Physics
Radioactive Decay

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Decay process (Activity)

- Radioactive decay is a random process. We cannot predict when an individual nucleus will decay but with large numbers of nuclei we can use a statistical approach.
- One of the most important quantities associated with a sample of radioactive material is its activity.
- Activity is the rate at which the nuclei within the sample undergo decay (disintegrations) and can be expressed in terms of the number of disintegrations per second (dps).

Activity

- **Activity** : It is the average number of disintegrations per second (dps)

- The SI unit of activity is the becquerel:

1 becquerel (1 Bq) = 1 disintegration/second (1dis/sec).

1 Bq= 1dis/sec= 1dps

- Another unit of activity is the curie (Ci):

1 curie = 1 Ci = 3.7×10^{10} dis/s

1 Ci = 3.7×10^{10} Bq

Radioactive Decay Laws

- Experimental measurements show that the activities of radioactive samples fall off exponentially with time. As the sample decays, less of the radioactive sample remains, so the activity decreases.
- The following equations can be used to calculate the activity of a radioactive material at any time.

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

$$A = \lambda N$$

$$A_0 = \lambda N_0$$

A = Activity remaining in the radioactive material after time (t)

A_0 = Initial Activity of the radioactive material

N = Number of radioactive nuclei present at a time t

N_0 = the initial number of radioactive nuclei present at time t=0

λ = Decay constant

t = Time

Radioactive Decay Laws

We can also calculate the number of remaining radioactive nuclei in the radioactive sample after period of time from the following equation

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

N = Number of radioactive nuclei present at a time t

N_0 = the initial number of radioactive nuclei present at time t=0

λ = Decay constant (s^{-1})

t = Time (s)

Radioactive Decay Laws

- Decay constant (λ): The probability that a nucleus will decay per unit of time. Its unit is s^{-1} , min^{-1} , h^{-1} , day^{-1}
- Half-Life ($t_{1/2}$): The time for half of the radioactive nuclei in a given sample to undergo decay. (i.e. the time it takes for the activity to drop by ½)

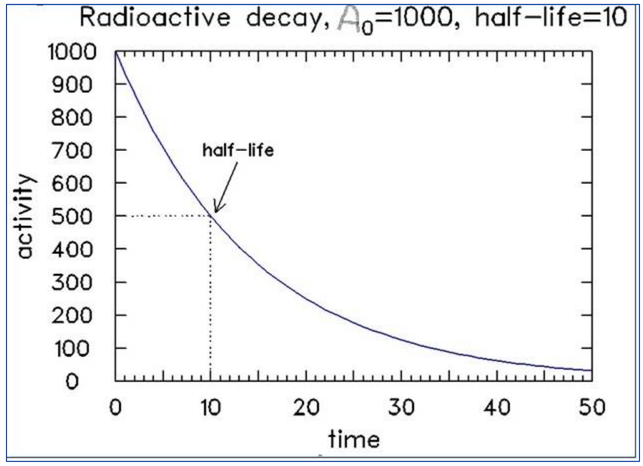
- Each radioactive nuclide has a particular decay constant and half life. The relationship between λ and $t_{½}$ is

$$\lambda = \frac{0.693}{t_{½}}$$

a plot of the activity of a radionuclides versus time.

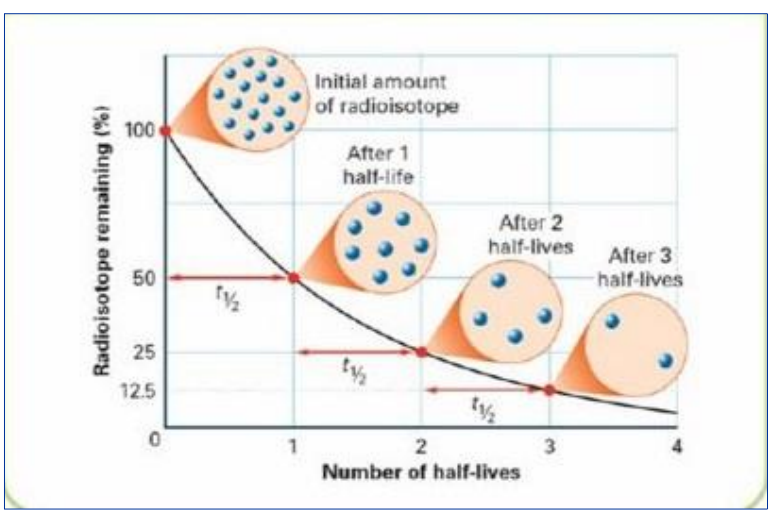
The initial activity was chosen to be 1000 for this plot.

The half-life is 10 (in whatever time units we are using).



Note: All decay curves look like this; only the numbers on the axes will differ, depending on the radionuclide (which determines the half-life) and the amount of radioactive material (which determines the initial activity).

a plot of number of a radionuclides versus half life.



Common Radioactive Isotopes

Isotope	*Half-Life*	*Radiation Emitted*
Technetium-99	6 hours	γ
Radon-222	3.8 days	α
Carbon-14	5,730 years	β, γ
Uranium-235	7.0×10^8 years	α, γ
Uranium-238	4.46×10^9 years	α

Note: You do not need to memorize these numbers

Examples

Ex.1: A sample of $3x10^7$ Radon atoms are trapped in a basement that is sealed. The half-life of Radon is 3.83 days. How many radon atoms are left after 31 days?

Answer:

Info: $N_0 = 3x10^7$ atom, $t_{½}$ = 3.83 days, t=31 days

To find N after 31 days, we will use this eq. $N_t = N_0 e^{-\lambda t}$

First, we should calculate λ from this eq. $\lambda = \frac{0.693}{t_{½}}$

λ= (0.693/3.83 d) = 0.1809 d^{-1}

Next step, we will find N by using $N_t = N_0 e^{-\lambda t}$

N_t = $3x10^7$ atom x exp(- 0.1809 d^{-1} x 31d)

N_t =$1.1x10^5$ atom

Ex.2: We received 10 millicuries (mCi) of I-125. The half-life of I-125 is 60 days. . How much activity remains after 3 months

Answer:

Info: A_0 = 10 m Ci, $t_{½}$ = 60 d, t = 3 months= 90 d

we are asked to calculate A_t= ???

Therefore, we will use this eq. $A_t = A_0 e^{-\lambda t}$

$t_{½}$ = 60 d ⟹ λ = (0.693/60 d) = 0.01155 d^{-1}

$A_t = A_0 e^{-\lambda t}$ ⟹ A_t = 10 mCi x exp(- 0.01155 x 90)

A_t =3.53 mCi the activity after 3 months

Ex.3: A sample of $3x10^6$ Radon atoms are trapped in a basement that is sealed. The half-life of Radon is 3.83 days. How much the current activity?

Answer:

Info: N= $3x10^6$, $t_{½}$ = 3.83 d ⟶ λ= (0.693/ $t_{½}$)

We are asked to find the activity (A) ??

Therefore, we will use this eq: $A = \lambda N$

Before solving this problem, you have to make the unit of λ in s^{-1}

$t_{½}$ = 3.83 d x 24 h/d x 60 min/h x 60 s/min = 330912 sec

λ = (0.693/330912) = 2 $x10^{-6}$ s^{-1}

A= 2 $x10^{-6}$ s^{-1} x 3 $x10^6$ atom = 6 atom/s = 6 Bq

Ex.4:A sample of Radon has an activity of 10 Bq. The half-life of Radon is 3.83 days. How many radioactive nuclides are in this sample?

Ex.5: A medical center received Tc-99 (half life = 6 h). The initial activity of Tc-99 was 3 mCi when it was delivered, . Calculate the activity of Tc-99 after 2 days ?

Radiation Dose

- The magnitude of radiation exposures is specified in terms of the radiation dose.

- There are two important categories of dose:

1. *Absorbed dose*
2. *Dose equivalent*

1- *Absorbed dose*

- *Absorbed dose:* the amount of energy deposited in a unit mass in human tissue or other media.
- SI unit used to measure absorbed dose is the gray (Gy)

1 Gy = 1 J/kg

- another unit used to measure absorbed dose is rad

1 Gy = 100 rad

Absorbed dose can be calculated from the following formula

$$\boxed{D = \frac{E}{m}}$$

Where: D=dose (Gy), E =energy(J), m= mass(Kg)

1- *Absorbed dose*

Example: 0.1 J of radiation energy was deposited in 30 g of tissue. Find the absorbed dose in Gy and in rad

Answer

Info: E=0.1 J, m=30g =30/1000 =0.03 Kg

$$\boxed{D = \frac{E(J)}{m(Kg)}}$$

D = 0.1J/0.03Kg = 3.3 Gy

Since 1 Gy = 100 rad

D = 3.3 Gy x 100 rad/Gy

D= 330 rad

2- *Dose equivalent*

Dose equivalent: A measure of the biological damage to living tissue as a result of radiation exposure. Also known as the " biological dose".

- SI unit used to measure Dose equivalent is *sievert* (Sv)
- another unit used to measure Dose equivalent is rem

1 Sv = 100 rem

Dose equivalent can be calculated from the following formula

$$\boxed{H\ (Sv) = D\ (Gy) \times Q} \qquad \boxed{H\ (rem) = D\ (rad) \times Q}$$

Where: H = Dose equivalent , D= absorbed dose

Q= weighting factors(previously called quality factor)

2- *Dose equivalent*

- Weighting factor (Q): is dimensionless factor used to convert physical dose (Gy) to equivalent dose (Sv).
- Example: If the absorbed dose is 20 rad and Q is 10. What is Dose equivalent in rem and in Sv

Answer:

H (rem) = D(rad) x Q = 20 rad x 10 = 200 rem

Since 1 Sv = 100 rem $\longrightarrow$ 1 rem = (1/100) Sv = 0.01 Sv

H (Sv) = 200 rem x 0.01 Sv/rem= 2 Sv

Or, we can solve it by this:

H (Sv) = D (Gy) xQ =20 rad x(1/100) Gy/rad x10

H = 0.2 Gy x 10 = 2 Sv

Factors Affecting Radiation Dose

- Target organ/tissue, i.e., radiation sensitivity of the tissue
- Type and energy of the radiation
- Rate of Delivery
- Interaction Volume
- Biological status: difference between young/old, male/female, population/individual, healthy/diseased

Radiation Interaction In Cells

- There are two principle ways to characterize the ways in which radiation interacts with cells. These ways are through direct effects and indirect effects.

1- Direct Effect - Direct ionization of DNA or other structure by radiation. The result may lead to the break-up or chemical change in the molecule.

2- Indirect Effect - Ionization of water molecules within the cell creates very chemically active agents (free radicals) which can chemically attack other molecules in their immediate vicinity. If a DNA molecule is located in this area, alteration to the DNA molecule could occur.

Radiation Safety and ALARA

- What is ALARA ?
- ALARA is an acronym for "As Low As Reasonably Achievable". This is a radiation safety principle for minimizing radiation doses and releases of radioactive materials by employing all reasonable methods.
- ALARA is not only a sound safety principle, but is a regulatory requirement for all radiation safety programs.
- Three of the most basic and easy to follow principles of radiation protection are time, distance, and shielding. We can greatly reduce our exposure by following these principles.

Radiation Safety and ALARA

- **Time:** As the length of time a person is exposed increases, the dose received increases.
- **Distance:** The most effective of the principles is distance. The further a person is from the source the less intense the radiation source is.
- **Shielding:** When the use of the time and distance principles are not possible shielding should always be used. Wearing protective lead shielding and thyroid collars can protect the radiosensitive areas of the body when it is required for the technologist to be near the source of radiation.

Reducing External Radiation Exposure

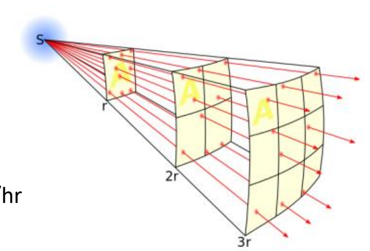
- Time:
  reduce time spent in radiation area
- Distance:
  stay as far away from the radiation source as possible
- Shielding:
  interpose appropriate materials between the source and the body

Inverse square law applied in radiation

Inverse Square law: The radiation Intensity is inversely proportional to the square of the distance from the source. The radiation source must be a point source

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

$$I_1 \times D_1^{\ 2} = I_2 \times D_2^{\ 2}$$



$\mathbf{I_1}$ = Intensity at a distance D1 measured as (R/hr or mR/hr)

$\mathbf{D_1}$ = first Distance
$\mathbf{I_2}$ = Intensity at Distance D2
$\mathbf{D_2}$ = second Distance

Example 1: If the intensity of point source = 100 IU at 1cm, what is its intensity at 10 cm?

Answer:
Given Information: I_1=100 IU, D_1=1 cm, D_2=10 cm, I_2=?

$$I_1 \times D_1^{\ 2} = I_2 \times D_2^{\ 2}$$

$100 \times (1)^2 = I_2 \times (10)^2$
$100 = I_2 \times 100$
$I_2 = 1$ IU

Example 2: A reading of 100 mR/hr is obtained at a distance of 1 cm from a point source. What would be the reading at a distance of 1 mm?

Answer:

Given information

I_1= 100 mR/hr, D_1= 1 cm, D_2=1 mm =0.1 cm, I_2=?

$100 \times (1)^2 = I_2 \times (0.1)^2$

$100 = I_2 \times 0.01$

$I_2 = 100/0.01$

$I_2 = 10000$ mR/hr