Topic: Nuclear Physics Date:

1) Concept of Binding Energy
2) Radioactivity.

1) Concept of Binding Energy. Binding Energy is defined as the amount of Energy released when individual particles e.g Proton and neutron combine to form a nucleus.

2) Why is Energy realeased :- It is believed that when ever mass combine there is always a slight loss in mass this loss in mass is known as mass defect. It is denoted by symbol (Δm) This loss in mass is believed to convert in Energy i.e binding energy.

Ex:1 : Calculate the binding energy released when the Helium nucleus is formed?

Information:

$m_p = 1.00728u$ $1u = 1.66 \times 10^{-27}$ kg

$m_n = 1.00867u$

mass of Helium nuclice $= 4.00260u$

Total mass of individual particles

$2p + 2n \Rightarrow 2(1.00728) + 2(1.00867) = 4.0319u$

mass of Helium $= 4.00260u$

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Δm (mass defect) $= 4.0319u - 4.0026u$

$= 0.0293u$

Binding Energy released b/c of mass defect can be calculated by $E = \Delta m c^2$

E = Binding Energy released

Δm = mass defect

c = speed of light.

$E = 0.0293\,u \times c^2$

$E = (0.0293 \times 1.66 \times 10^{-27})(3 \times 10^8)^2$

$\boxed{E = 4.38 \times 10^{-12}\,J}$

In this topic we use Mega Electron volt MeV

$1\,MeV = 1.6 \times 10^{-13}\,J$

hence in MeV $= \dfrac{4.38 \times 10^{-12}}{1.6 \times 10^{-13}} \rightarrow 27.4\,MeV$

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Ex 2 : Calculate the Binding Energy released when sodium nucleus is formed?

Information:

$m_p = 1.00728u$

$m_N = 1.00867u$

mass of Sodium = 22.9898u

Total mass of particle => $11p + 12n = 11(1.00728u) + 12(1.00867u)$

$= 23.18412u$

Δm (mass defect) $= 23.1812u - 22.9898u$

$= 0.19432u$

Binding Energy = $E = \Delta m c^2$

$E = 0.19432u \times (3.0 \times 10^8)^2$

$E = 2.9 \times 10^{-11}\ J$

$E = 181.4\ MeV$

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What is the Relevance of Finding out values of binding Energy

Values of Binding Energy are relevent because they provide us information regarding stability of nucleus which is formed i.e

It is generally believed that the greater the binding Energy released the left over Energy content of the nucleus which is formed will be less hence nucleus will be regarded as more stable

Conclusion: Greater the binding energy released greater the stability of nucleus which is formed.

Compare the stability of Helium nucleus and Sodium Nucleus.

Sodium is more stable as it releases more Energy

→ "For more fair comparision we need to calculate binding Energy per nucleon"

B.E/nucleon for helium : $\frac{27.4}{4} = 6.9\,MeV$

B.E/nucleon for Sodium : $\frac{181.4}{23} = 7.9\,MeV$

∴ Sodium is more stable as it releases a greater binding Energy per nucleon.

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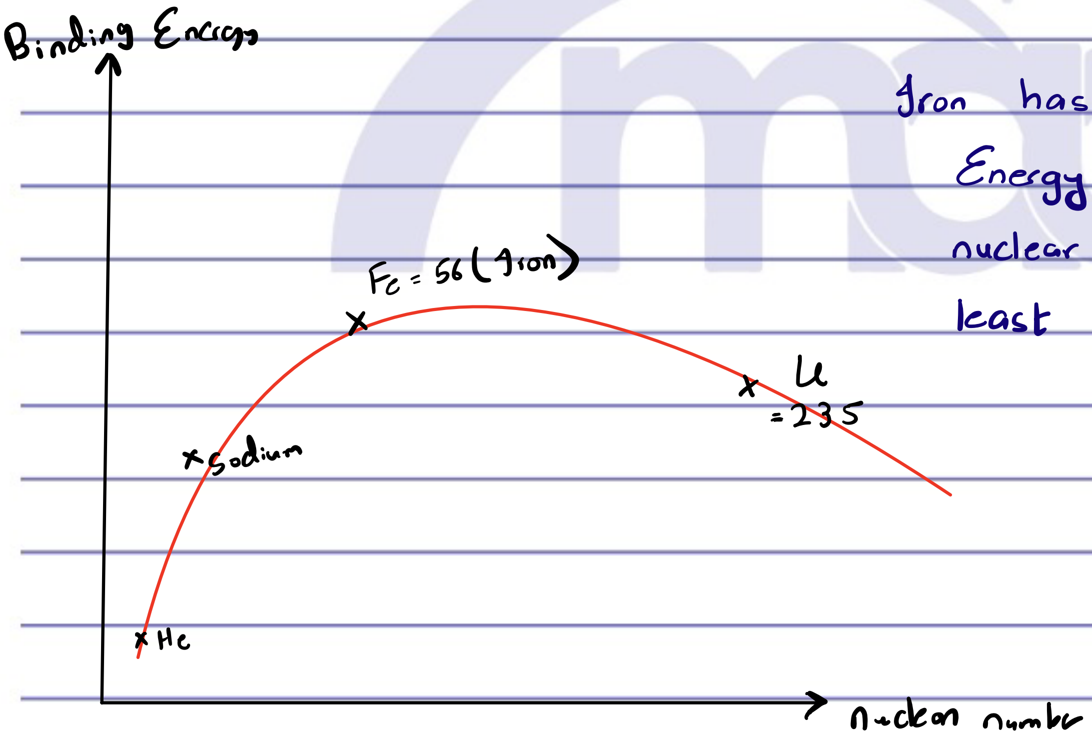
In Physics: nuclear stability (nucleus is more stable) indicates weather or not nucleus is keen to exhibit the process of radioactivity.

Sodium is more stable → ⇒ lesser probability of undergoing the process of Radioactivity.

This working is done for all Elements of preodic table

Graph for Binding Energy per nucleon (y axis) against mass (x axis)



Iron has greatest Binding Energy hence highest nuclear stability therefore least chance of Radioactivity

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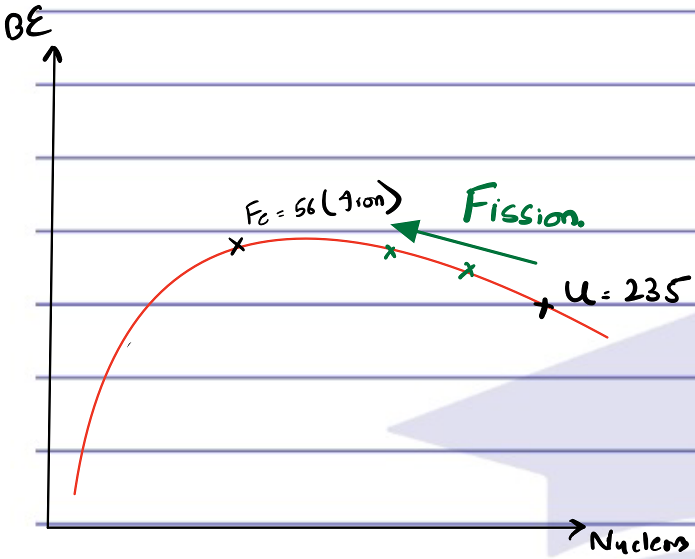
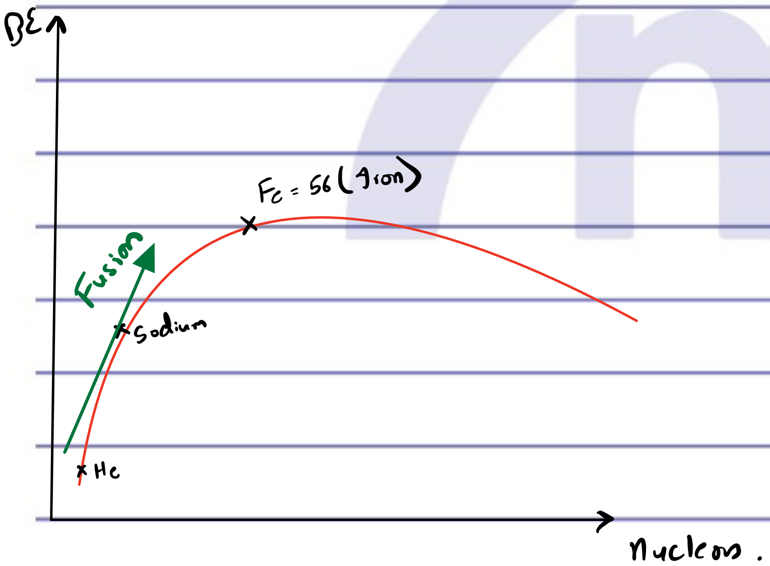
Fission and Fusion.

Fission → breakdown

Fusion → join/add up



Heavy nucleus prefer (Eg Uranium) fission because they will breakdown so that products will have higher BE/nucleon making the product more stable.



Elements having smaller nucleon number, they prefer to undergo fusion because they allow the products to exhibit a higher B.E per nucleon thereby making the product more stable.

* Elements close to iron they do not under go fusion or fission.

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Case no 1

How to calculate Binding Energy realeased in a nuclear Reaction.

$$^{236}_{92}U + ^{1}_{0}n \longrightarrow ^{90}_{36}Sr + ^{143}_{56}Xe + 4\,^{1}_{0}n$$

Information

Binding Energy per nucleon.

U-236 = 8.7 MeV

Sr-90 = 8.9 MeV

Xe-143 = 9.0 MeV

Calculate Energy released?

$$^{236}_{92}U + ^{1}_{0}n \longrightarrow ^{90}_{32}Sr + ^{143}_{56}Xe + 4\,^{1}_{0}n$$

$8.7 \times 236 = 8.9 \times 90 \quad 9.0 \times 143$

2053 MeV $\quad \underbrace{801\,MeV + 1287\,MeV}$

2053 MeV $\quad$ 2088 MeV

Energy released = 2088 - 2053 = 35 MeV Ans

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Q) Calculate Energy released if 1kg of Uranium undergoes the above reaction. (Give answer in Joules)

Step 1

No of moles in 1 kg of Uranium.

$$\Rightarrow \frac{1000}{236} = 4.24 \text{ moles} \qquad n = \frac{\text{mass}}{\text{nucleon Number}}$$

$$4.24 \times 6.02 \times 10^{23} = 2.6 \times 10^{24}$$

1 atom $\longrightarrow$ 35 MeV

2.6×10^{24} atoms $\longrightarrow x$

$$\boxed{x = 9.1 \times 10^{25} \text{ MeV}}$$

$$1 \text{ MeV} = 1.6 \times 10^{-13} \text{ J}$$

$$9.1 \times 10^{25} \text{ MeV} = 1.5 \times 10^{13} \text{ J}$$

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Reverse of Case no 1

$$^{236}_{92}U + ^{1}_{0}n \longrightarrow ^{90}_{36}Sr + ^{143}_{56}Xe + 4\,^{1}_{0}n + 35\,MeV$$

Information

Binding Energy per nucleon.

U-236 = 8.7 MeV

Sr-90 = x MeV

Xe-143 = 9.0 MeV

i) Calculate the mass defect in kg which occurs during this reaction given that 35 MeV is released?

$E = \Delta m c^2$

$$35\,MeV = \Delta m\,(3.0\times10^{8})^{2}$$

$$\frac{35\times1.6\times10^{-13}}{(3.0\times10^{8})^{2}} = \Delta m$$

$$\Delta m = 6.2\times10^{-29}\ kg$$

ii) Given that 35MeV is relaleased use this information find value of x?

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$$^{236}_{92}U + ^{1}_{0}n \longrightarrow ^{90}_{36}Sr + ^{143}_{56}Xe + 4\,^{1}_{0}n + 35\,MeV$$

$$8.7 \times 236 = 90x + 90 \times 143$$

$$2088\,MeV \quad 90x + 1287\,MeV$$

$$[90x + 1287] - 2088 = 35$$

$$\boxed{x = 8.9\,MeV}$$

Suggest why neutrons are not taken into account in the calculation

Ans) Concept of Binding Energy involves idea that individual particles combine to form nucleus Since neutron Exists as single particles/seperate Entity, they doesn't posess binding Energy hence ignored.

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Q :-

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n + 12\,MeV$$

Energy released

BE per nucleon

$^{2}_{1}H = 2.28\,MeV$

$^{3}_{1}H = x\,MeV$

$^{4}_{2}H = 7.07\,MeV$

i) Calculate mass defect of $^{4}_{2}He$.

$$E = \Delta m\, c^2$$

$$(7.07 \times 1.6 \times 10^{-13}) = \Delta m\,(3 \times 10^{8})^2$$

$$\Delta m = 5.0 \times 10^{-29}\,kg$$

ii) Calculate value of x?

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n + 12\,MeV$$

(2.28×2) $(x \times 3)$ (7.07×4)

$$(7.07 \times 10^{4}) - ((2.28 \times 2) + 3x) = 12$$

$$x = 3.9\,MeV$$

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$${}^{236}_{92}U + {}^{1}_{0}n \longrightarrow {}^{90}_{36}Sr + {}^{143}_{56}Xe + 4\,{}^{1}_{0}n$$

Explain why fission reaction is possible to occur?

If we calculate the (Binding Energy per unucleon x90) + (BE/nucleon x 143) will notice that this value will be greater than (BE per nucleon of U x 236) Hence total binding Energy of (Sr + Xe) > Total B·E of Reactant (Uranium) this confirms that product is more stable than reactant ∴ making reaction possible to occur.

Case no 2

In Case 2 you will be dealing with masses rather than Energy. Calculate Energy released?

$${}^{4}_{2}He + {}^{9}_{4}Be \longrightarrow {}^{12}_{6}C + {}^{1}_{0}n$$

4.0026u 9.01212u 12.00u 1.00867u

Solve

$$\underbrace{4.0026u + 9.01212}_{13.01472u} \qquad \underbrace{12.00 + 1.00867u}_{13.00867}$$

Δm (mass defect) = 13.01472u − 13.00867u = 0.00605u

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Binding Energy =

$$E = \Delta m c^2$$

$$E = (0.00605u) \times (3\times10^8)^2$$

$$E = (0.00605 \times 1.66\times10^{-27}) \times (3.0\times10^8)^2$$

$$= 9.04\times10^{-13}$$

$$\frac{9.04\times10^{-13}}{1.6\times10^{-13}} = \boxed{5.65\ \text{MeV}}$$

Reason of why neutron is taken into account in case #2

Since neutron has mass but doesn't have B. Energy ∴ It was ignored in case 1 but will be considered in case no 2.

Q) How much Energy (in MeV) is equivalent to the mass defect of 1u?

$$E = \Delta m \times c^2$$

$$E = 1u \times c^2$$

$$E = (1 \times 1.66\times10^{-27})(3\times10^8)^2$$

$$E = 1.494\times10^{-10}\ J \xrightarrow[\div 1.6\times10^{-13}]{} 934\ MeV$$

If you learn this its easy to multiply this value.

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Case no 3 : (It is an extension of the second case)

Q) An Electron $_{-1}^{0}e$ combine with a positron (same mass as electron but +ve) to produce 2 γ (gamma) rays. as given in the following Equation.

Show that the Binding Energy of Each γ ray is approximately 0.51 MeV?

$$\underset{(9.11\times10^{-31})}{_{-1}^{0}e} + \underset{(9.11\times10^{-31})}{_{+1}^{0}e} \longrightarrow \underset{\text{negligible mass.} \approx 0}{2\gamma}$$

Δm = mR − mP

$1.82\times10^{-31} - 0$

1.82×10^{-31}

B.E released = Δmc^2

$= (1.82\times10^{-31})\times(3\times10^{8})^2$

$= 1.64\times10^{-13}\ J$

Total Energy of both gamma rays.

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Energy of each γ ray

$$\frac{1.64\times10^{-13}}{2} = 8.2\times10^{-14}\ J$$

$$\text{In MeV} = \frac{8.2\times10^{-14}}{1.6\times10^{-13}} = 0.51\ \text{MeV Ans}$$

Q) Given that the resultant have negligible kinetic Energy at the start explain why you would expect the 2 γ rays to travel in opposite directions with equal kinetic Energies.?

Ans: Since the initial momentum of system is zero $\therefore$ For law of conservation of momentum to be valid the final momentum must also be zero. For this to happen 2 γ photons must have equal momentum in opposite direction.

Since both γ photons are identical they must also have equal kinetic Energies.

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Case no 4 (Artificially Triggered Nuclear reactions)

$${}^{4}_{2}He + {}^{14}_{7}N \longrightarrow {}^{17}_{8}O + {}^{1}_{1}P$$

$\underbrace{4.0026 \quad 14.003074u}_{m_R = 18.00567}$ $\underbrace{16.999134u \quad 1.007284u}_{m_P = 18.00641u}$

⇒ In this case there is an apparent increase in mass hence this reaction cannot occur on its own rather Energy must be supplied to initiate this reaction, hence the term "artificially triggered reaction"

Q) How much Binding Energy is required to make this reaction occur?

$\Delta m = 18.00641u - 18.00567u$

Increase in mass $= 0.00074u$

Conversion
If $1u = 934MeV$
$0.00074u = 0.69MeV$

$E = \Delta mc^2$

$= 0.00074 \times 1.66\times10^{-27} \times 3.0\times10^{8}$

$E = 1.1\times10^{-13}J$ or $E = 0.69$ MeV

$1MeV = 1.6\times10^{-13}J$

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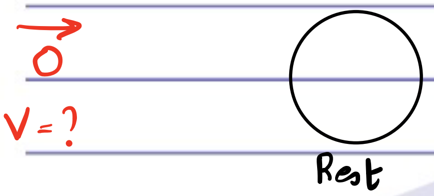
How do we trigger these nuclear reactions?

By Providing the reactant with thermal Energy Kinetic Energy will insure that one reactant gets the oppurtunity to bombard / Collide with other reactant thereby making the reaction possible.

$$^{4}_{2}He + ^{14}_{7}N \longrightarrow ^{17}_{8}O + ^{1}_{1}\beta$$



Q) Calculate the minimum speed with which helium nuclie must bombard with the nitrogen nuclie to make this reaction possible?

KE provided to He nuclie = 1.1×10^{-13} J

$$\frac{1}{2} m v^2 = KE$$

$$\frac{1}{2}(4.0026\,u)(v^2) = 1.1 \times 10^{-13}$$

$$\boxed{v = 5.8 \times 10^{6}\ m/s}$$

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Radioactivity / Radioactive decay.

* Phenomenon of the emission of radioactive radiation from the nucleus of an atom
* The unstability of the nucleus due to insufficient binding force to keep all the particles intact results in emission of these radiation.

Types of Radiation

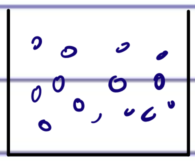
1) Alpha
2) Beta
3) Gamma.

Properties of Radioactivity.

1) Random process: All nuclie have equal chance to decay. i.e. emit radioactive radiation. at any time No prediction which nucleus decay when. (Random count rate)

2) Spontaneous Process: There is no effect on the rate of emission of radiation by changes in external conditions e.g temperature, pressure etc.

A2: Experiments have shown that the activity of a radioactive sample is known to be directly propotional to the no of radioactive nudie present in the sample, hence



$$A \propto N$$

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

λ = is a constant known as decay constant

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

This negative sign is placed just so that we can recognise the fact that the process of radioactivity is decaying process.

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The term activity is also called rate of decay or rate of disintegration.

$$\boxed{\frac{dN}{dt} = -\lambda N} \quad \text{OR} \quad \boxed{A = -\lambda N}$$

Same thing.

Units and definations

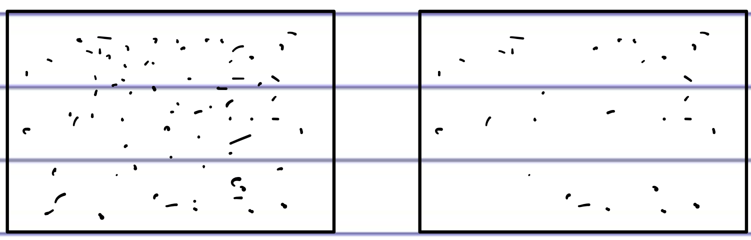
i) Units of Activity Becquerel (Bq) or s^{-1} $\frac{dN}{dt}$

ii) Units of decay constant (λ) = (Bq) or s^{-1}

$$A = -\lambda N \rightarrow \text{No unit}$$

Define decay constant (λ) : Probability of decay per unit time.

Second formula is used to obtain relationship between Initial no of radioactive Nuclie (N_0) and final no of Radioactive nuclie (N) left in the sample after time (t)



$t = 0$ after time t

Initial (N_0) Final = N

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$$\boxed{\ln N - \ln N_0 = -\lambda t}$$

$$\ln N = -\lambda t + \ln N_0$$

$$\boxed{\ln \frac{N}{N_0} = -\lambda t}$$

$$* \boxed{\frac{N}{N_0} = e^{-\lambda t}} \longrightarrow * \boxed{N = N_0 e^{-\lambda t}}$$

t = time

λ = decay constant

N_0 = initial No of nuclic

N = find No of nuclic

$\frac{N}{N_0}$ = Fraction of Nuclic Remaining.

Note : $A \propto N$

$$\boxed{\frac{A}{A_0} = e^{-\lambda t}} \qquad \boxed{A = A_0 e^{-\lambda t}}$$

Note = $N \propto m$

$$\boxed{\frac{m}{m_0} = e^{-\lambda t}} \qquad \boxed{m = m_0 e^{-\lambda t}}$$

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3rd Formula : 3rd Formula is used to obtain the Half life ($T\frac{1}{2}$) of the sample.

halflife ($T_{1/2}$) is time taken for the activity of the sample to reduce to Half of its orignal value.

$$A = A_0 e^{-\lambda t}$$

$$\frac{1}{2}\cancel{A_0} = \cancel{A_0} e^{-\lambda \frac{t}{2}}$$

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

$$\ln 0.5 = -\lambda T_{1/2}$$

$$-0.693 = -\lambda T_{1/2}$$

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

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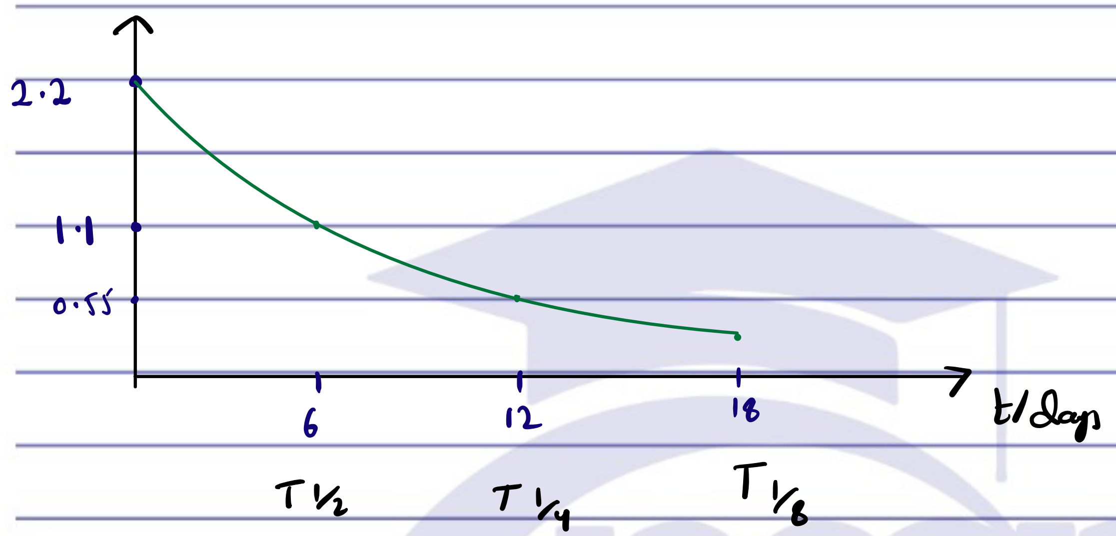
Q) Radon = 220 $m = 2.2mg$ $T_{1/2} = 6$ days

Radon 220 decays to form polonium.

i) Sketch the graph of mass of Radon 220 against time for 18 days.



On the same axis sketch graph of mass of polonium formed during this decay

t	Radon	Polonium
0	2.2	0
6	1.1	1.1
12	0.55	1.65
18	0.275	1.925

= 2.2
= 2.2
= 2.2
= 2.2

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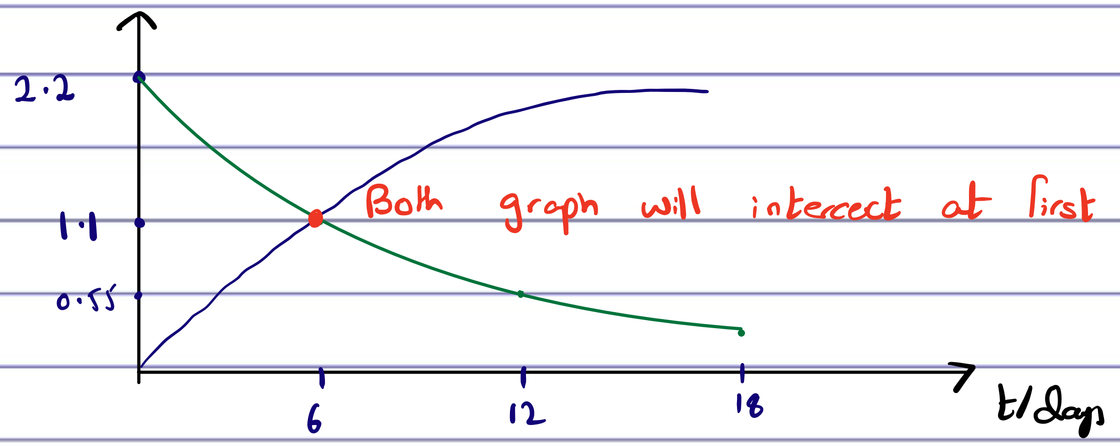

Calculate Activity of Radon after 28 days.

Initial Activity

$N = ?$

$220g \longrightarrow 6.02 \times 10^{23}$

$2.2mg \longrightarrow N$

$N = 6 \times 10^{18}$

$A = -\lambda N$

$\lambda = ??$

$\lambda = \dfrac{0.693}{T_{1/2}}$

$\lambda = \dfrac{0.693}{6 \times 24 \times 60 \times 60}$

$\lambda = 1.34 \times 10^{-6}\ s^{-1}$

$A = (1.34 \times 10^{-6})(6 \times 10^{18})$

$= 8.1 \times 10^{12}$ Bq

28 days later.

$\Rightarrow A = A_0 e^{-\lambda t}$

$A = (8.1 \times 10^{12}) e^{-(1.34 \times 10^{-6})(28 \times 24 \times 60 \times 60)}$

$A = 3.2 \times 10^{11}$ Bq

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