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Department of Biomedical Engineering

Course Name: 19BME301 – Medical Physics

III Year : V Semester

Unit I –RADIATION AND RADIOACTIVE DECAY

Topic : Alpha decay & Beta decay

Modes of radioactive decay /decay of radioactivity

Contents

- Radioactivity and types
- Modes of decay
- Alpha
- Beta &
- Gamma

Decay of radioactivity

- Activity
- Decay constant
- Exponential decay
- Half life
- Methods for determining decay factors
- Image frame decay corrections

What do we mean by Radioactivity?

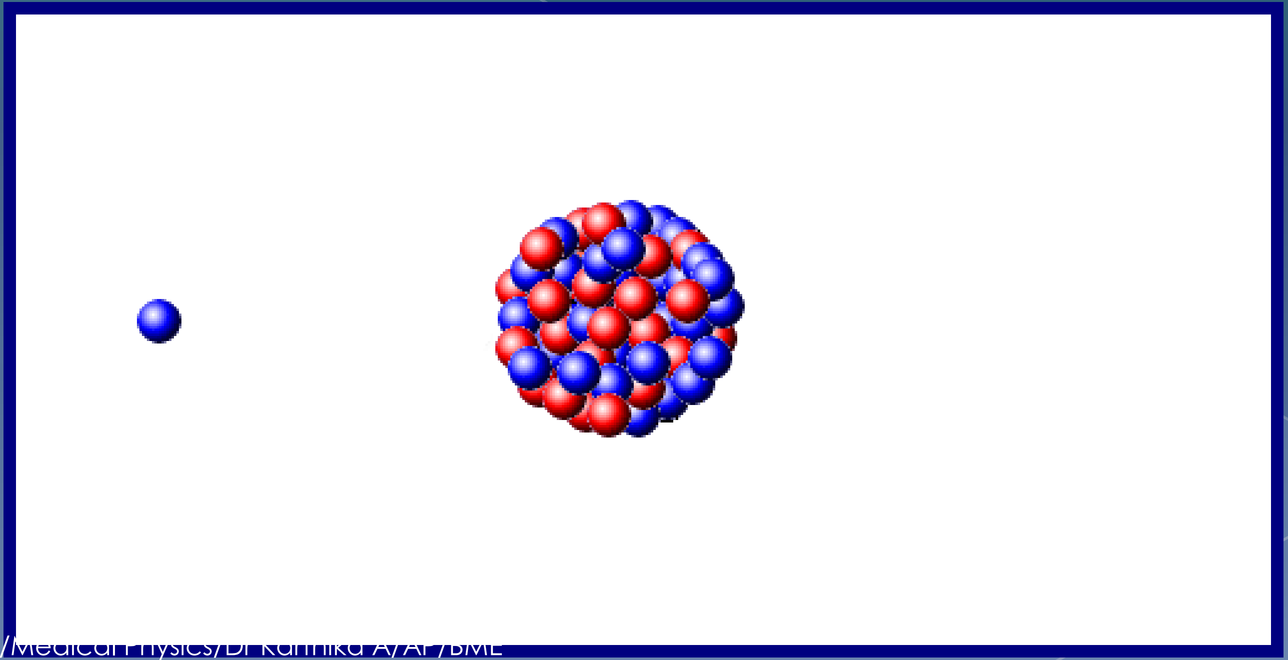
Radioactivity is the spontaneous disintegration of atomic nuclei

An unstable nucleus releases energy to become more stable

RADIOACTIVITY CAN OCCUR IN 2 WAYS
1.NUCLEAR FISSION
2.NUCLEAR FUSION

Nuclear fission

- The splitting of a nucleus into several smaller nuclei
- This is what happens in nuclear power plants



Nuclear fusion

- When two nuclei with low masses fuse to form one nucleus of larger mass, opposite of fission,
- The energy released by the sun and all stars is due to fusion reactions in the core

What is radioactive decay?

- **Radioactive decay** is the process in which an unstable atomic nucleus loses energy by emitting ionizing particles and radiation transforming the parent nuclide atom into a different atom called daughter nuclide .

The Radioactive Decay Law

- The rate at which a radioactive isotope disintegrates is defined by the following DECAY LAW:

$$\frac{N}{N_0} = e^{-\lambda t} = \left(\frac{1}{2}\right)^{\frac{t}{t_H}}$$

- Where
  - N: Number of atoms of a radioactive isotope at time t of atoms at time zero
  - λ: Decay constant
  - N_0: Number constant (each isotope has different)
  - t_H: Half-life (each isotope has different half-life)

MODES OF DECAY

1ALPHA DECAY

2.BETA DECAY

ARE 2 TYPES

A. BETA -MINUS PARTICLE

B. BETA PLUS PARTICLE

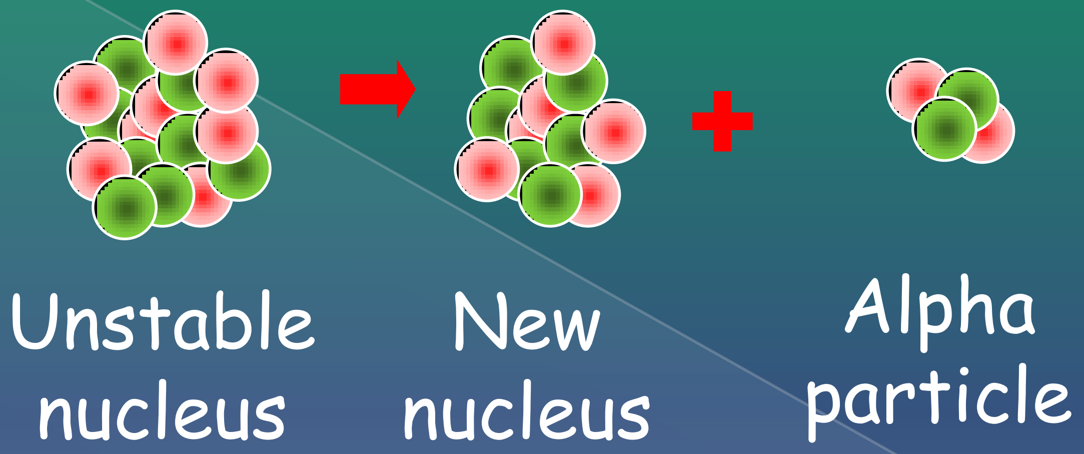
3.GAMMA EMISSION

ARE OF TWO FORMS

A. ISOMERIC TRANSITION

B. INTERNAL CONVERSION

Alpha decay



- Alpha (α) – an atom decays into a new atom and emits an alpha particle (2 protons and 2 neutrons– the nucleus of a helium atom)
- Very heavy nuclei are often unstable as they contain too many protons.
- Typical alpha emitters have an atomic number > lead (82).
- Alpha particles are emitted, as they are extremely stable. They have high binding energy.

ALPHA DECAY

- When a nucleus undergoes alpha decay, the parent nucleus will suffer a decrease in atomic number (*Z*) of two and a decrease of four in mass number (*A*).
- The daughter nucleus is now a different element.
- Alpha Decay Example

$${}_{Z}^{A}\mathrm{X} \rightarrow {}_{Z-2}^{A-4}\mathrm{Y} + {}_{2}^{4}\alpha \quad (\mathrm{Note:}\ {}_{2}^{4}\alpha = {}_{2}^{4}\mathrm{He})$$

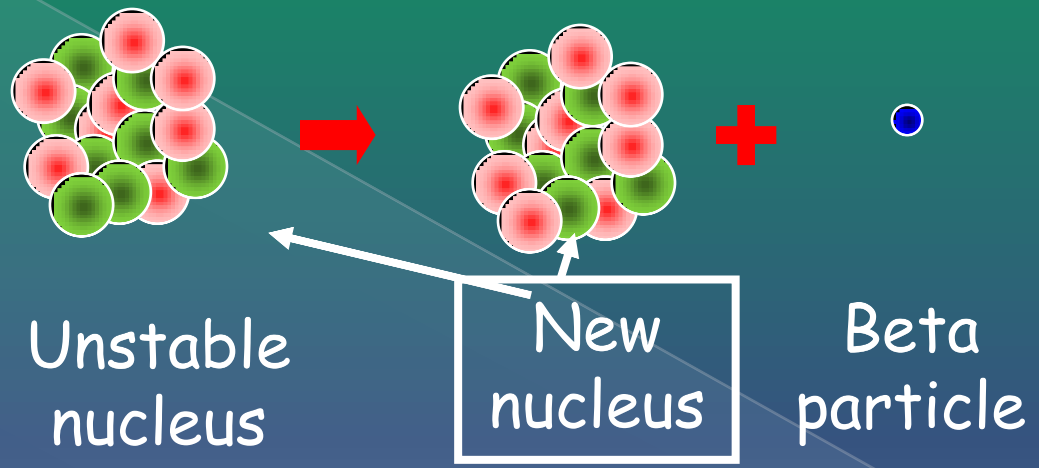
An example of the form of decay occurs in uranium-238.The equation represents what occurs is

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He$$

Biological effects of Alpha

- Alpha particles are not penetrating Their only biological effects are to the surface of the skin, with the production of radiation 'burns'.

BETA DECAY



BETA DECAY (β)

- Beta (β) – an atom decays into a new atom by changing a neutron into a protons and electron. The fast moving, high energy electron is called a beta particle.

- Betas are physically the same as electrons, but may be positively or negatively charged

- Betas are ejected from the nucleus, not from the electron orbitals
- In all beta decays the atomic number changes by one while the atomic mass is unchanged

BETA DECAYS ARE 2 TYPES

A.BETA- MINUS DECAY

B.BETA+ PLUS DECAY

Beta (β^-) Minus Decay

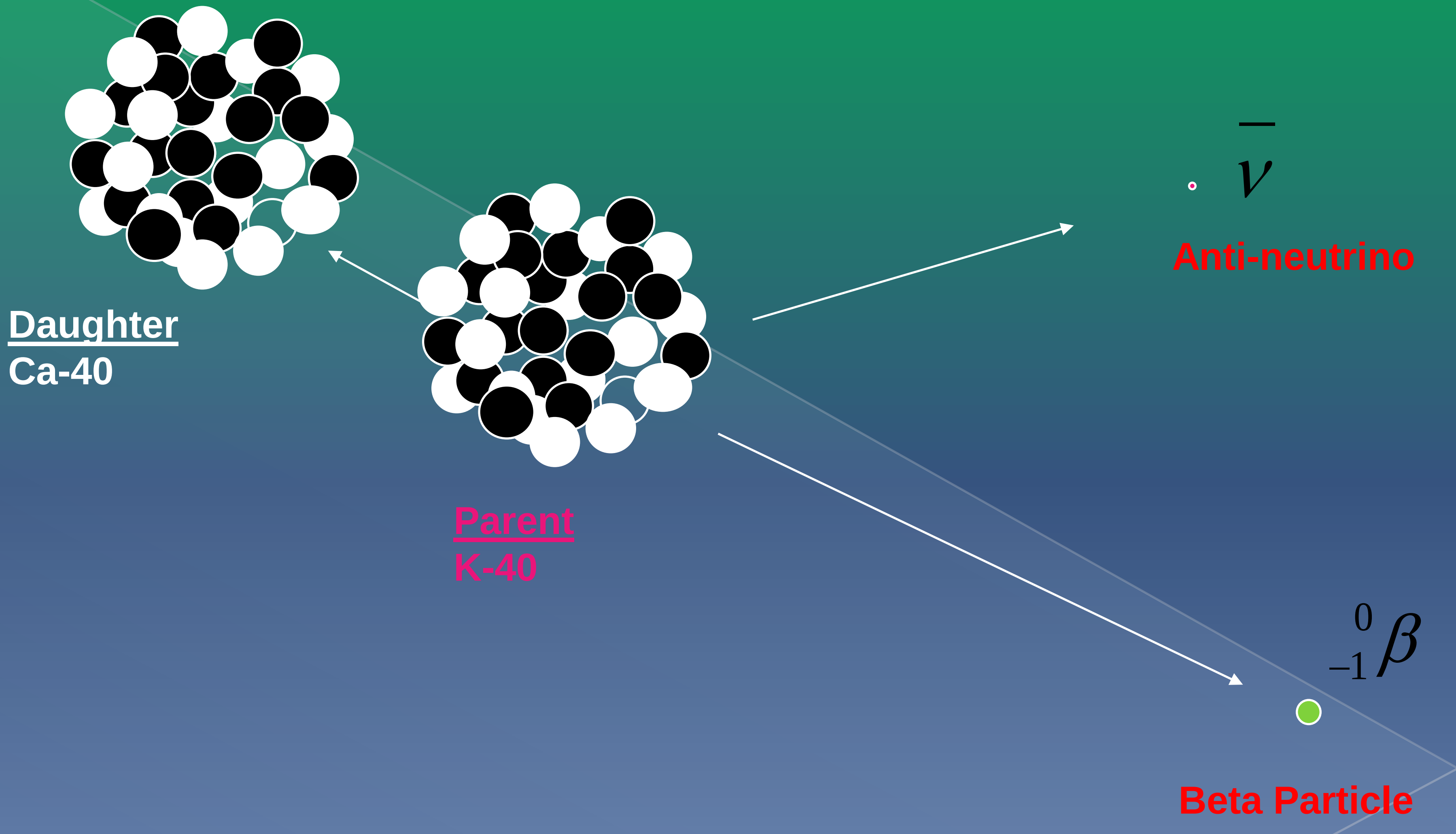
$$n \rightarrow p^+ + e^- + \nu + \text{energy}$$

- β^- emission is a process in which, essentially a neutron in the nucleus is transformed into a proton and electron
- The electron(e-) and the neutrino(v) are ejected from the nucleus and carry away the energy released in the process as kinetic energy
- The electron is called a β^- particle
- The neutrino is a "particle" having no mass or electrical charge

An example of this type of decays occurs in iodine-131 nucleus which decays into xenon 131 with the emission of an electron that is

$$^{131}_{53}I \rightarrow \, ^{131}_{54}Xe + \, ^{0}_{-1}e$$

Beta (β⁻) Minus Decay



Beta (β^+) plus decay

- Occurs in proton-rich nuclides
- A proton in the nucleus is transformed into a neutron and a positively charged electron
- The positively charged electron or positron **(β^+)** and a neutrino are ejected from the nucleus

$$p^+ \rightarrow n + e^+ + \nu + \text{energy}$$

- A positron is the antiparticle of an ordinary electron
- After ejection it loses its kinetic energy in collisions with atoms of the surrounding matter and comes to rest
- The positron and an electron momentarily form an "atom" called a positronium, has the positron as its nucleus and a lifetime of 10^{-10} sec.
- The positron then combines with the negative electron in an annihilation reaction, in which their masses are converted into energy
- The mass energy equivalent of each particle is 0.511Mev

DECAY BY ß+ emission may be represented in standard nuclear notation

$$ {}^{A}_{Z}X \xrightarrow{\beta^{+}} {}^{A}_{Z-1}Y $$

AN EXAMPLE OF THIS TYPE OF DECAY OCCURS IN SODIUM-22 WHICH DECAYS INTO NEON-22 WITH THE EMISSION OF POSITRON

$$ {}^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + {}^{0}_{+1}e $$

THE MASS NUMBER REMAINS THE SAME & THE ATOMIC NUMBER DECRESES BY 1

ELECTRON CAPTURE

In this form of beta decay an inner orbiting electron is attracted into an unstable nucleus where it combine with proton to form a neutron

The reaction can be re

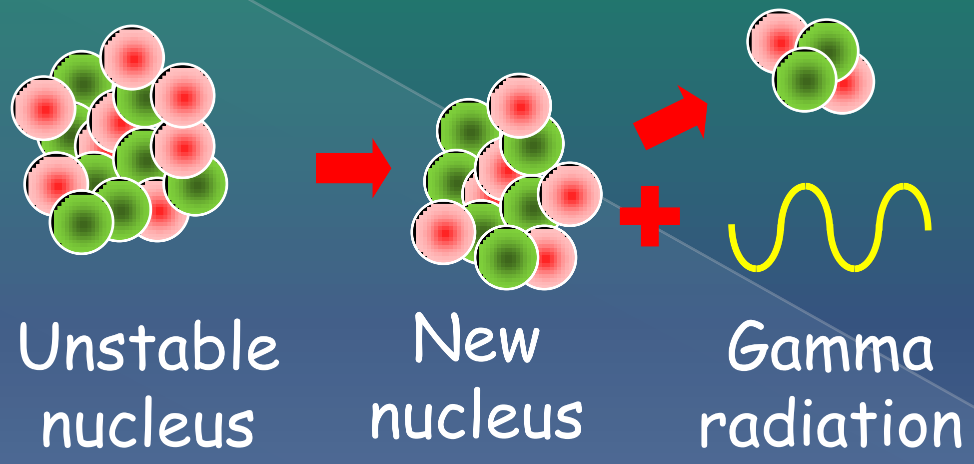
$$e^{-} + p^{+} \rightarrow n^{0}$$

This process is also known as k-capture since the electron is often attracted from the k-shell of the atom

Biological effects of Beta

- The penetration of beta particles is rather greater than alpha particles
  hazardous only if a beta emitter is ingested or inhaled.

GAMMA EMISSION



GAMMA EMISSION

Gamma – after α or β decay surplus energy is sometimes emitted. This is called gamma radiation and has a very high frequency with short wavelength. The atom is not changed

GAMMA EMISSION ARE IN TWO FORMS

A.ISOMERIC TRANSITION

B.INTERNAL CONVERSION

A.ISOMERIC TRANSITION

A nucleus in an excited state may reach its ground or unexcited state by the emission of gamma ray.

An example of this type of decay is that of technetium-99m

$$^{99m}_{43}Tc \rightarrow ^{99}_{43}Tc + \gamma$$

B.INTERNAL CONVERSION

In Internal Conversion the excess energy of an excited nucleus given to an atomic electron example a k-shell electron

Example of this type of radioactive decay occurs in iron-55 which decays into

manganese-55 following capture of an electron

The reaction can be represented as

$$^{55}_{26}Fe + ^{0}_{-1}e \rightarrow ^{55}_{25}Mn$$

Mass number unchanged in this form of decay & that the atomic number is decreased by 1

Biological effects of Gamma

Gamma-radiation affects the internal organs of the body due to its high penetrating power.

Properties

Property	α ray	β ray	γ ray
Nature	Positive charged particles, 2He4nucleus	Negatively charged particles (electrons).	Uncharged γ~0.01a, electromagnetic radiation
Charge	+2e	–e	0
Mass	6.6466×10^{-27} kg	9.109×10^{-31} kg	0
Range	~10 cm in air, can be stopped by 1mm of A l	Upto a few m in can be stopped~cm of A l	Several m in air stopped by~cm of Pb
Natural Sources	By natural radioisotopes e.g.$_{92}U^{236}$	By radioisotopes e.g.$_{29}Co^{68}$	Excited nuclei formed as a result of α, β decay

Decay of radioactivity

activity

- The activity of a quantity of radio nuclides is the number of nuclear transformation which occur in that quantity per unit time.

Curie (Ci) the activity in one standard gram of Radium = 3.7×10^{10} disintegrations per second

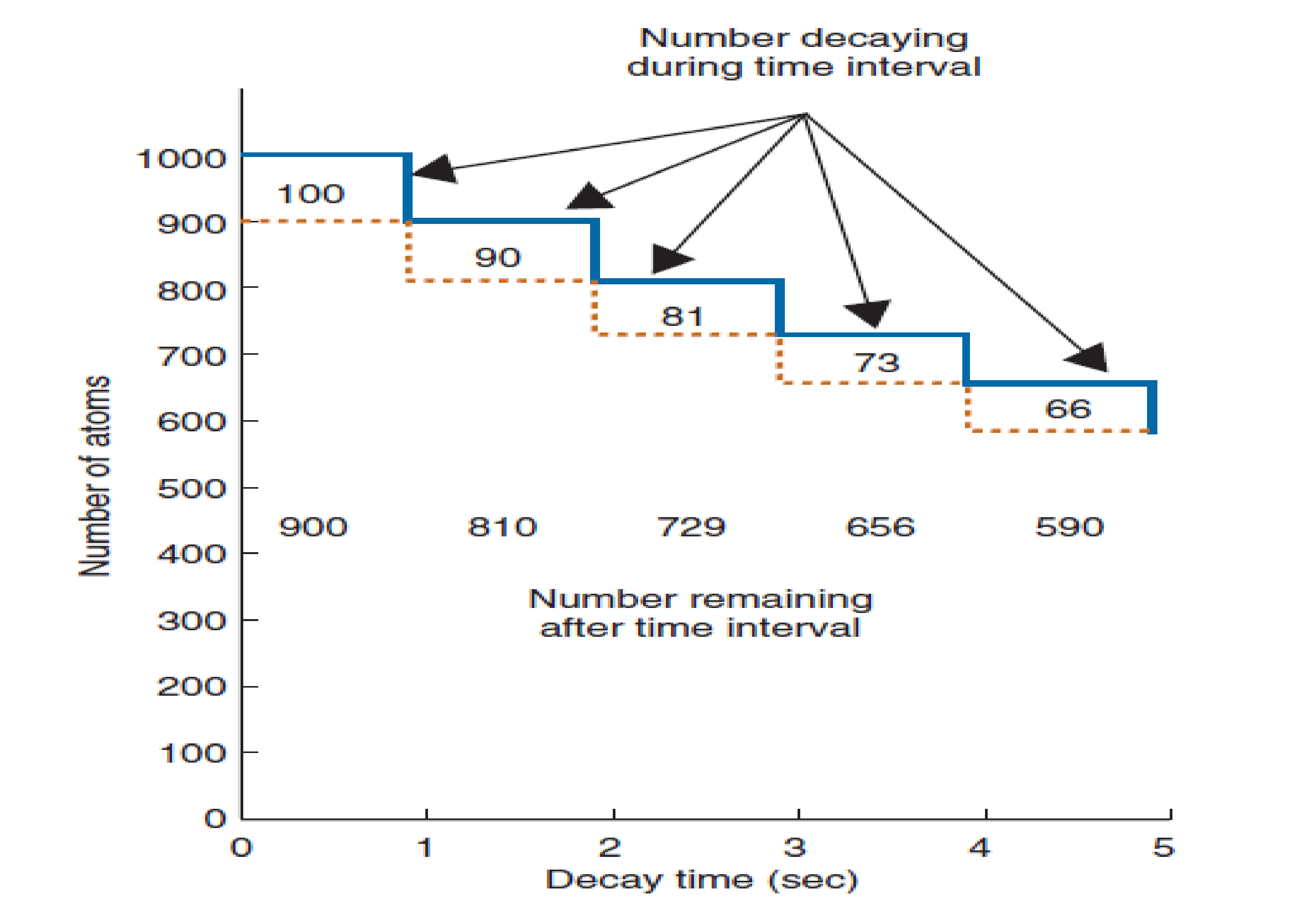
1 Curie (Ci) = 2.22×10^{12} disintegrations/min (dpm)

(S.I.)Becquerel (Bq) 1 disintegration per second – International Units (SI)

The Decay Constant

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

- Where,
  - λ is the decay constant for the radionuclide
  - N Is radioactive atoms of a certain radionuclide,
- the minus sign indicates that Δ N/Δ t is negative; that is, N is decreasing with time


Number decaying
during time interval
1000
900
800
700
600
500
400
300
200
100
0
Number of atoms
100
90
81
73
66
900
810
729
656
590
Number remaining
after time interval
0
1
2
3
4
5
Decay time (sec)

- Some radionuclides can undergo more than one type of radioactive decay(eg:^{18}F:97% β^+ ,3%EC) - branching decay
- The total decay constant for the radionuclide is the sum of the branching decay constants:

$$\lambda=\lambda_1+\lambda_2+\lambda_3+......$$

B. EXPONENTIAL DECAY

1. **<u>The Decay Factor</u>:**

the fraction of radio-active atoms remaining after a time *t*, is called the *decay factor* (DF).

It is represented by $e^{-\lambda t}$

$$N_{(t)} = N_{(0)} e^{-\lambda t}$$

Where,

Thus $N(t)$, the number of atoms remaining after a time t, is equal to $N(0)$,

the number of atoms at time $t = 0$, multiplied by the factor $e^{-\lambda t}$.

2. Half-Life (*T*1/2)

- It is the time required for a radionuclide to decay to 50% of its initial activity level. The half-life and decay constant of a radionuclide are related as †

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

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

3. Average Lifetime

- The *average lifetime* τ of the atoms in a sample has a value that is characteristic of the nuclide and is related to the decay constant λ by*

$$\tau = 1/\lambda$$

$$\tau = T_{1/2}/ln2$$

- The average lifetime for the atoms of a radionuclide is therefore longer than its half-life, by a factor 1/ ln 2 (≈1.44).

C. METHODS FOR DETERMINING DECAY FACTORS

1. **Tables of Decay Factors**

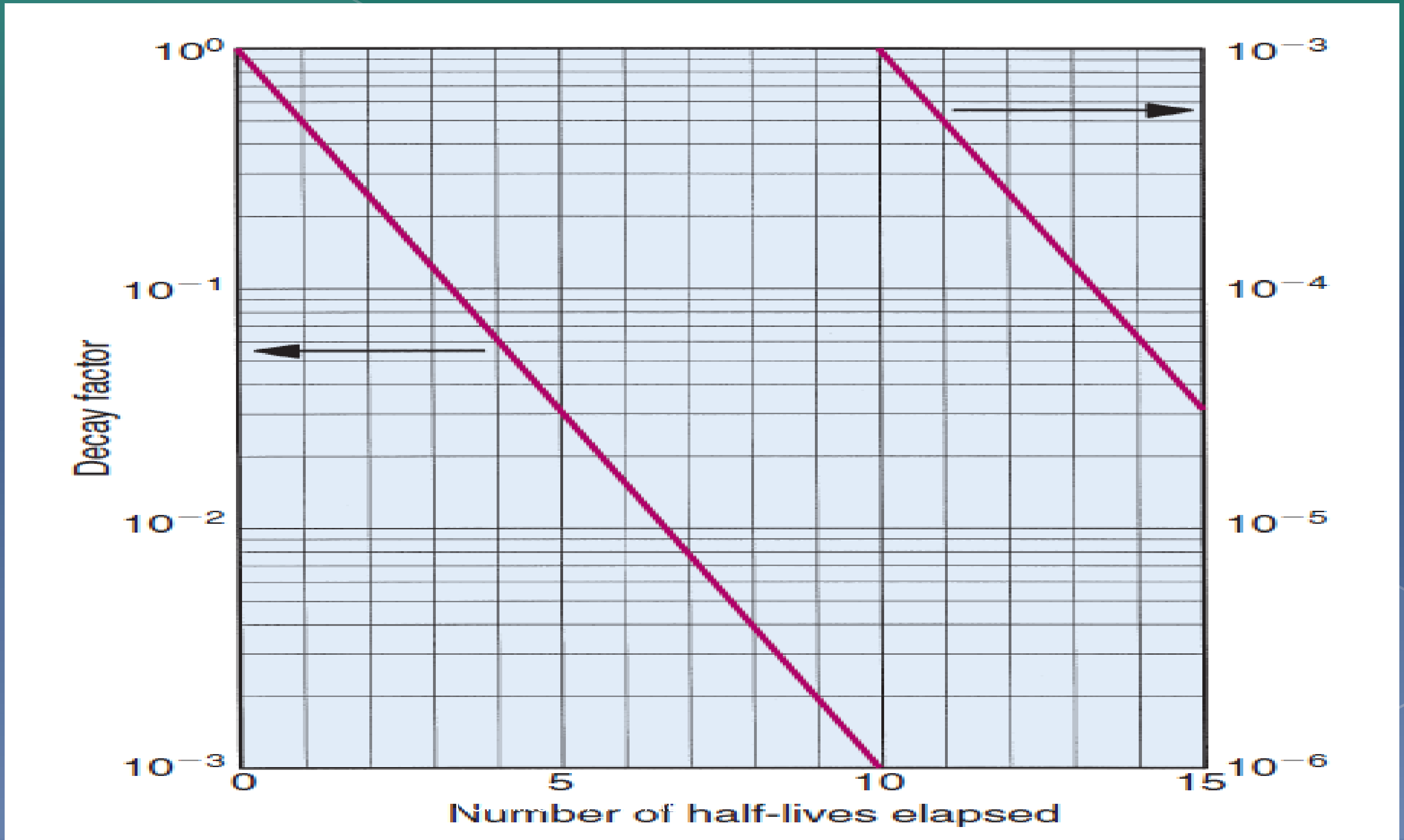
- It is essential that an individual working with radionuclides know how to determine decay factors.
- Perhaps the simplest and most straightforward approach is to use tables of decay factors, which are available from vendors of radiopharmaceuticals, instrument manufacturers, and so forth.
- Tables are generated easily with computer spreadsheet programs.

2. Pocket Calculators

- Many pocket calculators have capabilities for calculating exponential functions.
- First compute the exponent, $x = \ln 2 \times (t/T_{1/2})$, then press the appropriate keys to obtain e^{-x}.
- For precalibrated shipments, use e^{+x}.

3. Universal Decay Curve

- The graph can be used for any radionuclide provided that the elapsed time is expressed in terms of the number of radionuclide half-lives elapsed. An example of a universal decay curve.



D. IMAGE-FRAME DECAY CORRECTIONS

- In some applications, data are acquired over periods that are not short in comparison with the half-life of the radionuclide.
- An example is the measurement of glucose metabolism using deoxyglucose labelled with fluorine-18 .
- In such measurements, it often is necessary to correct for decay that occurs during each measurement period while data collection is in progress.
- Because data are acquired in a series of image frames, these sometimes are called **image-frame decay corrections**.

E. SPECIFIC ACTIVITY

- The ratio of radioisotope activity to total mass of the element present is called the *specific activity* of the sample.
- Specific activity has units of becquerels per gram, megabecquerels per gram, and so forth.
- The highest possible specific activity of a radionuclide is its *carrier-free specific activity* (CFSA).

f. decay of a mixed radionuclide sample

- When a sample contains a mixture of unrelated species (i.e., no parent daughter relationship), the total activity A_t is just the sum of the individual activities of the various species

$$A_t(t) = A_1(0)e^{-0.693t/T_{1/2,1}} + A_2(0)e^{-0.693t/T_{1/2,2}} + \cdots$$

- Where $A_1(0)$ is the initial activity of the first species and $T_{1/2,1}$ is its half –life, and so forth

THANK YOU