Radioisotopes

Radiation

- Many biochemical analysis require the detection of minute (10^{-14} – 10^{-6} mole) quantities of material. However chemical tests are rarely responsive to less than 10^{-7} mole . This limitation has been overcome by the development of **radiotracer technology** by which extraordinary sensitive detection of radioisotopically labeled material has allowed and made it possible to study substances in minute quantities (such as 10^{-12} mole).
- **Types of radiation:**

1- Ionizing radiation : It is radiation that has enough energy to remove electrons from atoms within material (thus ionizing it) . Ionizing radiation includes cosmic rays, alpha, beta and gamma rays, X-rays .

2-Non-ionizing radiation: It is radiation that does not have enough energy to remove electrons from atoms . Examples of non-ionizing radiation include most visible light, infrared light, micro- waves, and radio waves .

Atomic structure

- Atomic structure : An atom is composed of a positively charged nucleus that is surrounded by a cloud of negatively charged electrons. The mass of an atom is concentrated in the nucleus . The atomic nuclei is composed of two major particles , protons and neutrons . Protons are positively charged particles ,
- Neutrons are uncharged particles with a mass very close to that of the proton.
- The number of orbital electrons in the atom must be equal to the number of protons in the nucleus , since the atom as a whole is electrically neutral.
- The **atomic number** of an atom is equal to number of protons or electrons in the atom (Z) .
- The sum of neutrons and protons is the **mass number (A)** , A= N+Z

Where N is the number of neutrons in the atom.

Isotopes

- **What are isotopes?**
- Atoms of a given element may contain different number of neutrons , thus having different mass numbers .

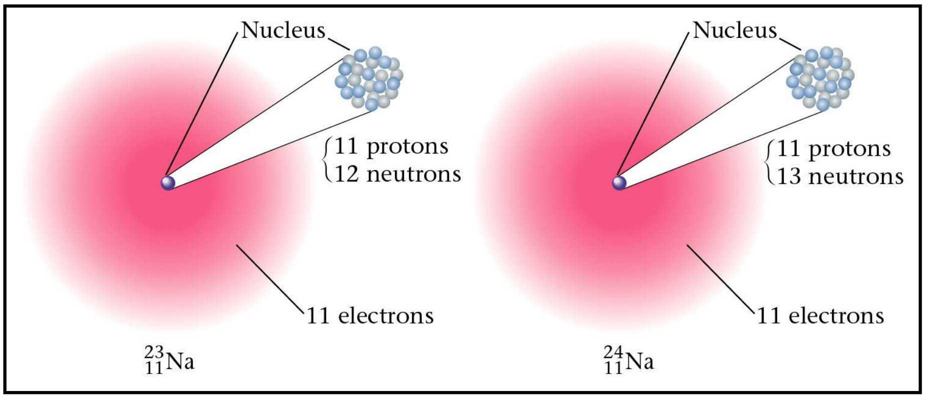
Isotopes: Are Atoms of an element with different number of neutrons (but the same number of protons) thus possessing different mass numbers.

$_{6}^{12}C$, where 6 represents the atomic number which should be identical for all atoms of the same element , while 12 represents the atomic mass which could be different in atoms of the same element giving rise to isotopes.

Example of isotopes : $_{6}^{12}C$, $_{6}^{14}C$, $^{16}{}_{8}O$, $^{18}{}_{8}O$. $_{1}^{1}H$, $_{1}^{2}H$, $_{1}^{3}H$.

- When the number of neutrons in the nucleus exceeds a threshold, then the nucleus becomes unstable or **radioactive** and will spontaneously “decay,” or emit excess energy (“nuclear” energy) in the form of charged particles or electromagnetic waves pursuing stability .

Two isotopes of sodium.



Radioactive decay

- **Types of radioactive decay:**
- 1- Decay by emission of β- particles (negatron emission):

In this type of decay a neutron is converted to a proton by the ejection (emission) of a negatively charged β- particle .

Neutron ➔ proton + β^- particle (negatron) .

The β^- particle (negatron) emitted is an electron but of a nuclear origin .

As a result of this type of decay the nucleus loses a neutron but gains a proton .

The N/Z ratio decreases (preferred for atom stability) , while Z (number of protons) increases by one , and A (atomic mass) remains constant .

A radio isotope frequently used in biochemistry work that decays by β- particles emission are:

^{14}C , ^{3}H . Which can be used to label organic compounds.

^{35}S can be used to label methionine and study proteins.

^{32}P is a very useful radio isotope to radiolabel and study nucleic acids .

Radio active decay

- 2- Decay by emission of Gamma "γ" rays :

Gamma emission involves electromagnetic radiation not particle radiation as seen in β- particles emission.

These gamma rays are uncharged and are similar to x-rays but have shorter wave-length and are highly energetic .

In Gamma radiation a nucleus which is in an excited state may emit one or more photons (packets of electromagnetic radiation) of discrete energies .

Radio active decay

- Radioactive decay is a spontaneous process and it occurs at a definite rate characteristic of the source . The rate always follows an exponential law .
- The number of atoms disintegrating at any time is proportional to the number of atoms of the radioactive isotope (N) at the time the measurement was taken (t).

- $-dN/dt \propto N$, $-dN/dt = \lambda N$
- $-dN/dt$ = the number of atoms decaying per small increment of time (i.e the count rate).
- N = the total number of radioactive atoms present at any time .
- λ is the decay constant , different for each isotope

Rate of radioactive decay

- λ the decay constant is defined as the fraction of the radioactive atom decaying (disintegrating) at unit time .
- The equation can be integrated and rewritten as :
- $2.3\log N_{\circ} / N = \lambda t$.
- $N_{\circ}$ = the original number of radioactive atoms .
- N = the number of radioactive atoms at any other given time .

Radio active decay

- $N_{\circ}$ can be expressed as 100% , and N % remaining after time interval , or expressed as $N_{\circ}$ = 1.0 and , N = fraction remaining as decimal after time t.

Half life :

The half life " $t_{1/2}$ " of a radioactive isotope is defined as the time required for half of the original number of radioactive atoms to decay.

The relationship between $t_{1/2}$ and λ is given in the following equation :

$\lambda = 0.693/t_{1/2}$.

Equations of radioactive decay

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

$t_{1/2}$ = half life

λ = decay constant

N = the total number of radioactive atoms present at any given time

N_0 = original number of radioactive atoms

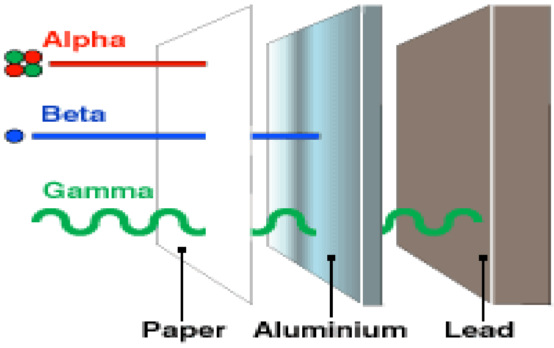
$2.3 \log \frac{N_0}{N} = \lambda t$

Radio active decay

Units for radioactivity : The international unit is" becquerel" (Bq) , this is defined as one disintegration per second . This unit is not applied widely .

The commonly used unit is the curie (Ci). It is defined as the quantity of radioactive material in which the number of nuclear disintegrations per second Is the same as that of in 1.0 gram of radium (namely 3.7×10^{10}) . For biological applications this unit is too large and the microcurie (µCi)) and millicurie (mCi) is used.

It is important to realize that the curie refers to the number of disintegrations actually occurring in the sample (d.p.s decay per second) not to the disintegrations detected by the radiation counter which will generally be only a proportion of the actual disintegrations occurring and is referred to as counts (c.p.s).



- Alpha particles are stopped by a sheet of paper and cannot pass through unbroken skin
- Beta particles are stopped by an aluminium sheet
- Gamma rays are stopped by thick lead

Radiation Safety
benefits and risks

exposure to ionizing radiation is a risk.

Effects of ionizing radiation on life depend on types of radiation, and dosages (amounts) received.

Natural ionizing radiation include cosmic rays, X-rays and gamma rays from space, and natural radioactivity.

Radiation Effects

Somatic effects
damages to cells passed on to succeeding cell generations.

Genetic effects
damages to genes that affect future generations.
Genes are units of hereditary information that occupy fixed positions (locus) on a chromosome. Genes achieve their effects by directing the synthesis of proteins.

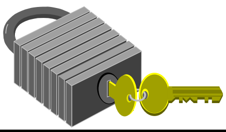
Somatic effects and genetic effects show no immediate symptoms

Radioactive safety

- Radio active material should be stored enclosed in either a capsule or another suitable container designed to prevent leakage or escape of the radioactive material
- .The containers should be tested periodically for leakage.

Radioactive safety

- All radiation sources must be kept locked up when not in use.
- Experiments left unattended should be labeled "Experiment in Progress."
- An up-to-date use log of all sources must be kept at the storage location.
- All radiation laboratories will be locked when unattended for extended periods.
- When you are the means for security, you must challenge unknown persons entering the lab.
- Sources can only be used in a registered radiation laboratory.



General Radiation Safety

- **No** food or beverages in the lab.
- Keep a survey meter conveniently close by.
- Time, distance, and shielding are important.
- Label radioactive materials and equipment.
- Never remove sources from the Lab.

Tutorial

Q1: The half life of cobalt -60 , is 5.3years .If an old sample of 10g has now decayed to 1gm , how much time has passed ?

Solution : $\lambda = \frac{0.693}{t_{1/2}}$

$\lambda = \frac{0.693}{5.3} = 0.13\ y^{-1}$.

$N = N_\circ\ e^{-\lambda t}$

$1 = 10\ e^{-(0.13)(t)}$

$1/10 = e^{-(0.13)(t)}$

lin1/10 = - (0.13)(t)

- 2.3 = - (0.13)(t)

t = -2.3 / - 0.13 = 17.69 years.

Tutorial

- Q2: The half life of Uranium- 232 is 68.9 years . How much of a 100g sample is present after 250 years ?
- Solution:
- $\lambda = \frac{0.693}{68.9} = 0.01\ y^{-1}$.
- $N = N_\circ\ e^{-\lambda t}$
- $N = 100e^{-(0.01)(250)}$
- $N/100 = e^{-(0.01)(250)}$
- linN/100 = - (0.01)(250)
- linN – lin100 = - (0.01)(250)
- linN = lin100 -(0.01)(250)
- linN = 4.6 – 2.5 = 2.1
- N = 8.166 g

Tutorial

- Q3: The half life of yttrium is 20min .If there are 1000g of yttrium present how much will be left after 30min?

Solution :

$\lambda = \frac{0.693}{20} = 0.034$ min .

$N = 1000e^{-(0.034)(30)}$

$N/1000 = e^{-(0.034)(30)}$

lin N/1000 = - (0.034)(30)

LinN – lin1000 = - (0.034)(30)

linN = lin1000 -(0.034)(30)

linN = 6.9 – 1.02

linN = 5.88

N = 357.8g

Tutorial

- A 30 kg sample of Plutonium-239, will decay by 1kg in 1180y. What is the half life of Plutonium -239 ?
- $N = N_{\circ}\ e^{-\lambda t}$
- $29 = 30e^{-\lambda\ (1180)}$
- $29/30 = e^{-\lambda\ (1180)}$
- lin29/30 = $^{-\lambda\ (1180)}$
- Lin29 – lin30 = -λ (1180)
- 3.367 -3.401 = -λ (1180)
- - 0.034 = -λ (1180)
- λ = - 0.034 / -1180
- $\lambda = 2.88 \times 10^{-5}$ y-1

$t_{1/2} = 0.693/\lambda$

$t_{1/2} = 0.693/2.88 \times 10^{-5} = 23896.5$ years .

Tutorial

- Q4:Calculate the total amount of radioactivity in Curie units Ci of 10g of U-235 $\lambda = 3.122x\ 10^{-17}$, .
- Solution:

Number of moles = wt / atomic mass

Number of moles = 10/235 = 0.04255moles.

Number of atoms = number of moles x Avogadros number

Number of atoms = 0.04255 x $6.023x10^{23}$ = 0.256 x 10^{23} atoms

Total amount of radiation = number of atoms x λ

Total amount of radiation = 0.256 x 10^{23} x 3.122x 10^{-17}

Total amount of radiation = 0.80002 x 10^{6} Decay per second DPS .

Convert to Curie units :

1 Curie unit ------------- 3.7 x 10^{10} Decay per second(DPS).

Amount of radiation in Curi units = 0.80002 x 10^{6} /3.7 x 10^{10}

Amount of radiation in Curi units = 0.0000216 Ci .

1-Determine the decay constant for Carbon-14, if it has a half-life of 5730 years?

2-If Radium-223 has a half life of 10.33 days, what time duration would it require for the activity associated with this sample to decrease 1.5% of its present value?

3-Determine the number of atoms in a 1.00 mg sample of Carbon-14?

4-What mass of Carbon-14 must be in a sample to have an activity of 2.00 mCi decay constant = 1.209 x10^{-4} y-1 ?