Radiobiological techniques: Characters of radioisotopes

Radioactivity: Introduction

- In 1895, while studying the properties of potassium Uranium sulphate, it was found that it has property to give out certain radiations which affect a photographic film though wrapped in a black paper sheet
- It was also noticed that these radiations cause ionization in air, can pass through thin sheets of glass and metal and can cause discharge the charged leaves of insulated electroscope.
- The process is known as Radioactivity and the radiation thus emitted are called Radioactive rays
- The such compounds are known as Radioactive compound (Substances)
- Radioactivity is thus the phenomenon of the disintegration of heavy elements into comparatively lighter by emission in the form of radiations

Principle of Radioactivity

- An unstable nucleus will decompose spontaneously, or decay, into a more stable configuration but will do so only in a few specific ways by emitting certain particles or certain forms of electromagnetic energy
- Radioactive decay is a property of several naturally occurring elements as well as of artificially produced isotopes of the elements
- The rate at which a radioactive element decays is expressed in terms of its half-life; i.e., the time required for one-half of any given quantity of the isotope to decay

Nuclear Radiations

- Rutherford in 1904, separated three types of radiations under the influence of strong electrical field
- The rays which are deflected towards negative plate are positively charged and known as alpha rays
- The rays which are deflected towards positive plate are negatively charged and known as beta rays
- The rays which do not show and deflection are neutral and known as gamma rays

What Are Radioactive Isotopes?

- The advent of Linear Accelerators, the chain reacting piles and portable activation sources, has made it possible to obtain artificially produced radioactive substances
- At present over 1000 radioactive isotopes are known
- Radioactive isotopes are atoms of elements that have the same atomic number but a different mass number are called isotopes
- Radioactive isotopes can also be defined as atoms that contain an unstable combination of neutrons and protons, or excess energy in their nucleus

- **This excess energy can be used in one of three ways:**
  - **release as a conversion electron**
  - **create and emit a new particle (alpha particle or beta particle) from the nucleus**
  - **emitted from the nucleus as gamma radiation**
- **During those processes, the radionuclide is said to undergo radioactive decay**
- **These emissions are considered ionizing radiation because they are powerful enough to liberate an electron from another atom**

Radioactive Emission

1.Alpha Rays:

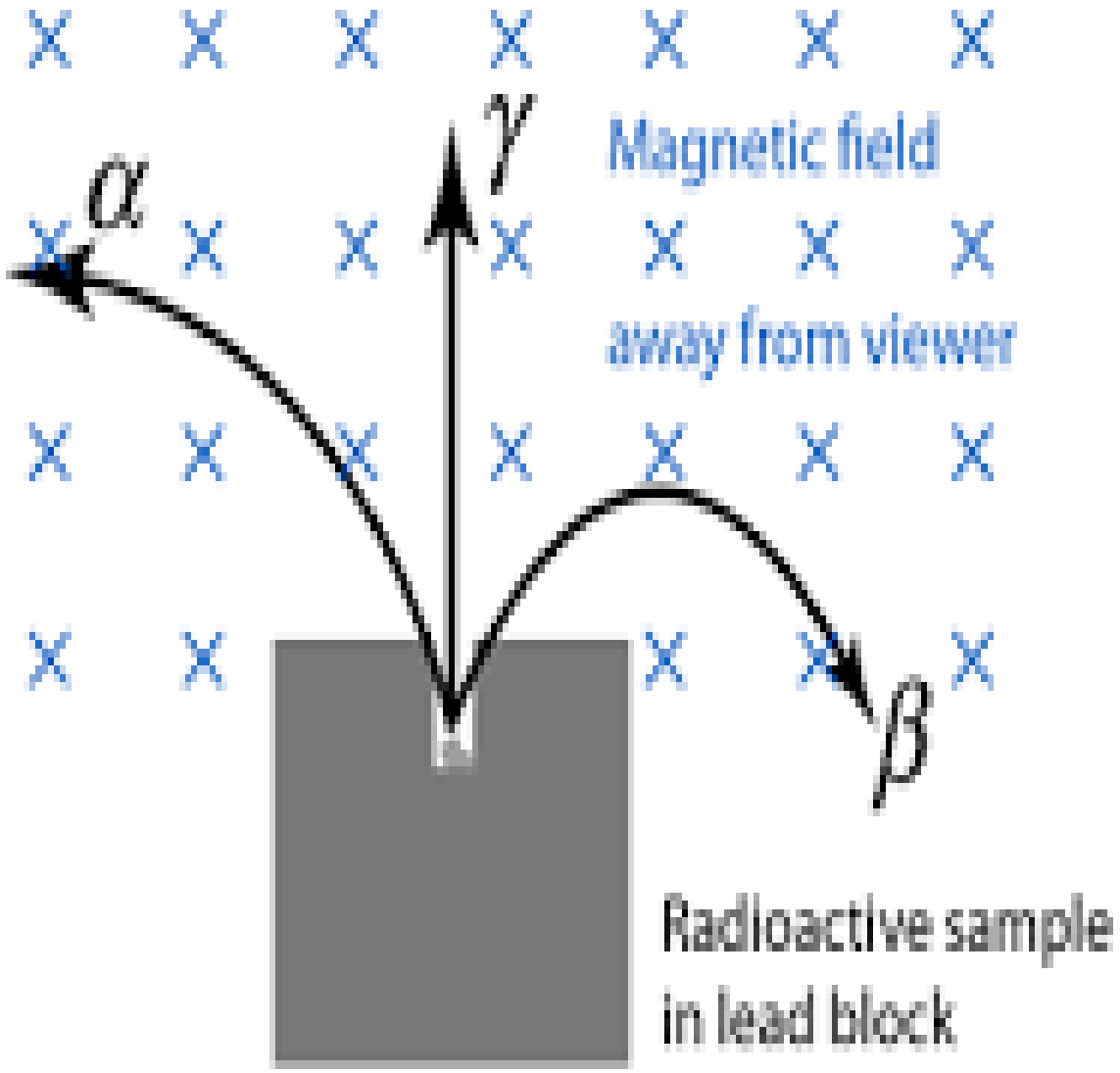
- The alpha rays consists of two units of positively charge and mass equal to four times mass of hydrogen atom
- When the number of neutrons is more than that of the proton, the excessive neutron converts into a proton and in this process an alpha particle is released
- Generally observed for elements heavier than lead
- This results in decreasing in Mass number A and Atomic Number Z
- Velocity over 10000 miles/ sec.
- Due to large mass, and size, they are greater momentum and smaller penetration power
- They can completely stop or absorbed by 1/10 mm thick aluminum foil
- They can ionize gases and cause luminescence on striking ZnS screen

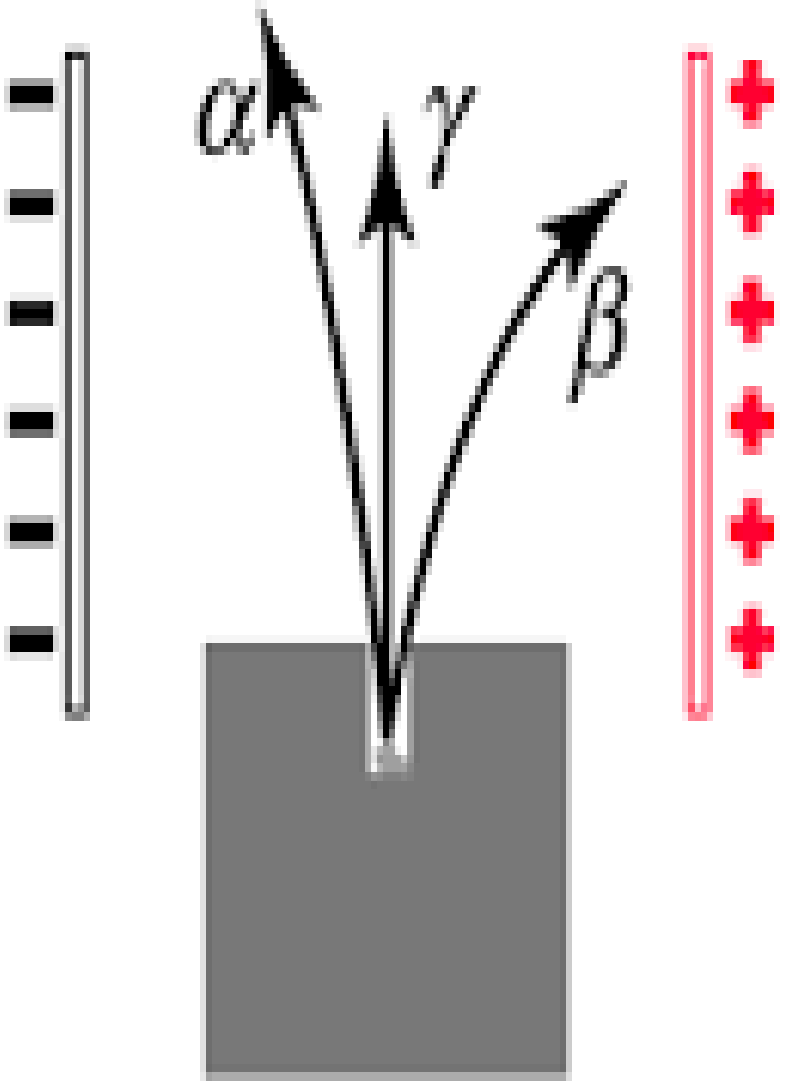
2. Beta Rays:

- They are high speed electrons and negatively charged streams of particles
- When an unstable nucleus contains neutrons more than the protons, a neutron may change into a proton by emitting an electron
- This result is increasing in atomic number and no change in the mass number
- They move faster than alpha particles having velocity of 100000 to 150000 miles/sec.
- They have more penetration power and can stop or absorbed by a 5 mm thick aluminum foil or 1 mm thick lead sheet
- They have less ionizing property and shoe little effect on ZnS plate

3. Gamma Rays:

- Released followed by alpha or beta emission
- It occurs when the daughter or the parent nucleus is in a state of excitation (i.e. it has an excess of energy)
- Gamma rays are fast-moving particles showing similarity with X rays
- They are massless and has no electric charge, no neutrons or protons are lost, hence the nucleus does not decay into a different nucleus
- There is no change in the mass number A and atomic number Z of the nucleus in gamma emission
- They travel with the velocity of light, having high penetration power
- They can penetrate 25 cm thick iron sheet and 8 cm thick lead sheet
- The cause ionization of gases under indirect manner and harmful to living tissues


α
γ
Magnetic field
away from viewer
β
Radioactive sample
in lead block


α
γ
β

Biology

- All living entities are made up of protoplasm, which consists if inorganic and organic compounds dissolved or suspended in water
- They have:
  - Group of cells - referred to as tissue
  - Group of tissues - is called an organ
  - Group of organs - is an organ system or an organism
- The protoplasm consists of the cytoplasm and the nucleus:
  - Cytoplasm supports all metabolic functions within a cell
  - Nucleus contains the genetic information (DNA)

- **Human cells are either somatic cells or germ cells**
- **Cells propagate through division:**
  - **Division of somatic cells is called mitosis**
  - **Division of germ cells is called meiosis**
- **Somatic cells are classified as:**
  - **Stem cells, which exists to self-perpetuate and produce cells for a differentiated cell population**
  - **Transit cells, which are cells in movement to another population**
  - **Mature cells, which are fully differentiated and do not exhibit mitotic activity**
- **Cell cycle: The cell proliferation cycle is defined by two well-defined time periods:**

(1) mitosis M where division takes place

(2) the period of DNA synthesis S

The S and M portions of the cell cycle are separated by two periods (gaps) G1 and G2 when DNA is not yet synthesized but other metabolic processes take place

Radiobiology

- Radiobiology is a branch of science which combines the basic principles of physics and biology and is concerned with the action of ionizing radiation on biological tissues and living organisms.
- Study of basic radiobiological mechanisms deals with biological effects produced by energy absorption in small volumes corresponding to single cells or parts of cells
- The living cells are most radiosensitive in the M and G2 phases, and most resistant in the late S phase
- Cell death for non-proliferating (static) cells is defined as the loss of a specific function, while for stem cells it is defined as the loss of reproductive integrity (reproductive death).
- A surviving cell that maintains its reproductive integrity and proliferates indefinitely is said to be clonogenic

- **In contrast to the stopping power of nuclear radiations, that focuses attention on the energy loss by an energetic charged particle moving through a medium**
- **The radiobiology refers to the quality of an ionizing radiation beam as the linear energy transfer (LET)**
- **The LET focuses attention on the linear rate of energy absorption by the absorbing medium as the charged particle traverses the medium**
- **LET of charged particles in a medium is the quotient dE/dl**
  - **where dE is the average energy locally imparted to the medium by a charged particle**
  - **dl is distance traversed**

$$LET = dE/dl$$

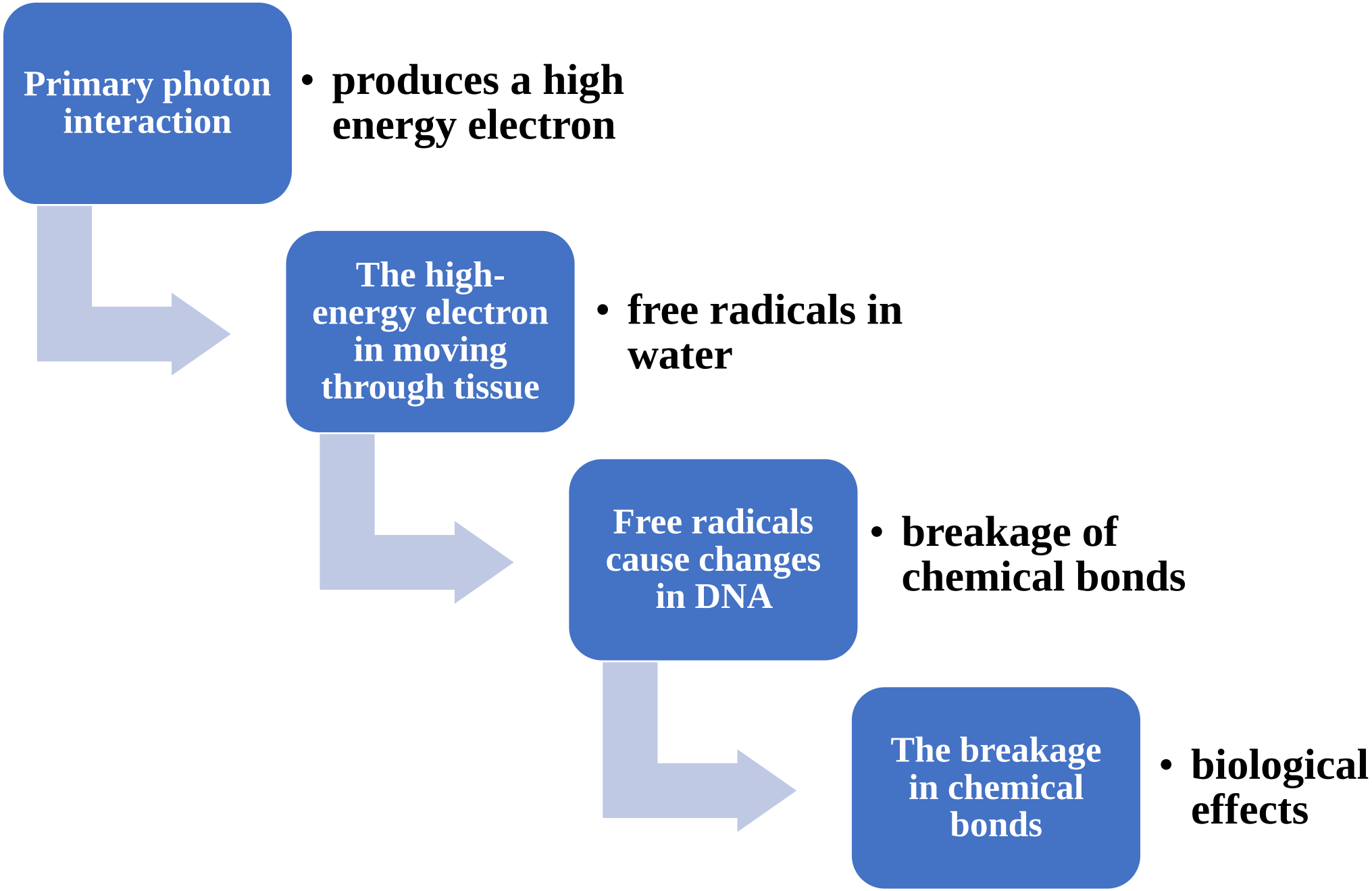
The unit usually used for the LET is keV/μm

Irradiation of Cells

- When cells are exposed to ionizing radiation:

1. Physical effects between radiation and atoms or molecules of the cells
2. Biological damage to cell functions, damage to the DNA

- When directly ionizing radiation is absorbed in biological material, the damage to the cell may occur in one of two ways:
  - **Direct:** The atoms of the target itself get ionized or excited leading to the chain of physical and chemical events (high LET particles)
  - **Indirect action:** The radiation interacts with other molecules and atoms (mainly water, since 80% of a cell is composed of water) within the cell to produce free radicals that can, through diffusion in the cell, damage the critical target within the cell


Primary photon interaction
• produces a high energy electron
The high-energy electron in moving through tissue
• free radicals in water
Free radicals cause changes in DNA
• breakage of chemical bonds
The breakage in chemical bonds
• biological effects

Fate of irradiated cells

(1)No effect

(2)Division delay: the cell is delayed from going through division

(3)Apoptosis: the cell dies before it can divide or afterwards by fragmentation into smaller bodies which are taken up by neighboring cells

(4) Reproductive failure: the cell dies when attempting the first or subsequent mitosis

Methods of Detection and Measurement of Radioactivity

- The radiations can be detected in various ways
- All these methods depend on its direct or indirect effects
- The radioactivity can be measured in terms of
  - Number of individual emissions in unit time
  - Total cumulative effect of all emissions in a given time

Methods of detection is based on:

(1) Gas ionization

(2) Excitation and production of light

(3) Effect on photographic emulsions