19

BASIC PRINCIPLES OF RADIOACTIVE MEASUREMENTS

19.1 INTRODUCTION

Radioactivity is defined as the process in which unstable atomic nuclei loses energy by emitting radiation in the form particles or electromagnetic waves. These radiations are able to ionize the atoms and molecules along their track. These radiations are able to cause cancer and death. Therefore these radiations are of health and safety concern.

To understand radioactivity we should be able to understand certain basic concepts like atom and atomic stability.

OBJECTIVES

After reading this lesson, you will be able to:

- describe Atom
- explain radioactive delay
- describe units of radioactivity
- explain the characteristics of radioactive emissions

19.2 ATOM

An atom is defined as the smallest component of an element having the chemical properties of the element. It consists of positively charged nucleus surrounded by negatively charged electrons. The nucleus is made up of positively charged protons and uncharged neutrons.

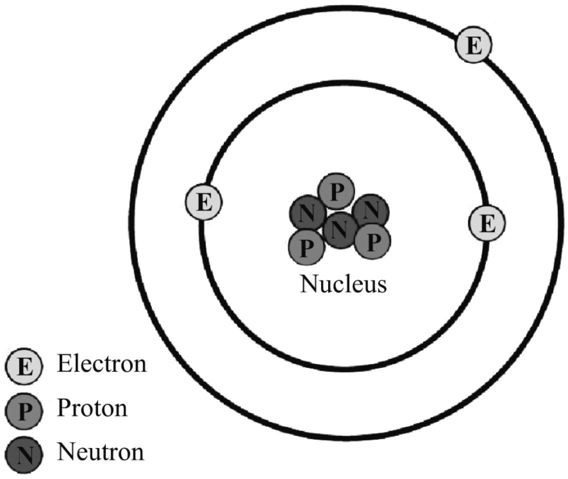

Fig. 19.1: Structure of an atom

In an atom the number of protons (P) and number of electrons (E) are equal. This number is termed as atomic number (Z).

Atomic number (Z) = (P) = (E)

The atomic number is independent of neutrons. Therefore it does not affect the chemical properties of an atom. The mass of the proton and neutron is equal and is1850 times more than that of electron. Hence the mass of an atom is concentrated in its nucleus. Mass number of an atom (A) is given by the sum of number of protons and number of neutrons in a given nucleus.

Mass number (A) = (P) + (N)

The number of neutrons for a given atom of an element may vary which gives rise to atoms with different mass number. Isotopes are defined as atoms with same atomic number but different mass number.

Eg: There are 3 isotopes for hydrogen- ^{1}H, ^{2}H, ^{3}H

19.2.1 Atomic stability and radiation

The stability of an atom depends upon the neutron to proton ratio (N: P)(also known as N:Z) in its nuclei. For elements with lower atomic number, N: P is 1. For elements with higher atomic number, N: P is greater than1. If this ratio is altered then the atom becomes unstable. By emitting particles or electromagnetic radiation these atoms tend to become stable. This process is known as Radioactivity or radioactive decay.

19.3 RADIOACTIVE DECAY

There are several types of radioactive decay. The most relevant to biochemistry are:

1. Decay by negatron emission
2. Decay by positron emission
3. Decay by alpha particle emission
4. Decay by emission of gamma rays
5. Decay by electron capture.

1. Decay by negatron emission

In this type of decay a neutron is converted into a proton by ejection of a negatively charged beta (β) particle called a negatron (β –ve)

$$\text{Neutron} \longrightarrow \text{Proton} + \text{Negatron } (\beta \text{ –ve})$$

Negatron is nothing but an electron of nuclear origin. As a result of this emission the nucleus gains a proton but loses a neutron. Here N: P ratio decreases, Z increases by 1 and A remains constant. An isotope frequently used in biological work that decays by negatron emission is ^{14}C.

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + (\beta \text{ –ve})$$

Negatron emission is important because most of the radioactive substances used in biochemistry decay by this mechanism.

^{3}H &^{14}C are used label any organic compound.^{35}S for methionine & ^{32} P for nucleic acid.

2. Decay by positron emission

In this type of decay a proton is converted into a neutron by ejection of a positively charged beta (β) particle called as positron (β +ve)

$$\text{Proton} \longrightarrow \text{Neutron} + \text{Positron } (\beta\text{+ve})$$

Positron is extremely unstable with transient existence. After losing their energy they interact with electrons and get destroyed. The mass and energy of these two particles gets converted into two gamma rays (γ) emitted at 180° to each other this is known as back to back emission.

As a result of this emission the nucleus gains a neutron but loses a proton. Here N: P ratio increases, Z decreases by 1and A remains constant. An isotope that decays by positron emission is 22 Na.

$$^{22}_{11}Na \longrightarrow {}^{14}_{7}N + (\beta \text{ –ve})$$

Positron emission tomography (PET),a brain scanning technique is used in finding out the active and inactive areas of the brain.

3. Decay by alpha particle emission

Isotopes of elements with high atomic number usually decay by alpha (α) particle emission. As a result of this emission the nucleus loses 2 protons and 2 neutrons, which is similar to helium nucleus ($^{4}_{2}He$)

Here N: P ratio remains constant, Z decreases by 2 and A decreases by 4. Alpha emitters are rarely used in biological work they are highly toxic due to its large mass and ionizing power.

4. Decay by emission of gamma rays

This is an electromagnetic radiation as a consequence of electron excitation that accompanies alpha and beta particle emission. It does not lead to change in atomic number or mass. Gamma radiation has low ionizing but high penetrating power.

$$^{131}_{63}I \longrightarrow {}^{131}_{64}I + (\beta -ve) + \gamma$$

5. Decay by electron capture

In this type of decay a proton captures an electron orbiting in the innermost k shell. The proton becomes a neutron and an electromagnetic radiation (X-ray) is given out.

$$\text{Neutron + Electron} \longrightarrow \text{Proton +X-rays}$$

. $$^{125}_{53}I \qquad\qquad ^{125}_{52}Te$$

19.3.1 Radioactive decay energy

The radioactive decay energy is expressed as electron volt. One electron volt is the energy acquired by one electron accelerating through a potential difference of 1volt and is equivalent to 1.6×10^{-9} J. For isotopes million or mega electron volts is applicable. Alpha particles are more energetic falling in the range 4-8 Mev. Beta and gamma emitters have decay energies less than 3 Mev.

19.3.2 Rate of radioactive decay

Radioactive decay is a spontaneous process, which takes place in an exponential way. Different isotopes decay at different rate. The number of atoms disintegrating in a given time depends upon number of isotopes present (N) at that time (t) and λ is decay constant. This λ is specific for a given isotope and is defined as number of atoms disintegrating in unit time (t – 1).

$$dN/dt = - \lambda N$$

This equation can be converted into logarithmic form

$$Ln\ Nt/N0 = - \lambda t$$

Nt is the number of radioactive atoms present at time t,and N0 is the number of radioactive atoms present originally. In practice decay constant is expressed in terms of half life $t_{1/2}$.

The half-life of an radioactive material is defined as the time taken to become half of its original value

So Nt/No becomes ½ at t becomes $t_{1/2}$. Now the above said equation becomes

$$Ln_{1/2} = -\lambda t_{1/2}$$

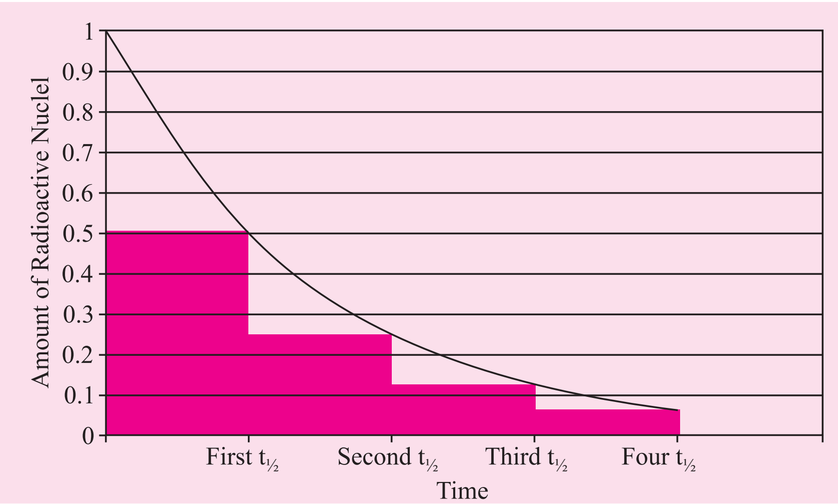

Fig. 19.2: Radioactive decay

Conversion of ln to log it becomes

$$2.303 \log_{10}(1/2) = -\lambda t_{1/2}$$

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

The values of $t_{1/2}$ varies from 10^{19} years for lead (^{204}pb) and 3×10^{-7} s for polonium (^{212}Po).

Half life of some isotopes used in biological studies

Isotopes	Half-life
^{3}H	12.26 years
^{14}C	5760 years
^{32}P	14.20 days
^{35}S	87.20 days
^{125}I	60 days

19.4 UNITS OF RADIOACTIVITY

The radioactivity of a substance can be measured using different units. They are

- Becquerel is the SI unit for measurement of radioactivity. It is defined as the number of disintegration per second (d.p.s.)

  1 **Becquerel** (Bq) = 1 dps

  Terra Bq = 10^{12} Bq

  Giga Bq = 10^{9} Bq

  Mega Bq = 10^{6} Bq

- Curie is the commonly used unit. It is defined as the quantity of radioactive material having nuclear disintegration similar to that of 1g of radium i.e. 3.7×10^{10} dps (or 37 Giga Bq)

  1 **Curie** (Ci) = 3.7×10^{10} dps

  Milli Ci = Ci × 10^{-3}

  Micro Ci = Ci × 10^{-6}

- Specific activity of a substance is defined as activity per unit weight or volume (e.g., Bq/gm or B/l).
- Counts per minute (c.p.m) is disintegration detected by a radiation counter.

19.5 CHARACTERSTICS OF RADIOACTIVE EMISSIONS

19.5.1 Alpha Particles

- Alpha particles have helium nucleus with double positive charge
- These are high energy particles (3-8 Mev) with less speed
- They interact with matter in 2 ways

1. Excitation: In this electrons of nearby atoms are shifted to higher orbitals
2. Ionisation: It removes the orbital electron completely from nearby atoms

- Their penetrating power is less

19.5.2 Negatrons

- Negatrons are very small and rapidly moving particles
- They also cause excitation and ionization but lesser than alpha particle
- They have more penetrating power
- These are low energy particles (0.018-4.81 Mev)

19.5.3 Gamma Rays

- These are electromagnetic rays with no mass and charge.
- They have very high penetrating power
- They lead to production of secondary electrons which in turn cause excitation and ionization.

INTEXT QUESTIONS 19.1

1. Match the following:

1.	Alpha particles	(a)	Electromagnetic radiation
2.	Negatron	(b)	Electron capture
3.	Positron	(c)	High energy radiation
4.	Gamma rays	(d)	Low energy radiation
5.	X-rays	(e)	Extremely unstable radiation

2. True or false:

1. Curie is SI unit of radioactivity.
2. One Becquerel is number of disintegrations equal to 1 gram of Radium.
3. Alpha particles have Helium nucleus.
4. Negatrons have high penetrating power than gamma rays.
5. Positron emission tomography is used for studying active regions of the brain.

WHAT YOU HAVE LEARNT

- Radioactivity is defined as the process in which unstable atomic nuclei loses energy by emitting radiation in the form particles or electromagnetic waves
- The half-life of an radioactive material is defined as the time taken to become half of its original value
- Different types of radioactive decay are:

  1. Decay by negatron emission
  2. Decay by positron emission
  3. Decay by alpha particle emission
  4. Decay by emission of gamma rays

TERMINAL QUESTIONS

1. What is Radioactivity?
2. What are the different types of radioactive decay?
3. What is half-life?
4. What are the characteristics of various radioactive emissions?
5. Write a note on units of radioactivity.

ANSWERS TO INTEXT QUESTIONS

18.1

1.	1. (a)	2. (b)	3. (c)	4. (d)	5. (e)
2.	1. F	2. F	3. F	4. F	5. F