Radioactivity and Nuclear Reaction.

Radioactivity

→ The phenomena of spontaneous emission of raditions (like α-particles, β-particles and γ-~~particles~~ rays) by the unstable nuclei like uranium is called radioactivity.

→ ${}_{92}U^{235}$ is a radioactive element

→ Radioactive element may be proton or neutron.

There are three types of emission by radioactive element as shown in fig below :-

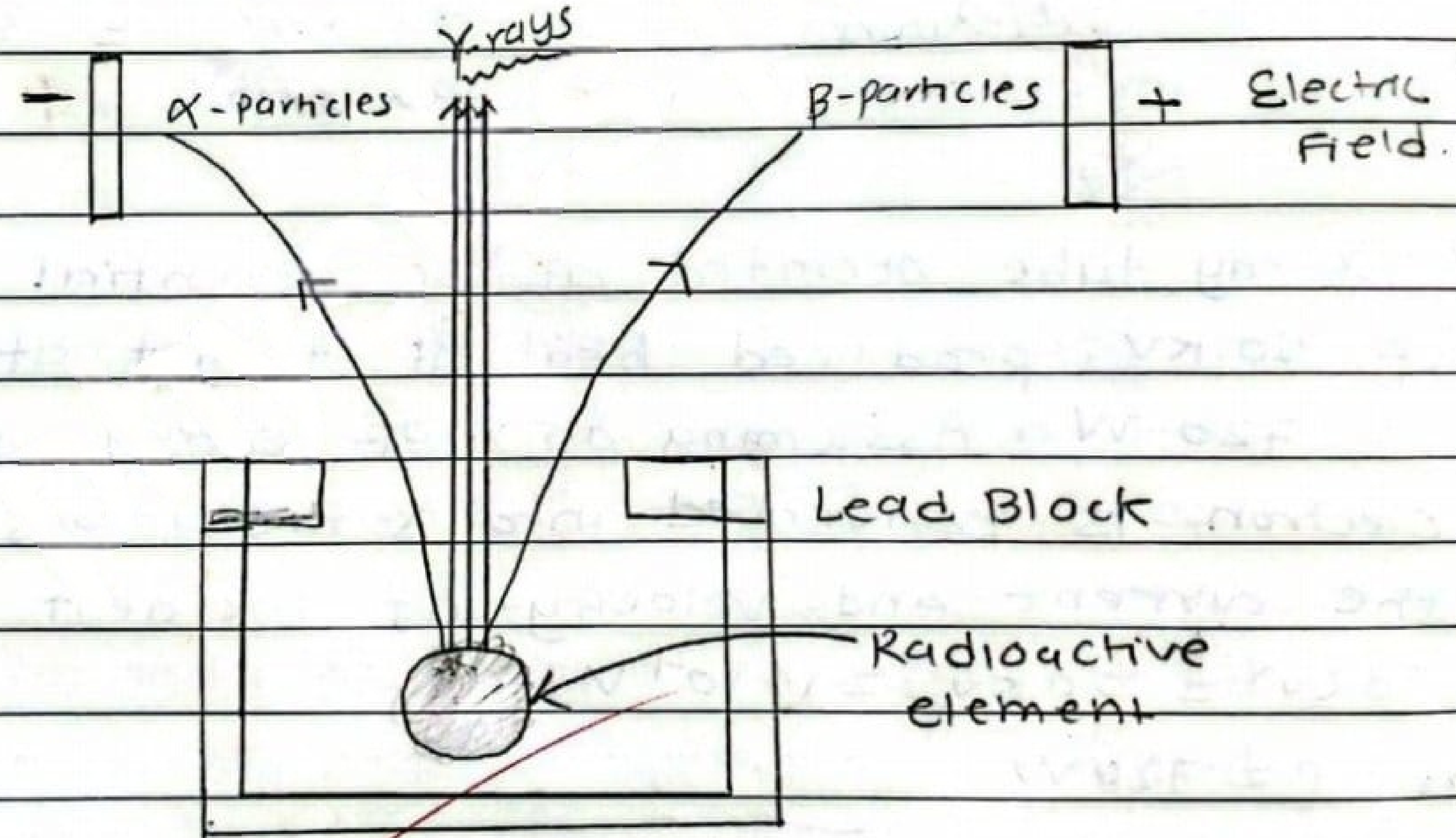

fig :- Deflection of radioactive emission in Electric Field.

properties of α-particles.

- α-particle is equivalent to Helium in mass and charge [$q = 2e$ and $m = 4m_p$] [$\alpha = {}_2He^4$]
- Deflects in electric and magnetic field (+ve)
- They have very less penetrating power
- They Ionizes the gases through which they passes.

properties of β-particles

(+ve or -ve)

- They are fast moving electrons ($q = q$ of $e^- = 1.6 \times 10^{-19} C$)
- Deflected in electric and magnetic field.
- can penetrate few mm (100 times than α-particles)
- It's speed is less than the speed of light.
- Ionization power 100x than α-particles

properties of γ rays:-

- chargeless and massless
- Not deflected in electric and magnetic field.
- Travels with speed of light.
- High-penetration power.

Ionization power: $\alpha > \beta > \gamma$

penetration power: $\alpha < \beta < \gamma$

Q1) What is the main cause of unstablity of the nucleus.

→ The main cause of unstablity of the nucleus is change in nuclear content.

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2) Define natural and artificial Radioactivity.

→ Natural Radioactivity :- The phenomenon of spontaneous emission of highly penetrating radiation from heavy elements (A>206) naturally is called natural radioactivity. For eg :- radiation from uranium, radium, thorium.

Artificial Radioactivity :- The radioactivity induced in an elements by bombarding it with fast moving particle like α-particles, neutrons, protons etc is called artificial radioactivity.

3) Are Inerts element radioactive?

→ No, they are not radioactive because their outermost orbit is completely filled i.e. they are very stable in nature. They do not react with other elements in ordinary condition. Thus, being highly stable they are non-radioactive.

4) Define α and β decay with suitable example.

→ The spontaneous process of emission of α-particle from a radioactive nucleus is called α-decay.

$$_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4} \text{ (α particle)}$$

The spontaneous process of emission of β-particle from a radioactive nucleus is called β-decay.

$$_{Z}X^{A} \longrightarrow {}_{Z+1}X^{A} - {}_{1}e^{0} \text{ (β-particle)}$$

$$_ZX^A \rightarrow {}_{Z-2}X^{A-2} + {}_2He^4$$

$$_ZX^A \rightarrow {}_{Z+1}X^A + (-{}_1e^0)\ \beta$$

$$({}_ZX^A)^* \rightarrow {}_ZX^A + \gamma$$

Types of β-decay.

1) Electron emission or β^- decay :- Here, parent nucleus disintragetes to give a daughter nucleus, a β^- particle and a new particle called anti neutrino.

(atomic no. increases by 1 unit)

$$_6C^{14} \rightarrow {}_7N^{14} + \beta^- + \bar{\nu}$$

2) Positron emmission or β^+ decay :- parent nucleus disintragetes to give a daughter nucleus, a β^+ particle along with new partile called neutrino (ν)

$(z = -1)$

$$_{29}Cu^{64} \rightarrow {}_{28}Ni^{64} + \beta^+ + \nu$$

3) Electron capture : Parent nucleus capture one of the orbital electrons with the emission of a neutrino (ν)

$(z = -1)$

$$_{29}Cu^{64} + (-{}_1e^0) \rightarrow {}_{28}Ni^{64} + \nu$$

γ-decay

The disintegration in which the the new atom formed has the mass

Any necleus in excited state when deexcited to lower state emits an radiation called γ-rays.

$$_{38}Sr^{87*} \rightarrow {}_{38}Sr^{87} + \gamma \text{ (gamma radiation)}$$

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Laws of Radioactive Disintegration.

- The radioactivity is random and spontaneous process, and is not affected by external conditions such as tempeature, pressure etc.
- During disintegration, each atom emmits only one particle (α or β or γ) at a time (displacement law).
- The rate of disintegration of radioactive sample at an instant is directly porpotional to the number of radioactive atoms present at that time.

i.e, $-\frac{dN}{dt} \propto N$

$\therefore \frac{dN}{dt} = -\lambda N$ (decay law)

where λ is decay constant.

or $\frac{dN}{N} = -\lambda dt$ ------------- (1)

Negative sign in eqn (1) indicates rate of decay decreases when time increases. and no. of atoms present in sample is continuously decreasing.

Integrating eqn (1) from $t=0$ to $t=t$, we get

$$\int_{N_0}^{N} \frac{dN}{N} = \int_{0}^{t} -\lambda dt$$

or $[\log_e N]_{N_0}^{N} = -\lambda [t]_0^t$

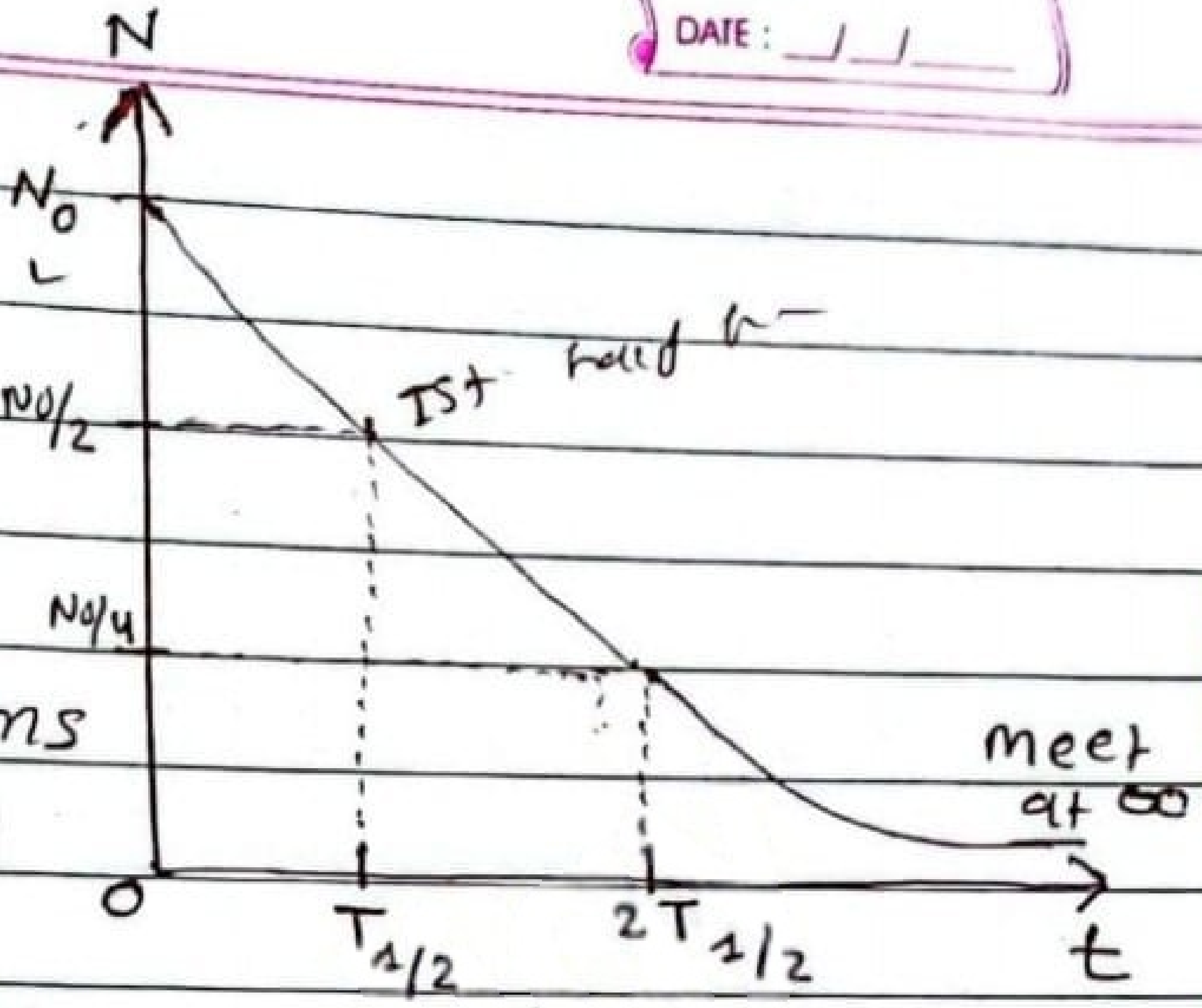
or $\log_e N - \log_e N_0 = -\lambda t$.

or $\log_e \left(\frac{N}{N_0}\right) = -\lambda t$

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

or, $\boxed{N = N_0 \cdot e^{-\lambda t}}$

which is decay equation and gives no. of undecayed atoms remained at any time (t)



Graph btn. N and t

In beginning decay occurs rapidly. Then became more and more slow. And N becomes zero only when t approaches ∞

Decay Constant (λ)

We have, $\frac{dN}{dt} = -\lambda N$

$$\therefore \lambda = \frac{(dN/dt)}{N}$$

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

$N = N_0 e^{-1}$ (If $t = 1/\lambda$)

$N = \frac{N_0}{e} = \frac{N_0}{2.718} = 0.368 N_0$

$\therefore N = 37\%$ of N_0.

Thus, it is defined as the ratio of rate of disintegration of radioactive sample to its no. of undecayed atoms at instant of time.

Also the constant time for which the no. of atoms of a radioactive substance decreases to about 37 %. of their original number.

Half Time ($T_{1/2}$)

The time taken to decay half of the initial amount of a radioactive substance is called Half life period (or time) of that substances.

i.e. $t = T_{1/2}$.

Thus if No be the initial number of radioactive atoms of substance the after ;

$$t = T_{1/2}$$

$$N = N_0/2$$

Thus $N = N_0 \cdot e^{-\lambda t}$ can be written as ;-

$$\frac{N_0}{2} = N_0 \cdot e^{-\lambda \cdot T_{1/2}}$$

or, $$\frac{1}{2} = \frac{1}{e^{\lambda \cdot T_{1/2}}}$$

or, $$e^{\lambda \cdot T_{1/2}} = 2 \cdot$$

Taking log on both sides we get,

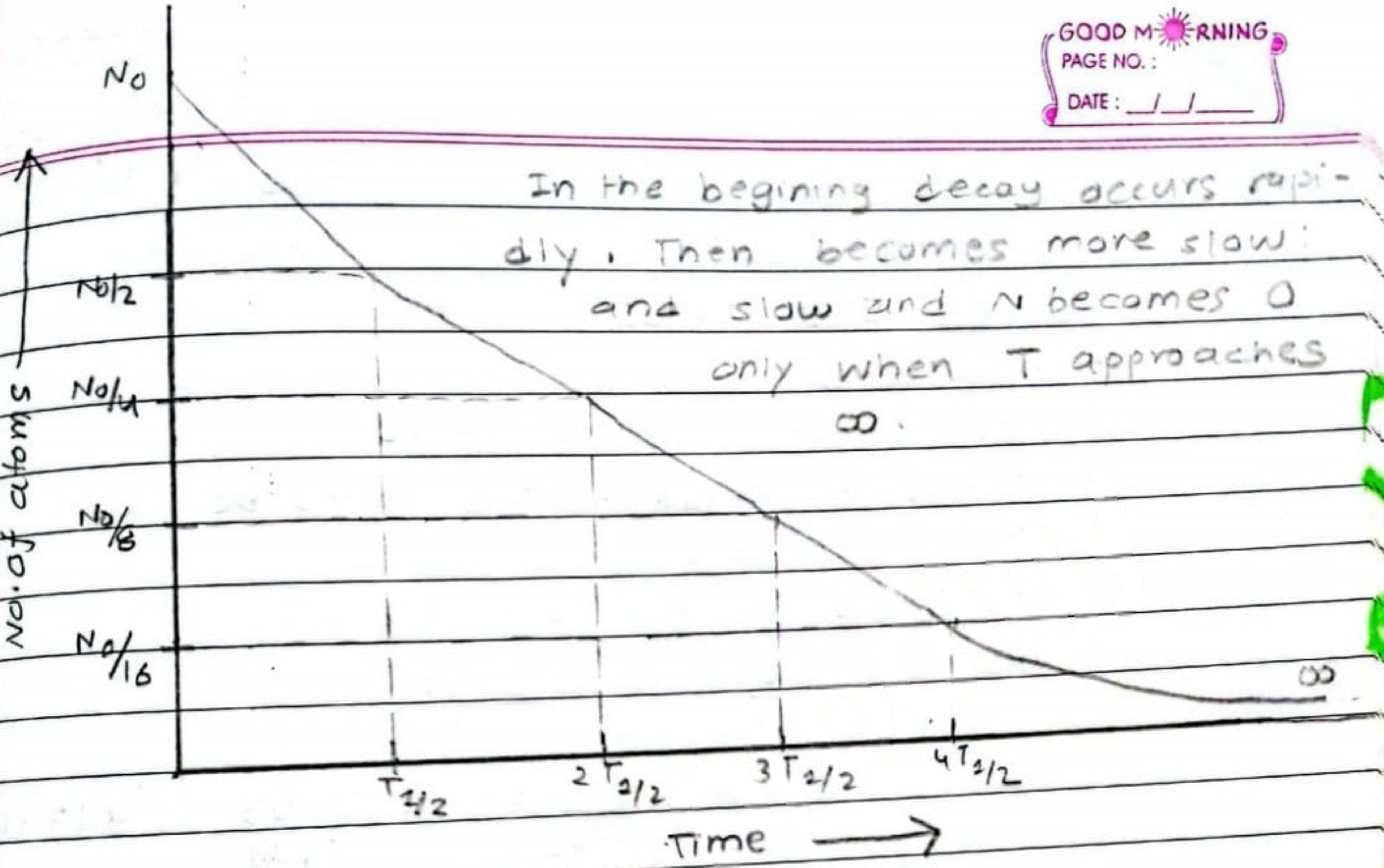
$$\log_e 2 = \log_e e^{\lambda \cdot T_{1/2}}$$

or, $$\ln 2 = \lambda \cdot T_{1/2} \log_e \cdot e \quad [\log x^y = y \log x]$$

or, $$0.693 = \lambda \cdot T_{1/2} \cdot 1 \quad [\log_x x = 1]$$

or, $$T_{1/2} = \frac{0.693}{\lambda}$$

Thus Half life of a radioactive substance is inversly propotional to its decay constant (λ) and is independent of the number No, the number of radioactive nuclei present initially in the Sample.



In the begining decay occurs rapidly. Then becomes more slow and slow and N becomes 0 only when T approaches ∞.

1) If a radioactive nucleus has a half life of one year, will it be completely decayed at the end of two years? Explain.

→ No, It is because as the time increases the no of undecayed atoms decreases.

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Qn) The half life of radium is 1620 years. After how many years 25% of radium block remains undecayed? [3] (2079)

Solution :- Here,

$T_{1/2}$ of radium $= 1620$ years

Let initial no. of radioactive atoms be x

i.e. $N_0 = x$.

Then, $N = 25\%$ of $x = 0.25x$.

Also, we have, $T_{1/2} = \frac{0.693}{\lambda}$

$\therefore \lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{1620} = 4.27 \times 10^{-4}$

Also, $N = N_0 . e^{-\lambda t}$

or, $0.25\cancel{x} = \cancel{x} . e^{-\lambda t}$

or, $0.25 = e^{-\lambda t}$

Taking ln on both sides we get

$-1.38 = -\lambda t$

or, $1.38 = 4.27 \times 10^{-4} \times t$

or, $t = 3246$ years.

Qn) A sample of radioactive isotopes cointains 50% of the its original number in two years. Then

i) What is its half life [1]

ii) If there are 10^8 such nuclei remaining after 8 years how many numbers are there in the begining. [2] (NEB 2079)

Solution :- Here,

Let original number be x. Then

$N =$ 50% of N_0 $(N_0 = x)$

$= 0.5x$.

Directly we can say that is half-life is 2years.

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

$0.5x = x \cdot e^{-\lambda t}$

$0.5 = e^{-\lambda \times 2}$.

Taking ln on both sides. we get

$\ln(0.5) = \ln(e^{-\lambda \times 2})$

$-0.693 = -\lambda \times 2 \times (\ln e)$ $(\ln e = 1)$

$\therefore \lambda = \frac{0.693}{2} = 0.346$

Now, $T_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{0.346} = 2$ years. #

And,

Remaining number $(N) = 10^6$ atoms.

Time $(t) = 8$ years.

original number $(N_0) = ?$

we have, $N = N_0 \cdot e^{-\lambda t}$

or, $10^6 = N_0 \cdot e^{-0.346 \times 8}$

or, $10^6 = N_0 \cdot e^{-2.768}$

or, $10^6 = N_0 \times 0.0628$.

$\therefore N_0 = 1.6 \times 10^7$ atoms

Qn) A radioactive sample has its half life 8.3×10^4 years calculate its disintegration constant and time taken for 25%. of its activity to disappear. [2078] [4]

→ Here, Half life $(T_{1/2}) = 8.3 \times 10^4$ years.

decay constant $(\lambda) = ?$

we have, $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{8.3 \times 10^4}$

$= 8.35 \times 10^{-6}$ ./year.

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And. $\left(\frac{N}{N_0}\right) = 75\%$

$e^{-\lambda t} = 0.75$

Taking ln on both sides we get,

$-\lambda t = -0.287682.$

$8.35 \times 10^{-6} \times t = 0.287682$

$t = 34453$ years

Q> A radioactive element has a half life of 2500 yrs, In how many year will it mass decay by 90% of its initial mass? [2077]

→ Here,

Half life ($T_{1/2}$) = 2500 yrs.

Let initial mass = N_0

Final mass (N) = $N_0 - 90\%$ of N_0

$= 0.1 N_0$.

Now, $\frac{N}{N_0} = 0.1$.

or, $e^{-\lambda t} = 0.1$

Taking ln on both sides we get.

$-\lambda t = -2.30$.

or $\lambda t = 2.3$

or, $2.772 \times 10^{-4} \times t = 2.3$

or, $t = 8297$ years

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

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

or $\lambda = \frac{0.693}{2500}$

or $\lambda = 2.772 \times 10^{-4}$ /yr.

Qn) A radioactive source has decayed to one tenth of one percent of its initial activity in one hundred days. What is its half life period?

Soln

Here, Initial atoms = No.

(N) Final atoms = $\frac{1}{10}$ No = 0.1 No.

$\frac{N}{No} = 0.1$

or, $e^{-\lambda t} = 0.001$

or, Taking ln on both sides we get,

$-\lambda t = -6.90$

$\therefore \lambda = \frac{6.90}{100}$

or $\lambda = 0.0691$ /day

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

or, $T_{1/2} = \frac{0.693}{0.069}$

= 10 days //

$\therefore$ Its half life period is 10 days.