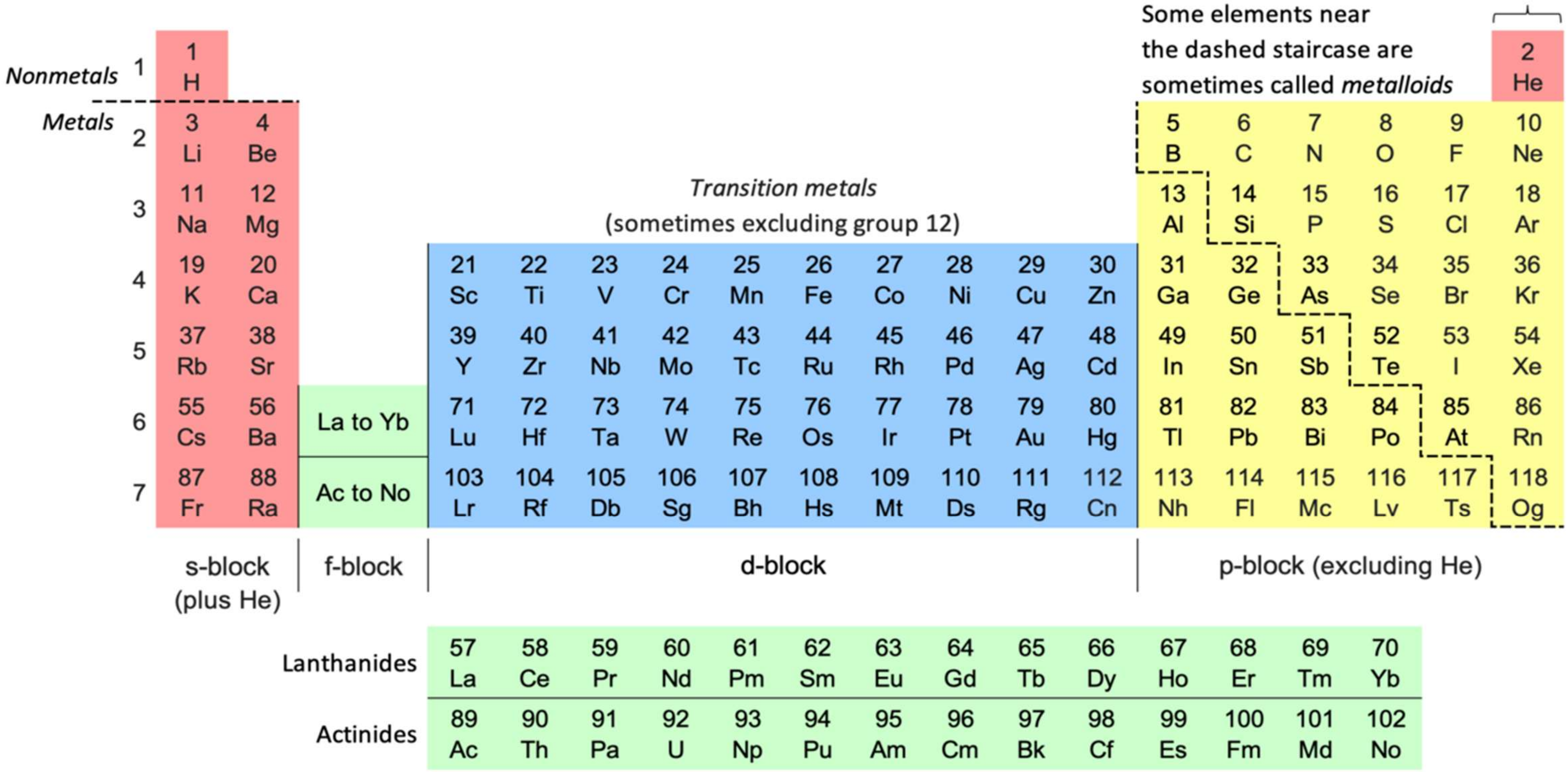
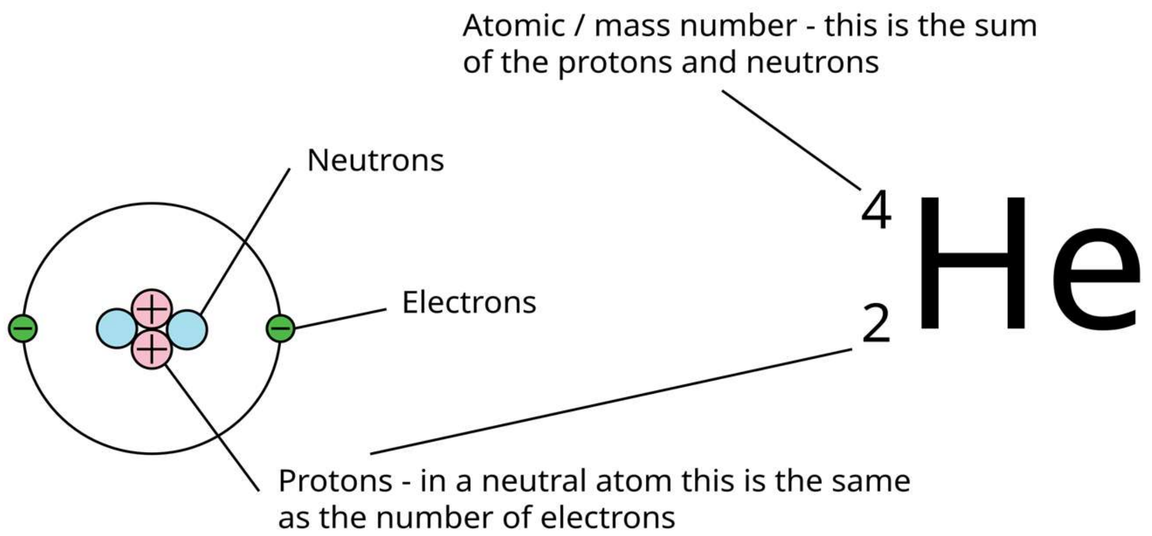
(Physics of Nuclear Medicine)
Radioactive Decay, Activity, and Half-Life


Some elements near the dashed staircase are sometimes called *metalloids*
Nonmetals
Metals
1
2
3
4
5
6
7
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
Transition metals
(sometimes excluding group 12)
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
La to Yb
71 Lu
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
Ac to No
103 Lr
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113 Nh
114 Fl
115 Mc
116 Lv
117 Ts
118 Og
s-block (plus He)
f-block
d-block
p-block (excluding He)
Lanthanides
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
Actinides
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No

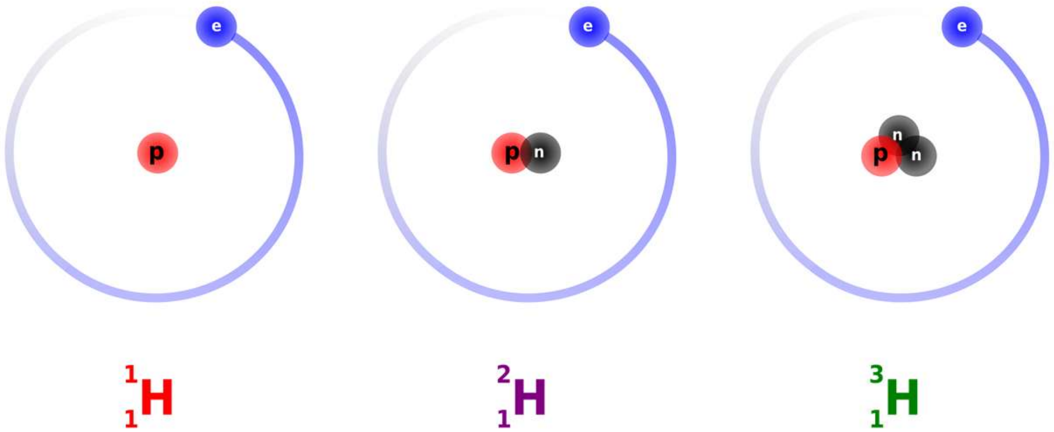
Isotopes

- Isotopes are distinct nuclear species (or nuclides) of the same chemical element.
- They have the same atomic number (number of protons in their nuclei) and position in the periodic table (and hence belong to the same chemical element), but different nucleon numbers (mass numbers) due to different numbers of neutrons in their nuclei.
- While all isotopes of a given element have virtually the same chemical properties, they have different atomic masses and physical properties



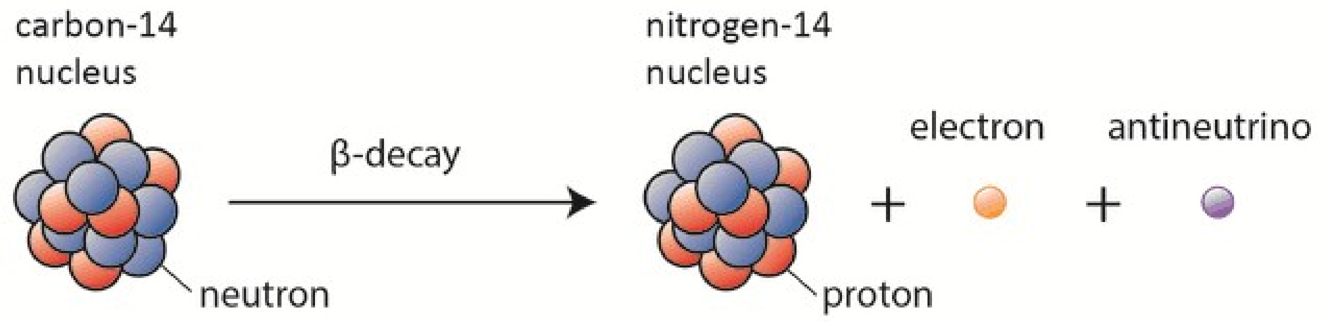
Isotopes of hydrogen

The three naturally occurring isotopes of hydrogen. The fact that each nuclide has 1 proton makes them all isotopes of hydrogen: the identity of the isotope is given by the number of protons and neutrons. From left to right, the isotopes are protium (1H) with 0 neutrons, deuterium (2H) with 1 neutron, and tritium (3H) with 2 neutrons.



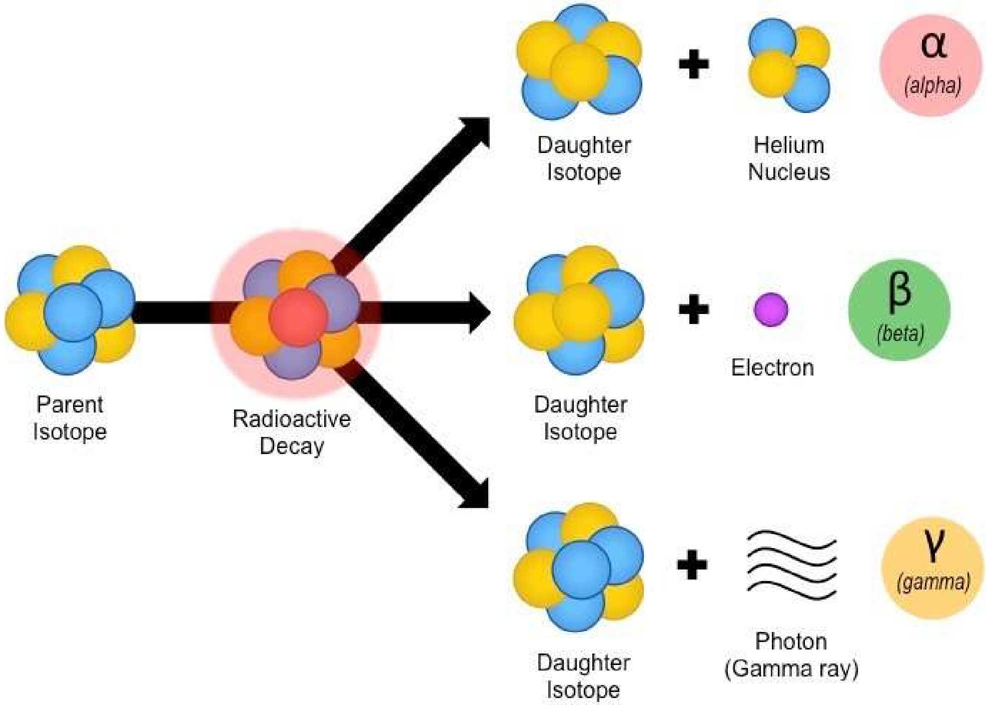
Radioisotopes

- Some isotopes/nuclides are radioactive, and are therefore called radioisotopes or radionuclides,
- whereas others have never been observed to decay radioactively and are called stable isotopes or stable nuclides.
- For example, ^{14}C is a radioactive form of carbon, while ^{12}C and ^{13}C are stable isotopes.
- A nuclide that is unstable and known to undergo radioactive decay into a different nuclide, which may be another radionuclide or be stable.
- Radiation emitted by radionuclides is almost always ionizing radiation because it is energetic enough to liberate an electron from another atom.



1. What Is Radioactive Decay?

Radioactive decay is the spontaneous transformation of an unstable nucleus into a more stable one, accompanied by the emission of radiation.



📌 Key features:

- Random process
- Cannot be predicted for a single atom
- Predictable for a large number of atoms

2. Activity (A)

Activity is the rate of radioactive decay (rate of decrease in total population).

$$A = -\frac{\mathrm{d}N}{\mathrm{d}t}$$

(A) = activity (Becquerel, Bq)
(N) = number of radioactive nuclei
(t) = time

📌 Unit:

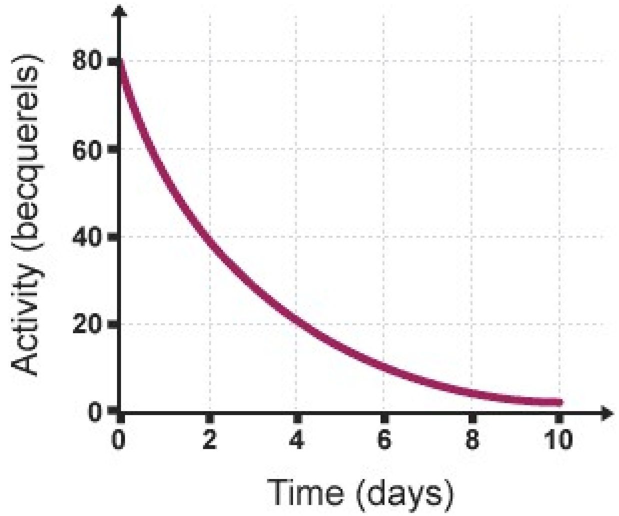
Becquerel (Bq) = 1 decay per second
Curie (Ci) (older unit):1Ci $= 3.7 \times 10^{10}$

3. Decay Constant (λ)

The decay constant (λ) is the probability per unit time that a nucleus will decay.

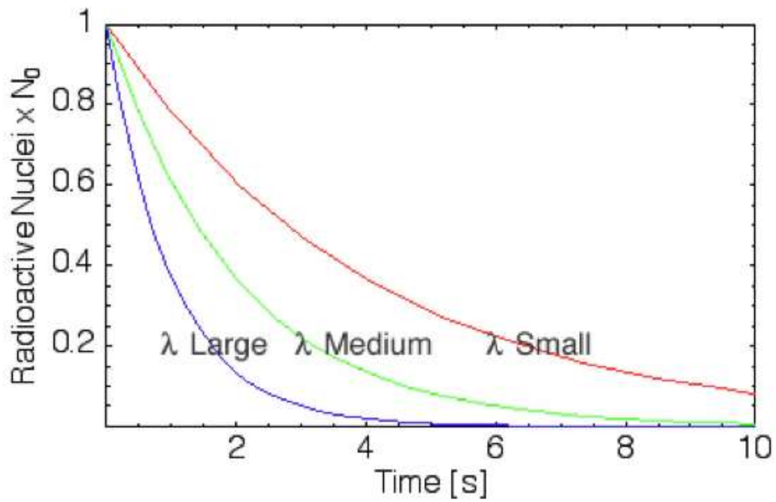
$$\boxed{\lambda = \text{decay probability per second}}$$

$$A = \lambda N$$



📌 Properties:

- Characteristic for each radionuclide
- Independent of temperature, pressure, or chemical form



4. Fundamental Decay Law

The number of undecayed nuclei decreases exponentially with time:

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

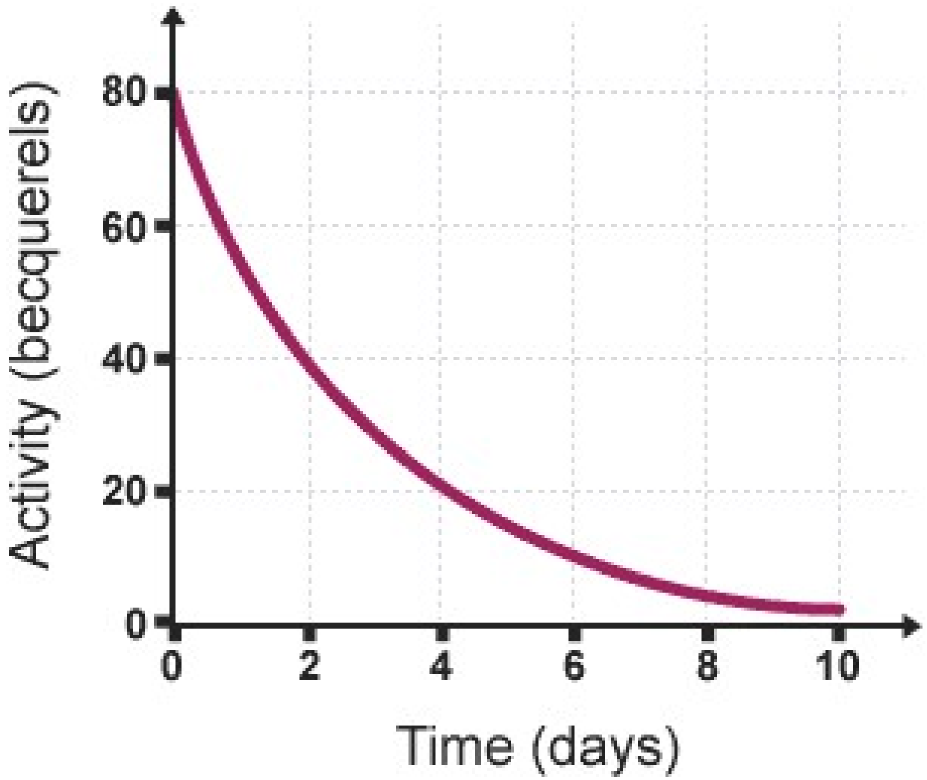
Where:

$N(t)$ =number of nuclei at time t

N_0 =initial number of nuclei

λ= decay constant

t= time



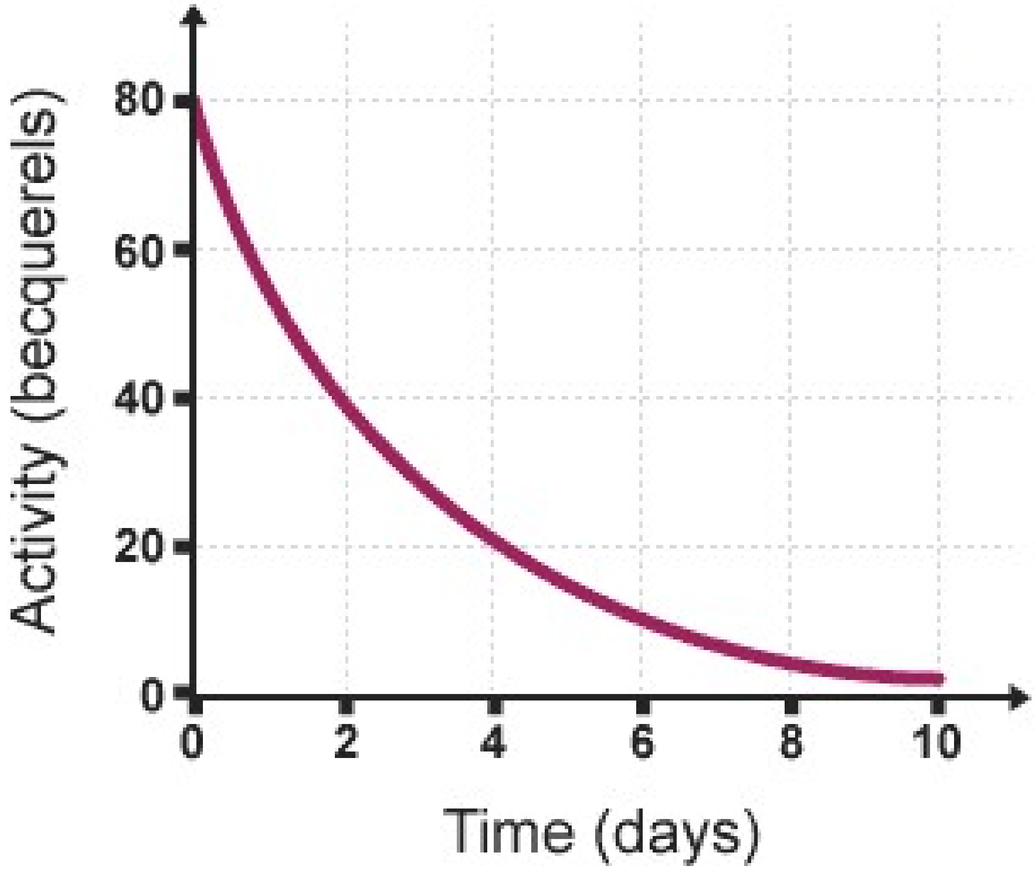
5. Activity as a Function of Time

Since activity is proportional to the number of nuclei:

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

Where:
$A(t)$ =activity at time t
A_0 =initial activity

📌 **This is the most important equation in nuclear medicine practice.**



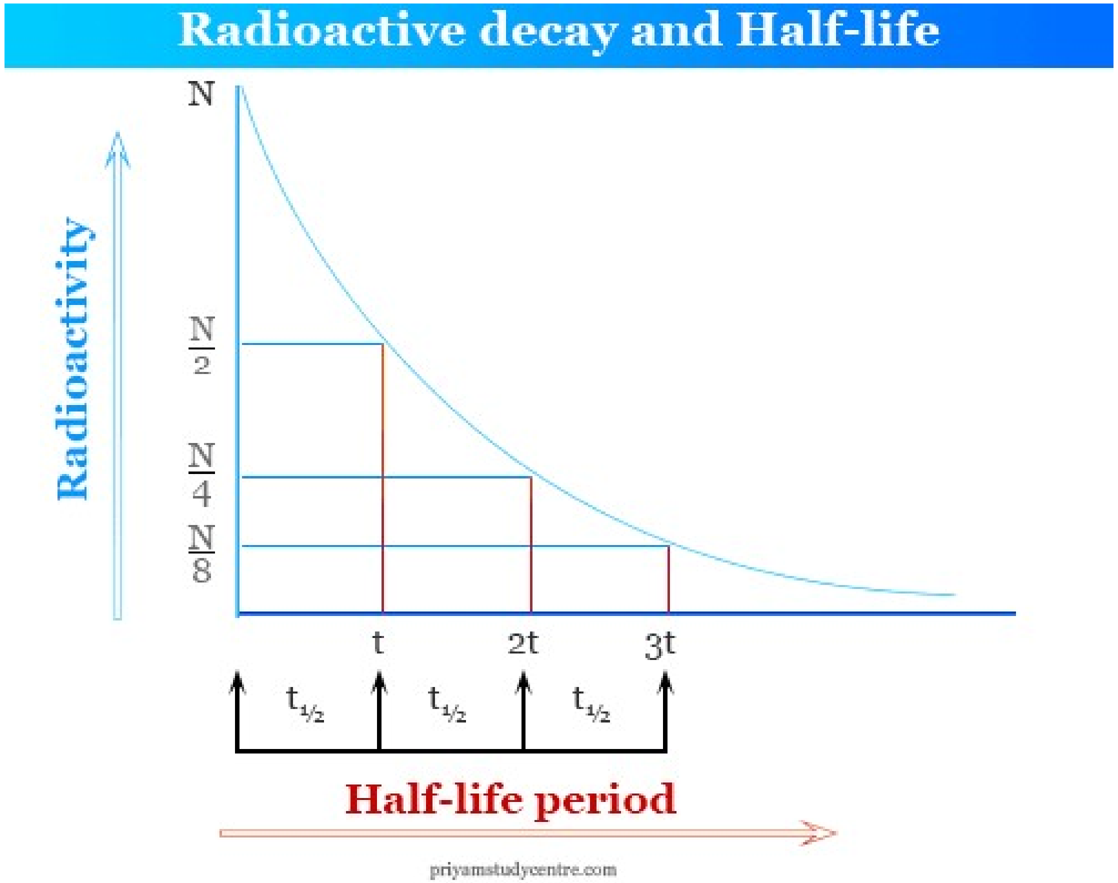
6. Physical Half-Life ($T_{1/2}$)

Definition

The physical half-life is the time required for the activity (or number of nuclei) to decrease to half of its initial value.

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

📌 After each half-life:
50% → 25% → 12.5% → 6.25%



8. Example: Radioactive Iodine

Isotope	Radiation	Use
I-123	Gamma	Diagnosis
I-131	Beta + Gamma	Therapy & imaging

I-131 (Therapy)

•Physical half-life: **8.02 days**

•Radiation: β^{-} (therapy) + Gamma (imaging)

$$\lambda_{I-131} = \frac{0.693}{8.02\ days} \approx 0.0864\ day^{-1}$$

I-123 (Diagnosis)

Physical half-life: **13.2 hours**

Radiation: γ only

$$\lambda_{I-123} = \frac{0.693}{13.2\ hours} \approx 0.0525\ h^{-1}$$

📌 **Short half-life = lower patient dose**

9. Simple Calculation Example

A patient receives 400 MBq of I-131. What is the activity after 8 days ($\lambda_{I-131} = 0.0864\ day^{-1}$)?

What is Nuclear Medicine?

Nuclear Medicine is a medical specialty that uses radioactive substances (called radiopharmaceuticals) to:

- Diagnose diseases
- Treat certain medical conditions

Unlike X-ray or CT (which image anatomy), nuclear medicine focuses on function — how organs work.

Key idea for pharmacy students:
We administer a drug that emits radiation, then detect that radiation to study or treat disease.

What is a Radiopharmaceutical?

A radiopharmaceutical consists of two parts:

1. Radioisotope Emits radiation (gamma, beta, or positrons)
2. Pharmaceutical (carrier molecule)Targets a specific organ or tissue

📌 Example structure: Radioisotope + Drug → Targeted radioactive compound

10. Importance in Nuclear Medicine Practice

Understanding decay equations allows us to:

- Calculate administered dose
- Determine imaging time
- Ensure radiation safety
- Manage radioactive waste
- Optimize diagnostic image quality

Why Radiopharmaceuticals Are Useful

Radiopharmaceuticals allow us to:

Study organ function

Detect disease early

Deliver targeted therapy

✔ Very small doses

✔ Minimal pharmacological effect

✔ Radiation is the main mechanism of action

Nuclear Medicine Imaging Techniques

a. Gamma Camera / SPECT
Detects gamma rays
Common isotopes: Tc-99m, I-123

b. PET (Positron Emission Tomography)
Detects positron emitters
Common isotope: F-18 (FDG)

Diagnostic vs Therapeutic Radiopharmaceuticals

Diagnostic Radiopharmaceuticals

Emit gamma or positrons
Short half-life
Low radiation dose
📌 Example: I-123 for thyroid imaging

Therapeutic Radiopharmaceuticals

Emit beta or alpha particles
Cause cell damage
Used to destroy diseased tissue
📌 Example: I-131 for thyroid cancer

Role of the Pharmacist in Nuclear Medicine

As pharmacy students, your future roles may include:

Preparation of radiopharmaceuticals
Dose calculation
Quality control
Radiation safety
Patient counseling

Radiation Safety Considerations

Time: minimize exposure
Distance: keep safe distance
Shielding: lead containers
Proper waste disposal

📌 ALARA principle
As Low As Reasonably Achievable