^{27}MeV)

2. Atypical fission reaction is as below;

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{95}_{42}Mo + {}^{139}_{35}La + 2\,{}^{1}_{0}n + 7\,{}^{0}_{-1}e$$

Calculate the total energy released by one gram of uranium – 235 undergoing fission, neglect the masses of the electron

(mass of 1n = 1.009U, of 95Mo = 94.906U of 139La = 138.906U of 235U =235.044U, 1U = 931MeV). **An (8.51 x 10^{10}J)**

Application of fission

- In the production of neutrons
- In production of atomic bombs

Condition for fission

- It requires an energetic particle like a neutron

4.2.5: NUCLEAR FUSION

Nuclear fusion is the union of two light nuclei to form a heavier nucleus accompanied by release of energy. Energy is released in the process.

An example is the fusion of two deuterium nuclei to produce helium -

$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He \qquad + ^{1}_{0}n$

Examples

1. $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He \qquad + ^{1}_{0}n$

Calculate the amount of energy released by 2kg of Deuterium given (2H = 2.015U, 1n = 1.009U, 3He = 3.017U)

Solution

Mass of reactant = 2.015 + 2.015 = 4.03U

Mass of products = 3.017 + 1.009 = 4.026U

Mass defect = 4.03 – 4.026 = 0.004U

Energy released = Mc^2

= 0.004 x 1.66 x 10^{-27} x $(3 \times 10^8)^2$

= 5.976 x 10^{-13}J

Energy released by 2 atoms of $^{2}_{1}H$ = 5.976 x 10^{-13}J

Energy released by 1 atom of $^{2}_{1}H$ = $\frac{5.976 \times 10^{-13}}{2}$

Energy released by 1 atom $^{2}_{1}H$ = 2.988 x 10^{-13}J

Numbe of atoms = $\frac{m}{M} N_A$ atoms

2 kg contains = $\frac{2x6.02 \times 10^{23}}{2 \times 10^{-3}}$ = 6.02 x 10^{26} atoms

1 atom of $^{2}_{1}H$ = 2.988 x 10^{-13}J

6.02 x 10^{26} atoms = 2.988 x 10^{-13} x 6.02 x 10^{26}

= 1.799 x 10^{14}J

Energy released by 2kg = 1.799 x 10^{14}J

EXERCISE:58

$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He \qquad + ^{1}_{0}n$

How much Energy in Joule is released

(mass of 2H = 3.345 x 10^{-27}kg, of 3H = 5.008 x 10^{-27}kg, of 4He = 6.647 x 10^{-27}kg of 1n = 1.675 x 10^{-27}kg c = 3 x 10^8ms^{-1})

An (2.79 x 10^{-12}J)

Condition for fusion

- High temperatures (in excess of 10^8K) are required to provide the nuclei which are to fuse with the energy needed to overcome their mutual electrostatic repulsion.

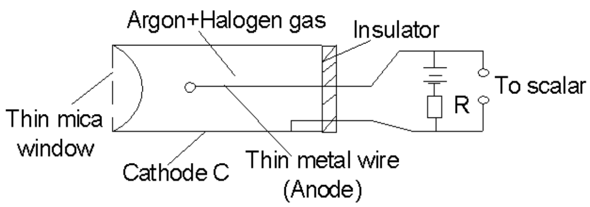
Note

- Fusion is the basis of hydrogen bond
- Solar energy is produced by the process of fusion.

4.2.6: DETECTION OF IONISING RADIATIONS

1. THE GEIGER – MULLER TUBE / (GM) TUBE

Gm tube is a very sensitive type of ionization chamber which can detect single ionizing events



- When Ionising radiations enter the G.M tube through the thin mica window, argon atoms are ionised
- The electrons move very fast to the anode and the positive ions drift to the cathode.
- When electrons reach anode, a discharge occurs and a current flows in the external circuit.
- A p.d is obtained across a large resistance R which is amplified and passed to a scale
- The magnituide of the pulse reigitsered gives the extent to which ionisatin occurred.

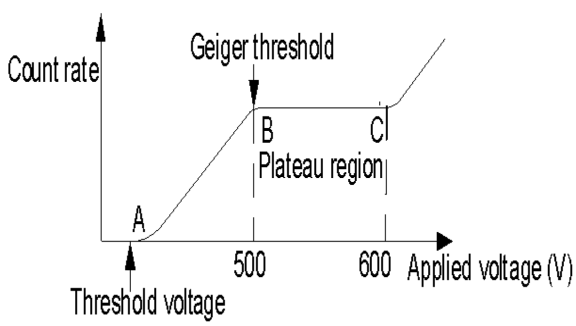
Note

- To prevent a second avalanche due to positive ions, a halogen gas ($e.g$ Bromine) is mixed with the argon gas to form **a quenching agent**.
- Bromine water acts as a quenching agent so as to prevent secondary electrons to be emitted from the cathode by the positive ions bombarding it.
- An avalanche is a large number of moving ionised particles created as a result of secondary ionisation due to collisions between ions and the gas atoms, when the ions are accelerated by a high enough p.d where each ionisation leads to the formation of more ions pairs which themselves cause further ionisation.

Definitions

- A **quenching agent** is a halogen gas placed in a GM-tube to prevent positive ions from causing the release of electrons from the cathode.
- Time taken by the positive ions to travel towards the cathode is called **dead time**.

G.M tube characteristic curve

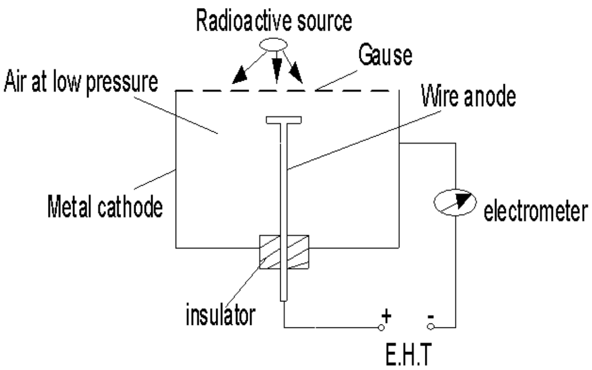


- Up to the threshold voltage no counts are recorded at all since the amount of electron amplification is not enough to give pulses of sufficient magnitude to be detected.
- Between A and B, the magnitude of pulse developed in the tube depends on the initial ionization which in turn depends on the energy of the incident ionizing particle. Only some of the freed electrons give pulses of sufficient magnitude to be recorded but their number increases with applied voltage.
- Between B and C (plateau region), the count rate is almost constant. A full avalanche is obtained along the entire length of the anode and all particles whatever their energy produce detectable pulses.
- Beyond C, the count rate increases rapidly with voltage due to incomplete quenching. One incident ionizing particle may start a whole train of pulses.

Note:

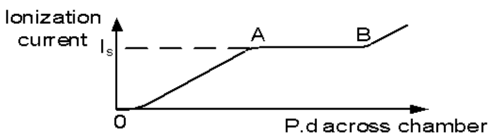
GM tubes should be operated in the plateau region (500 – 600V) preferably in the middle of the region. The sensitivity is then greatest and independent of supply voltage such that every particle that produced ionization is detected.

2. THE IONISATION CHAMBER



- The ionization radiation enter through the thin wire gauze and ionises the air molecules.
- The ions produced are accelerated by E.H.T to their respective electrodes
- The electrons move towards the anode and the positive ions towards the anode.
- Current flows flows in the external circuit which is amplified and detected by electrometer
- The pulse per second (count rate) gives a measure of the intensity of radiation

Variation of the ionization current with $p.d$ (x-tic curve for ionization chamber)



- Between O and A, the $p.d$ is not large enough to draw all the electrons and positive ions to their respective electrodes. As the p.d increases more ions reach the electrode increasing the current.
- Between A and B, all the ions are attracted to their respective electrodes and there is no recombination. So the current reaches it's saturation value (Is) and remains constant as the p.d changes.
- Beyond B, the $p.d$ is large enough to cause secondary ionization. A point is reached when there is rapid multiplication of the ions in the chamber (gas amplification) thereby causing uncontrollable increase in the ionizing current.

Note:

(1) The $p.d$ at which an ionization is operated should be such that the ionization current has its saturation value. Under such condition;

(i) The ionization current is independent of fluctuations in supply voltage

(ii) The ionization current is proportional to the rate at which ionization is being produced in the chamber.

(2) Saturation current I_s is a measure of the rate of primary ionization.

$$\boxed{I_s = ne}$$

Where e = 1.6 x10^{-19} C, n is the number of primary ion pair produced per second.

Calculation on ionization chamber

1. If 32eV is required to produce an ion-pair in air, calculate the current produced when an alpha particle per second from a radium source is stopped inside an ionization chamber, the energy of alpha particles from a radium source is 4.8MeV

Solution

32eV produces one ion pair

4.8x10^{6}eV will produce = $\frac{1}{32}x4.8x10^6$

= 1.5x10^5 ion pairs

But I = ne

I = 1.5x10^{5}x1.6x10^{-19} = 2.4x10^{-14}A

2. A radioactive source emits 2x10^5 alpha particles per second. The particles produce a saturated current of 1.1x10^{-8} in an ionization chamber. If the energy required to produce an ion pair is 32eV. Determine the energy in MeV of an alpha particle emitted by the source.

Solution

From I= ne

$n = \frac{1.1x10^{-8}}{1.6x10^{-19}}$= 6.875x$10^{10}$ ion pairs

One ion pair produces 32eV

6.875x10^{10} ion pairs will produce 6.875x10^{10}x32eV

= 2.2x10^{12}eV

Energy of an alpha particle = $\frac{total\ energy}{no\ of\ \alpha-\ particle}$

$= \frac{1.1x10^{12}}{10^5}eV$= 1.1x$10^7$eV= $\frac{1.1x10^7}{10^6}MeV$

Energy of an α-particle = 11MeV

3. A radioactive source produces alpha particles each of energy 60MeV. If 20% of the alpha particles enter the ionization chamber, a current of 0.2μA flows. Find the activity of the alpha source, if the energy needed to make an ion pair in the chamber is 32MeV.

Solution

I = ne

$\frac{0.2x10^{-6}}{1.6x10^{-19}} = n$

n = 1.25x10^{12} ion pairs

one ion pair requires 32MeV

1.25x10^{12} ion pairs will require 32x1.25x10^{12}

= 4x10^{13}MeV

Energy of an alpha particle = $\frac{total\ energy}{no\ of\ \alpha-\ particle}$

$60\ = \frac{32x1.25x10^{12}}{number\ of\ alpha\ particles}$

Number of alpha particles = $\frac{32x1.25x10^{12}}{60}$

= 6.667x10^{11} alpha particles

If A is the activity then

Number of particles = $\frac{20}{100}A$

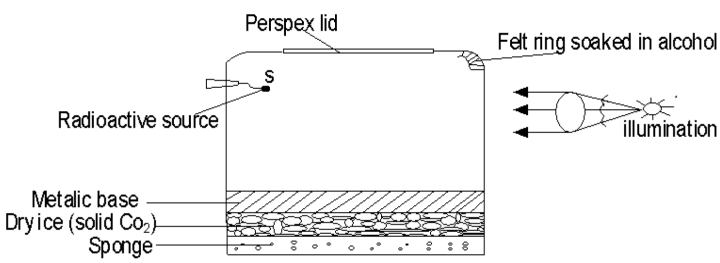
6.667x10^{11} = $\frac{20}{100}A$

A = 3.33x10^{12}s

CLOUD CHAMBERS

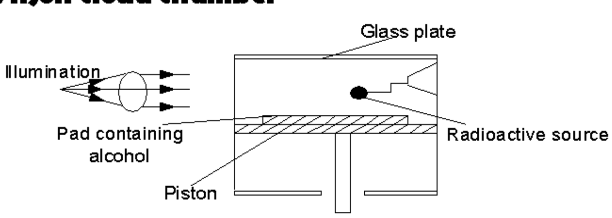
The cloud chamber is used to show tracks of the radioactive particles rather than to measure the intensity of the cloud chambers are;

DIFFUSION CLOUD CHAMBER



- From the diagram above the base of the chamber is maintained at about -80°C and the top is at room temperature so that there is a temperature gradient between the top and bottom.
- The air in the chamber is saturated with alcohol, where the vapour diffuses continuously from the top to the bottom and the air above the metal base becomes supersaturated.
- Then the radioactive particles cause ionisation of the air molecules
- The saturated vapour condenses on the ion formed producing tracks which can be seen by looking through the lid, hence radiation is detected

Wilson cloud chamber



- The piston is moved down quickly so that the air in the chamber undergoes an adiabatic expansion and cools.
- Dusts nuclei are carried away by drops forming on air after a few expansions. The dust free air is subjected to a controlled adiabatic expansion, where by it becomes super saturated and it is exposed to the radioactive source.
- Water droplets collect round the ions producing tracks viewed through the glass plate

4.3.0: THE RADIOACTIVE –DECAY LAW [$N = N_0 e^{-\lambda t}$]

Activity is the number of decays per second. OR it is the number of radiations emitted per second.

$$\boxed{A = \lambda N}$$

Where A is activity or count rate per second.
The S.I unit for activity (A) is Becquel (Bq)

Decay constant is the fraction of radioactive atoms which decay per second.

4.3.1:HALF LIFE [$t_{\frac{1}{2}}$]

Half life of a radioactive element is the time taken for half of the atoms to decay

Relation between half life and decay constant

If N_0 is the number of original atoms at $t = t_{\frac{1}{2}}$, $N = \frac{N_0}{2}$

From $N = N_0 e^{-\lambda t}$

$$\frac{N_o}{2} = N_o e^{-\lambda t_{1/2}}$$

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

Taking logs to base e on both sides

$$In(\frac{1}{2}) = Ine^{-\lambda t_{1/2}}$$

$$In\left(\frac{1}{2}\right) = -\lambda t_{1/2}$$

$$t_{1/2} = \frac{-In(1/2)}{\lambda} = \frac{In2}{\lambda}$$

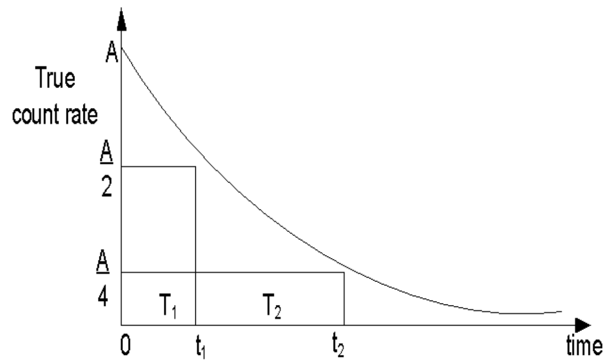
$$\boxed{t_{1/2} = \frac{0.693}{\lambda}}$$

Note: Activity A at any one given time t is given **by** $A = A_0 e^{-\lambda t}$

Measurement of half-life

(a) Half-life of short lived isotopes

- Switch on the G.M.T, note and record the background count rate A_O .
- Place a source of ionising radiation near the GM-tube window. Note and record the count rate at equal tim intervals
- For each count rate recorded, substrate the background countrate to get true countrate.
- A graph of true counte rate against time is plotted
- Find the time T_1 taken for acitivity to rduce to $\frac{A}{2}$ and time T_2 taken for activity to reduce to $\frac{A}{4}$ from $\frac{A}{2}$. Half life=$\frac{1}{2}(T_1 + T_2)$



Measurement of long Half-life (days and years)

- A small mass, m of the specimen of relative molecular mass, M is weighed and noted
- The number of atoms, N in mass, m is determined from $N = \frac{m}{M} x6.02x10^{23}$
- The count rate of specimen, λN all round the specimen is determined by placing the specimen at a distance R from the window of G.M.T of area A connected to the counter
- The decay constant is then determined from $\lambda N = \frac{4\pi R^2}{A} C$ where C is count rate through the area
- Half-life is then determined from $t_{\frac{1}{2}} = \frac{0.693}{\lambda}$

Note:

Background count rate is the activity detected by GM-tube in the absence of a radioactive source

Examples

1. A point source of alpha particles containing a tiny mass of nucleus $^{241}_{95}Am$ is mounted 7cm in front of a G.M.T. a rentimeter connected to the tube records $5.4x10^4$counts per minute. If the number of $^{241}_{95}Am$ atoms in the sample is $5.8x10^{15}$. calculate,
   i) The number of disintegrations per second within the source if the window of the G.M.T has an area of $3cm^2$
   ii) The half-life of $^{241}_{95}Am$

Solution

i) $\lambda N = \frac{4\pi R^2}{A}C$

$$\lambda N = \frac{4x3.14x7^2}{3}x\frac{5.4x10^4}{60} = 184632Bq$$

ii) $\lambda N = 184632$

$$\lambda = \frac{184632}{5.8x10^{15}}$$

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

$$t_{\frac{1}{2}} = \frac{0.693}{184632}x5.8x10^{15} = 2.177x10^{10}s$$

2. A sample of a radioactive material contains 10^{18} atoms. The half life of the material is 2.0days. Calculate
   (i) The fraction remaining after 5.0days
   (ii) The activity of the sample after 5.0days

Solution

i) $t_{1/2} = 2\ days, t = 5\ days,$

$N_0 = 10^{18} atoms$

But $\lambda = \frac{0.693}{t_{1/2}}$

$$\lambda = \frac{0.693}{2}day^{-1}$$

But $N = N_0e^{-\lambda t}$

$$\frac{N}{N_0} = e^{\frac{-0.693}{2}x5}$$

$$\frac{N}{N_0} = 0.1768$$

Fraction remaining after 5 days $= 0.1768$

ii)Activity $\frac{dN}{dt} = \lambda N$

$$\lambda = \frac{0.693}{2x24x60x60}s^{-1}$$

$$\lambda = 4.0104x10^{-06}s^{-1}$$

$$\frac{dN}{dt} = \lambda N$$

But from $\frac{N}{N_0} = 0.1768$

N =0.1768N_0

$$\frac{dN}{dt} = 4.01x10^{-06}x0.177x10^{10}$$

$$= 7.09x10^{11}Bq$$

3. Potassium $^{44}_{19}K$ has half life of 20 minutes and decays to form $^{14}_{20}Ca$, a stable isotope of calcium
   i) How many atoms would there be in 10mg sample of potassium -44
   ii) What would be the activity of the sample?
   iii) What would be the activity be after one hour
   iv) What would the ratio of potassium atoms to calcium atoms be after one hour [N_A = $6.0x10^{23}mol^{-1}$]

Solution

Numbe of atoms = $\frac{m}{M}N_A$ atoms

10x10^{-3}g of potassium = $\frac{6x10^{23}}{44}x10x10^{-3}g$

= 1.364x10^{20}atoms

10mg of potassium - 44 has .364x10^{20}atoms

i) A = $-\lambda N$

A = $\frac{0.693}{t_{1/2}}\ x\ 1.364x10^{20}$

A = $\frac{0.693}{20x60}\ x\ 1.364x10^{20}$ = 7.88x10^{16}Bq

Activity of the sample = 7.88x10^{16}Bq

iii) When t = 1 hour

t = 3600s

$$N = N_0e^{-\lambda t}$$

N = 1.364 x $10^{20}e^{\left(\frac{-0693}{20x60}x3600\right)}$ = 1.706x10^{19} atoms

Number of atoms remaining after 1hour = 1.706x10^{19}atoms

But A = $-\lambda N$

A = $\frac{0.693}{20x60}x1.706x10^{19}$ = 9.85x10^{15}Bq

Activity after one hour = 9.85x10^{15}Bq

iv) Let N_K = number of potassium atoms present after time t

N_C = number of Calcium atoms present after time t

Then N_K + N_C = Number of potassium atoms present initially

From $N = N_0e^{-\lambda t}$

$N_K = (N_K + N_C)e^{-\lambda t}$

$$\frac{N_k}{N_k+N_c} = e^{-\frac{In2}{20x60}x3600}$$

$$\frac{N_k}{N_k+N_c} = \frac{1}{8}$$

$8N_K = N_K + N_C$

$7N_K = N_C$

$$\frac{N_k}{N_c} = \frac{1}{7}$$

Ratio would be = $1:7$

4. **An isotope of krypton $^{87}_{36}Kr$ has a half-life of 78 minutes. Calculate the activity of 10μg of $^{87}_{36}kr$**

Solution

Numbe of atoms = $\frac{m}{M}N_A$ atoms

$10x10^{-6}$g = $\frac{6x10^{23}}{87}x10x10^{-6}$ = $6.9x10^{16}$ atoms

But $\frac{dN}{dt} = \lambda N$

= $\frac{In2}{78x60}x6.9x10^{16}$ = $1.022x10^{13}$ Bq

5. **A sample of radioactive waste has a half-life of 80 years. How long will it take for its activity to fall to 20% of its current value**

Solution

A = $\frac{20}{100}A_o$ but

$A = A_0e^{-\lambda t}$

$$\frac{20}{100}A_o = A_oe^{\left(\frac{-In2}{80}t\right)}$$

In(0.2) = $-t\left(\frac{In2}{80}\right)$

t = $-80\frac{In0.2}{In2}$ = 185.75 years

it will take ≈ 186 years

6. **A sample of radioactive material has an activity $9x10^{12}$Bq. The material has half life of 80s. how long will it take for the activity to fall to $2x10^{12}$Bq**

Solution

$A = A_0e^{-\lambda t}$

$2x10^{12} = 9x10^{12}e^{\left(\frac{In2}{80}t\right)}$

$\frac{2}{9} = e^{\left(\frac{In2}{80}t\right)}$

In$\left(\frac{2}{9}\right) = \frac{-t/_{In2}}{80}$

t = $\frac{-80In(2/9)}{In2}$ = 173.594

Time taken = 174s

7. **A radioactive source contains 1.0μg of plutonium of mass number 239. If the source emits 2300 alpha particles per second. Calculate the half life of plutonium, assume [$N = N_0e^{-\lambda t}$]**

Solution

239g of plutonium contains= $6.02x10^{23}$

$1x10^{-6}$g of plutonium contains= $\frac{6.02x10^{23}}{2.39}x10^{-6}$

= 2.519×10^{15} atoms

Since it emits 2300 alpha particles per second, then

A = $2300s^{-1}$

A = $-\lambda$N

2300 = $\lambda x2.519x10^{15}$

2300 = $\left(\frac{In2}{t_{1/2}}\right)x2.519x10^{15}$

$t_{1/2} = \frac{2.519x10^{15}In2}{2300} = 7.591x10^{11}s$

8. **What mass of radium -227 would have an activity of $1x10^6$Bq. The half life of radium-227 is 41minutes (N_A=$6X10^{23}mol^{-1}$)**

Solution

$t_{1/2} = 41minutes$ But A = $-\lambda$N

$1x10^6 = \left(\frac{In2}{41x60}\right)N$

$N = 3.55x10^9$ atoms

But $6x10^{23}$ atoms contains 227g

$3.55x10^9$ atoms will contain $\frac{227}{6x10^{23}}x3.55x10^9$

$= 1.34x10^{-12}g$

9. **A radioactive source has a half life of 20s and an initial activity of $7x10^{12}$ Bq. Calculate its activity after 50s have elapsed**

Solution

$t_{1/2} = 20s, t = 50s$ $A_O = 7x10^{12}$ Bq

$A = A_0e^{-\lambda t}$

$A = 7x10^{12}$ $e^{\frac{-In2}{20}x50} = 1.24x10^{12}Bq$

10. **The half-life of a particular radioactive material is 10minutes, determine what fraction of a sample of the material will decay in 30 minutes.**

Solution

using $N = N_0e^{-\lambda t}$

$$\frac{N}{N_o} = e^{\frac{-In2}{20}x30}$$

$\frac{N}{N_o} = \frac{1}{8}$

The fraction remaining = $\frac{1}{8}$

The fraction that has decayed = $1 - \frac{1}{8} = \frac{7}{8}$

11. Find the activity of 1g sample of radius $^{226}_{88}Ra$ whose half-life is 1620years

Solution

Numbe of atoms = $\frac{m}{M}N_A$ atoms

1g of $^{226}_{88}Ra = \frac{6.02x10^{23}}{226} atoms$

$= 2.664x10^{21} atoms$

But $A = -\lambda N$

$A = \frac{In2}{t_{1/2}}N$

$A = \left(\frac{In2}{1620x365x24x3600}\right) x2.664x10^{21}$

$A = 3.61x10^{10} s^{-1}$

Activity = $3.61x10^{10}Bq$

12. A small volume of a solution which contains a radioactive isotope of sodium had an activity of 12000 disintegration per minute when it was injected into a blood stream of a patient. After 30 hours, the activity of 1.0cm³ of the blood was found to be 0.50 disintegration per minute. If the half life of the sodium isotope is taken as 15 hours, estimate the volume of blood in a patient

Solution

At $t = 0, activity\ A = 1200min^{-1}$

$T = 15\ (half\ life)\ A = 6000min^{-1}$

$T = 30 \quad A = 3000min^{-1}$

Total activity in the blood stream = 3000min^{-1}

Total volume of blood = $\frac{blood\ in\ the\ blood\ stream}{activity\ in\ 1cm^3}$

$= \frac{3000}{0.5} = 6000cm^3$

Therefore volume of blood in a patient= 6litres

Examples on carbon dating

1. Wood from a buried ship was forced to have a specific activity of $1.2x10^2\ BqKg^{-1}$due to ^{14}C whereas a comparable living wood has a specific activity of $2x10^2\ BqKg^{-1}$

What is the age of the ship? [half life of $^{14}C = 5.7x10^3 years$]

Solution

$A_O = 2x10^2\ BqKg^{-1}$

$A = 1.2x10^2\ BqKg^{-1}$

$A = A_Oe^{-\lambda t}$

$1.2x10^2 = 2x10^2 e^{-\frac{In2}{t_{1/2}}t}$

$\frac{1.2}{2} = e^{-\frac{In2}{t_{1/2}}t}$

$In(\frac{1.2}{2}) = t\frac{-In2}{(5.7x10^3)}$

$t = 4.2x10^3 years$

2. Archeological wood was found to have an activity of 20 units due to ^{14}C. Recent wood gave an activity of 47.8units, estimate the age of the wood [half life of ^{14}C = 5600years]

Solution

Using $A = A_Oe^{-\lambda t}$

$20 = 47.8e^{-\frac{In2}{5600}t}$

$In(\frac{20}{47.8}) = t\frac{-In2}{(5600)}$

$t = 7.4x10^3 years$

3. A rock containing$^{238}_{92}U$. Decays to produce a stable isotope of $^{206}_{82}Pb$. Estimate the age of the rock if the ratio of $^{206}_{82}Pb$. to $^{238}_{92}U$ is 0.6. [half life of $^{238}_{92}U$. = 4.5x109years]

Solution

Let N_u = number of uranium atoms present at time t

N_{Pb} = number of lead atoms present at time t

$(N_u + N_{Pb})$= number of uranium atoms present initially

From $N = N_0e^{-\lambda t}$

$N_u = (N_u + N_{Pb})\ e^{\frac{-In2}{4.5x10^9}t}$

$\frac{N_u}{N_u+N_{Pb}} = e^{\frac{-In2}{4.5x10^9}t}$

$In(\frac{N_u}{N_u + N_{Pb}}) = \frac{-tIn2}{4.5x10^9}$

$In(\frac{N_u + N_{Pb}}{N_u}) = t\frac{In2}{4.5x10^9}$

$In\left(1 + \frac{N_u}{N_{Pb}}\right) = t\frac{In2}{4.5x10^9}$

$In(1 + 0.6) = t\frac{In2}{4.5x10^9}$ | $t = 3.1x10^9 years$

EXERCISE: 59

1. A certain $\alpha - part$icle the track in a cloud chamber has length of 37mm. Given that the average energy required to produce an ion pair in air is $5.2x10^{-18}$J and that $\alpha - part$icles in air produce on average $5x10^3$ such airs per mm of track. Find the initial energy of the $\alpha - part$icle . Express your answer in MeV [e=$1.6x10^{-19}$C] **An(6.0MeV)**
2. Calculate the count rate produced by $0.1\mu g$ of caesium-137(The half of Cs-137=28years) **An($3.45x10^5$ Bq)**
3. A piece of bone from archaeological site is found to a count rate of 15 counts per minute. A similar sample of fresh bone give a count rate of 19 counts per minute due to ^{14}C. Estimate the age of the of the specimen .[half life of ^{14}C = 5700years] **An($1897\ years$)**
4. A radioactive source has a half-life of 20days. Calculate the activity of the source after 70days have elapsed if it's initial activity is 10^{10}Bq **An($8.8x10^8$Bq)**
5. The radioactive isotope $^{218}_{84}P_o$ has a half life of 3minutes, emitting $\alpha - part$icles according to the equation;
$$^{218}_{84}Po \rightarrow \alpha + {}^{x}_{y}Pb$$
   (i) What are the values of x and y
   (ii) If N atoms of $^{218}_{84}P_o$ emit $\alpha - part$icles at a rate of $5.12x10^{-4}s^{-1}$, what will be the rate of emission after $1/2$ hour. **An($50s^{-1}$)**
6. An isotope of the element radon has a half life of 4days . A sample of radon originally contains 10^{10} atoms.[Take 1day to be $86x10^3$s]. Calculate;
   (i) The number of radon atoms remaining after 16days
   (ii) The radioactive decay constant for radon
   (iii) The rate of decay of the radon sample after 16days

   An($6.3x10^8$atoms, $2x10^{-6}s^{-1}$, $1.3x10^3$Bq)
7. The half life of $^{30}_{15}P$ is 2.5 minutes. Calculate the mass of $^{30}_{15}P$ which has an activity of 10^{15}Bq. (N_A = $6.0x10^{23}mol^{-1}$] **An[11μg]**
8. The activity of a particular radioactive nuclide falls from $1x10^{11}$Bq to $2x10^{10}$Bq in 10 hours, calculate the half life of the nuclide **[An 4.3hours]**
9. Calculate the activity of 2μg of $^{64}_{29}Cu$. [half life of $^{64}_{29}Cu$ = 13hours, N_A = $6.0x10^{23}mol^{-1}$] **An [$2.8x10^{11}$Bq]**
10. The radioactive isotope of iodine ^{131}I has a half life of 8 days and is used as a tracer in medicine, calculate;
    (a) The number of atoms of ^{131}I which must be present in the patient when she is tested to give a disintegration rate of $6x10^5s^{-1}$
    (b) The number of atoms of ^{131}I which must have been present in a dose prepared 24 hours before. **[An $6.0x10^{11}$, $6.5x10^{11}$]**
11. The activity of a mass of $^{14}_{6}C$ is $5x10^8$Bq and the half life is 5570 years. Estimate the number of $^{14}_{6}C$ nuclei present [ln2 = 0.69] **[An $1.27x10^{20}$]**
12. (a) What is meant by the decay constant λ and the half life $T_{1/2}$ for a radioactive isotope?.
    Show from first principles that $\lambda T_{1/2}$ = 0.69
    (b) At a certain time, two radioactive sources R and S contain the same number of radioactive nuclei. The half life is 2hours for R and 1 hour for S, calculate
       (i) The ratio of the rate of decay of R to that of S at this time
       (ii) The ratio of the rate of decay of R to that of S after 2 hours
       (iii) The proportion of the radioactive nuclei in S which have decayed in 2 hours

    An [1:2, 1:1, 75%]
13. (a) The various isotopes of an element X are distinguished by using the notation $^{A}_{Z}X$. Explain the meaning of A, Z and of the term isotope

(b) Radioactive sources which might be used in schools are ^{226}Ra which emits α, β, and γ-rays and ^{90}Sr which emits β-rays only

(i) List three safety precautions which need to be taken into account when using such sources.

(ii) The half-life of the ^{90}Sr is 28 years when its activity falls to 25% of its original value, it should be replaced. After how many years should it be replaced? **An [56 years]**

(c) (i) When $^{226}_{88}Ra$ emits an α-particle, it decays to Radon (Rn). Write down a balanced equation for this change

(ii) Radioactive isotopes have many applications merely by virtue of being isotopes, describe and explain one such application

14. (a) In 420 days, the activity of a sample of polonium P_o, fell to one – eighth of its initial value. Calculate the half life of polonium

(c) Give the numerical values of a, b, c, d, d, e, f, in the nuclear equation

$$^{a}_{b}Po \rightarrow \, ^{c}_{d}\alpha + \, ^{206}_{82}Pb + \, ^{e}_{f}\gamma$$

An[140days, a = 210, b = 84, c = 4, d = 2, e = 0, f = 0]

15. A steel piston ring of mass 16g was irradiated with neutrons until its activity due to the formation of an isotope of iron was 10micro curie. Ten days later after the irradiation, the ring was installed in an engine and after 80 days of continuous use, the crankcase oil was found to have a total activity of $1.65 x 10^3$ disintegrations per second. Determine the average mass of iron worn off the ring per day, assuming that all the metal removed from the ring accumulated in the oil and that one curie is equivalent to $3.7 x 10^{10}$ disintegration per second. [half life of the isotope of iron = 45days] **An[4.0mg per day]**

16. A tube containing an isotope of radon, $^{222}_{86}Rn$ is to be implanted in a patient. The radon has an initial activity of $1.6 x 10^4$Bq, a half life of 4 days and it delays by a alpha emission. To provide the correct dose, the tube, containing a freshly for 8 days

(a) What are the protons and nucleon number of the daughter nucleus produced by the daughter of the radon?

(b) Determine;

(i) The decay constant for radon in S^{-1}

(ii) The initial number of radioactive radon atoms in the tube. **An[$2.0 x 10^{-6} s^{-1}$, $8.0 x 10^9$]**

17. At the start of an experiment a mixture of radioactive materials contain 20μg of a radio isotope A, which has a half-life of 70S and 40μg of radio isotopes β has a half life of 35s

(i) After what period of time will the mixture contain equal masses of each isotope. What is the mass of each isotope at this time?

(ii) Calculate the rate at which the atoms of isotope A are delaying when the masses are the same [molar mass of isotope A = 234g, $N_A = 6 x 10^{23} mol^{-1}$ **An[70s, 10μg , $2.5 x 10^{14} s^{-1}$]**

18. The isotope of bismuth of mass number 200 has a half life of $5.4 x 10^3$s. It emits alpha particles with an energy of $8.2 x 10^{-13}$J.

(a) State the meaning of the term half life

(b) Calculate for this isotope;

(i) Decay constant

(ii) The initial activity of $1 x 10^{-6}$ mole of the isotope

(iii) the initial power output of this quantity of the isotope

[$N_A = 6 x 10^{23} mol^{-1}$] **[Hint, power = activity x Energy] [An $1.3 x 10^{-4} s^{-1}$, $7.7 x 10^{13} S^{-1}$, 63W]**

19. The radioactive isotope ^{60}Co decays to ^{60}Ni which spontaneously decays to give two gamma-ray photons, the half life of ^{60}Co is 5.27years.

(i) find the activity of 20g of ^{60}Co

(ii) estimate the power obtainable from 20g of ^{60}Co

[Mass of ^{60}Co= 59.93381U, mass of ^{60}Ni = 59.93079U] **[An $8.35 x 10^{14} s^{-1}$, $3.76 x 10^2 Js^{-1}$]**

20. wood has an activity of 15.3 counts per minute per gram of carbon. A certain sample of dead wood is found to have an activity of 17.0 counts per minute for 5.0 grams. Calculate the age of the sample of dead wood in years. Assume the half-life of crbon-14 is 5568 years.

An($1.21x10^4 years$)

21. A patient was given an injection containing a small amount of isotope sodium-24, which is beta emitter with half-life of 15 hours. The initial activity of the sample was 60Bq. After a period of 8 hours the activity of 10ml sample of blood was found to be 0.08Bq, estimate the volume of blood in a patient

UNEB 2017Q.8

(a) What is meant by the following.
  (i) Radioactivity. (01mark)
  (ii) Isotopes (01mark)

(b) (i) Define **mass defect**. (01mark)
  (ii) State the condition for a heavy nucleus of an atom to be unstable. (01mark)
  (iii) Explain your answer in (b) (ii) (02marks)

(c) A sample of $^{226}_{88}Ra$ emits both α −particles and $\gamma - rays$. A masss defect of 0.0053u occurs in the decay
  (i) Calculate the energy released in joules **Ans** $[7.92x10^{-13}J]$ (03marks)
  (ii) If the sample decays by emission of α −particles, each of energy 4.60MeV and $\gamma - rays$, find the frequency of the $\gamma - rays$ emitted. **Ans** $[8.5x10^{19}Hz]$ (04marks)

(d) (i) Sketch a graph showing the variation of binding enrgy per nucleon with mass number, clearly showing the fusion and fission regions (02marks)
  (ii) Use the sketch in (d) (i) to explain how enrgy is released in each of the processes of fusion and fission (03marks)

(e) State **two**
  (i) Applications of radioisotopes (01mark)
  (ii) Health hazards of radioisotope (01mark)

UNEB 2016 Q.8

(b) (i) Distiguish between **mass defect** and **binding energy**. (01mark)
  (ii) Sketch a graph of nuclear binding energy per nucleon versus mass number of naturally occurring iostopes and use it to distinguish between nuclear fission and fusssion. (04marks)

(c) Describe with the aid of labelled diagram, milikan's oil drop experiment to determine charge on an oil drop. (07marks)

UNEB 2015 Q.10

(a) with reference to a Geiger-Muller tube, define the following
  (i) quenching agent (01mark)
  (ii) back ground count rate (01mark)

(b) (i) with the aid of a labelled diagram, describe the operation of Geiger-Muller tube (01mark)
  (ii) Explain how the half-life of a short lived radioactive source can be obtained by use of a Geiger-Muller tube (04marks)

(c) A radioactive isotope $^{32}_{15}P$ which has a half-life of 14.3 days, disintegrates to form a stable product. A sample of the isotope is prepared with an initial activity of $2.0x10^{6}s^{-1}$. Calculate the,
  (i) Number of $^{32}_{15}P$ atoms initially present **An[$3.57x10^{12}$atoms]** (03marks)
  (ii) Activity after 30 days **An[$4.67x10^{5}s^{-1}$]** (03marks)
  (iii) Number of $^{32}_{15}P$ atoms after 30 days **An[$8.33x10^{11}$atoms]** (02marks)

(Assume $N = N_0e^{-\lambda t}$ **)**

UNEB 2014 Q.8 d

(i) What is binding energy of a nucleus (01mark)

(ii) Calculate the energy in MeV released by fusing four protons to form an alpha particle and two beta particles.

Mass of $beta\, particle = 0.000549u$
Mass of $hydrogen\, atom = 1.007825u$
Mass of $helium\, atom = 4.002664u$
$(1U = 931MeV)$ **An(25.64MeV)** (05marks)

UNEB 2013 Q.10

(d) **(i)** What is a **decay constant** (01mark)

(ii) A sample from fresh wood of a certain species of tree has an activity of 16.0 counts per minute per gram. However, the activity of 5g of dead wood of the same species of tree is 10.0 counts per minute. Calculate the age of the dead wood (Assume half-life of 5730years) **An(1.7**$2x10^4$**years)**

UNEB 2012 Q9

a) (i) What is meant by the terms radioactive decay, half life and decay constant.
(ii)Show that the half life $t_{1/2}$ of a radio isotope is given by $t_{1/2} = \frac{0.693}{\lambda}$
Where λ is the decay constant [assume the decay law $N = N_o e^{-\lambda t}$] [03 marks]

b) With the aid of a labeled diagram, describe the structure and action of a cloud chamber (05 marks)

c) A radioactive isotope $^{99}_{43}X$ decays by emission of a gamma ray. The half life of the isotope is 360 minutes. What is the activity of 1mg of the isotope (06 mark) **[An 1.95x10^{14}Bq]**

d) Explain the term avalanche as applied to an ionization chamber (03 marks)

UNEB 2011 Q10

a) What is meant by unified atomic mass unit (1 mark)

b) (i) Distinguish between nuclear fission and nuclear fusion (2 marks)
ii) State the condition necessary for each of the nuclear reactions in b(i) to occur

c) (i) With the aid of a labeled diagram, describe the operation of an ionization chamber (6 marks)
ii)Sketch the curve of ionization current against applied p.d and explain its main features(4 marks)

d) A typical nuclear reaction is given by $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{95}_{42}Mo + ^{139}_{57}La + 2^{1}_{0}n + 7^{0}_{-1}e$
Calculate the total energy released by 1g of uranium

mass of $^{1}_{0}n = 1.009U$ of $^{0}_{-1}e = 0.00055U$
$^{95}_{92}Mo = 94.906U\ of\ ^{139}_{57}La = 138.906U$
$^{235}_{92}U = 235.044U \quad 1U = 1.66x10^{-27}kg$

Ans $[8.387x10^{10}J]$

UNEB 2010 Q 10

a) (i) What is meant by mass defect? (1 mark)
(ii) Sketch a graph showing how binding energy per nucleon varies with mass number and explain its main features (3 marks)
iii)Find the binding energy per nucleon of $^{56}_{26}Fe$ given that mass of 1proton = 1.007825U.
Mass of 1neutron=1.008665U, [1U = 931MeV] **[Ans 7.7Mev]**

b) With the aid of a diagram, explain how an ionization chamber works (6 marks)

UNEB 2008 Q9

a) (i) Define the term binding energy (1 mark)
(ii) Sketch a graph showing the variation of binding energy per nucleon with mass number(2 marks)
(iii) Use the sketch graph you have drawn in a(ii) to explain how energy is released during fission and fusion

b) Explain why high temperature is required during fusion of nuclides (1 mark)

c) The isotope $^{238}_{92}U$ emits an alpha particle and forms an isotope of thorium (Th) while the isotope $^{235}_{92}U$ when bombarded by a neutron, forms $^{144}_{56}Ba$, $^{90}_{36}Kr$ and neutrons
i) Write the nuclear equations for the reactions of $^{238}_{92}U$ and $^{235}_{92}U$ (2 marks)
ii) How does the reaction of $^{235}_{92}U$ differ from that of $^{238}_{92}U$ (3 marks)

d) A steel piston ring contains 15g of radioactive iron, $^{54}_{26}Fe$. The activity of $^{54}_{26}Fe$. Is 3.7x10^5 disintegrations per second. After 100 days of continuous use, the crank case oil was found to have a total activity of 1.23x10^3 disintegration per second. Find the;
i)Half life of $^{54}_{26}Fe$ (5 marks)
ii)Average mass of iron worn off the ring per day, assuming that all the metal removed from the ring accumulates in the oil. **An[3.13x10^{17}s, 4.9x10^{-4}g]**

UNEB 2007 Q9

c) Explain the purpose of each of the following in a Geiger muller tube
i) A thin mica window
ii) Argon gas at low pressure
iii)Halogen gas mixed with argon gas

iv)An anode in the form of a wire (4 marks)

d) (i) What is meant by binding energy per nucleon of a nucleus (1 mark)

ii)Sketch a graph of binding energy per nucleon against mass number for naturally occurring nuclides

iii)State one similarity between nuclear fusion and nuclear fission (1 mark)

e) (i) At a certain time, an α-particle detector registers account rate of $32s^{-1}$. Exactly 10 days later the count rate dropped to $8s^{-1}$. Find the decay constant. (4 marks) **[Ans 0.139 per day]**

ii)State two industrial uses and two health hazards of radioactivity (2 marks)

UNEB 2006Q10

a) i) What is meant by half life of a radioactive material (1 mark)

ii) Given the radioactive law $N_t = N_o e^{-\lambda t}$, obtain the relation between λ and half life $T_{1/2}$

iii) What are radio isotopes (1 mark)

iv) The radio isotope $^{90}_{38}Sr$ decays by emission of β-particles. The half life of the radio isotope is 28.8years, determine the activity of 1g of the isotope (5 marks) **An[$5.1x10^{12}s^{-1}$]**

c) i) With aid of a diagram, describe the structure and action of a Geiger Muller tube (06 marks)

ii) Sketch the count rate –voltage characteristic of the Geiger muller tube and explain it's main features

(iii) Identify, giving reasons, the suitable range in (b)(ii) of operation of the tube (2mk)

UNEB 2005 Q10

a) Define Binding energy of nuclide (1mk)

b) i) Sketch a graph showing how binding energy per nucleon varies with mass number (1mk)

(ii) Describe the main features of the graph in (b)(i) (3 marks)

c) Distinguish between nuclear fission and nuclear fusion; and account for the energy released.

d) (i) With the aid of a labeled diagram, the working of the Geiger-Muller tube(5 marks)

(ii) How would you use a Geiger-Muller tube to determine the half life of a radioactive sample (4 marks)

UNEB 2004 Q10

b) Describe with the aid of a labeled diagram the structure and action of diffusion cloud chamber (6 marks)

c) i) Define the terms radio activity and half life of radioactive substance (2 marks)

(ii) A radioactive isotope of strontium of mass 5μg has half-life of 28 years, find the mass of the isotope left after 14years. **An[3.54μg]**

UNEB 2003 Q10

a) What is meant by the following terms

i)Nuclear number

ii)Binding energy (2mk)

b) Calculate the energy released during the decay of $^{220}_{86}Rn$ nucleus into $^{216}_{84}Po$ and an alpha-particle

Mass of $^{220}_{86}Ra = 219.964176U$

Mass of $^{216}_{84}Po = 215.955794U$

Mass of $^{216}_{84}Po = 4.001566U$

$(1U = 931MeV)$ **Ans [6.35MeV]**

UNEB 2002 Q10

a) What is meant by

i)Half life of a radioactive element (1mk)

ii)Nuclear fission (1mk)

iii)Nuclear fusion (1mk)

b) An atom of ^{222}Ra emits an alpha-particle of energy 5.3MeV. Given that the half life of ^{222}Ra is 3.8 days, use the decay law to calculate the

i)Decay constant (3mk)

ii)Amount of energy released by $3.0x10^{-9}$kg $of\ ^{222}Ra$ after 3.8 days(5mk)

An[$2.11x10^{-6}s^{-1}$,$2.16x10^{16}$MeV]

UNEB 2001 Q9

a) What is meant by the following

i)An alpha particle (1mk)

ii)Radioactivity (1mk)

C) Describe the structure and actions of a cloud chamber (6 marks)

d) State four uses of radioactive isotopes (2 marks)

UNEB 2000 Q9

a) I) Define the term half life and decay constant as applied to radio activity (2 marks)

(ii) State the relationship between half life and delay constant (1 mark)

b) The radio isotope ^{60}Co decays by emission of a β-particles and γ-rays. Its half-life is 5.3years

i)Find the activity of a source containing 0.1g of ^{60}Co

ii)In what ways do γ-rays differ from β-particles? **[Ans $4.15\times10^{12}s^{-1}$]**

c) i) What is meant by mass defect in nuclear physics (1 mark)

ii)Calculate the mass defect of $^{59}_{26}Fe$. Given the following information.

Mass of $^{59}_{26}Fe$ nucleus $= 58.93488u$

Mass of proton $= 1.00728u$

Mass of neutron $= 1.00867u$ **Ans [0.54051U]** (4 marks)

d) Describe the structure and action an ionization chamber.