Introduction to Radiobiology

Faculty of Applied Science- Department of Radiology

Course Name: Radiobiology Course Code: MTR 211

Second Grade/ Fall Semester 2025-2026

Lecture 1/ 12th October 2025

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Outlines

- Introduction to Radiobiology.
- History of Radiation Biology.
- Importance, Goals, and Applications of Radiobiology.
- Radiation Chemistry.
- Initial Physical Effect of Radiation.
- Radiolysis of Water.
- Direct and Indirect Effects of Radiation.
- Eukaryotic Cell Structure and Types.

Learning Outcomes

By the end of the lecture, students should be able to:

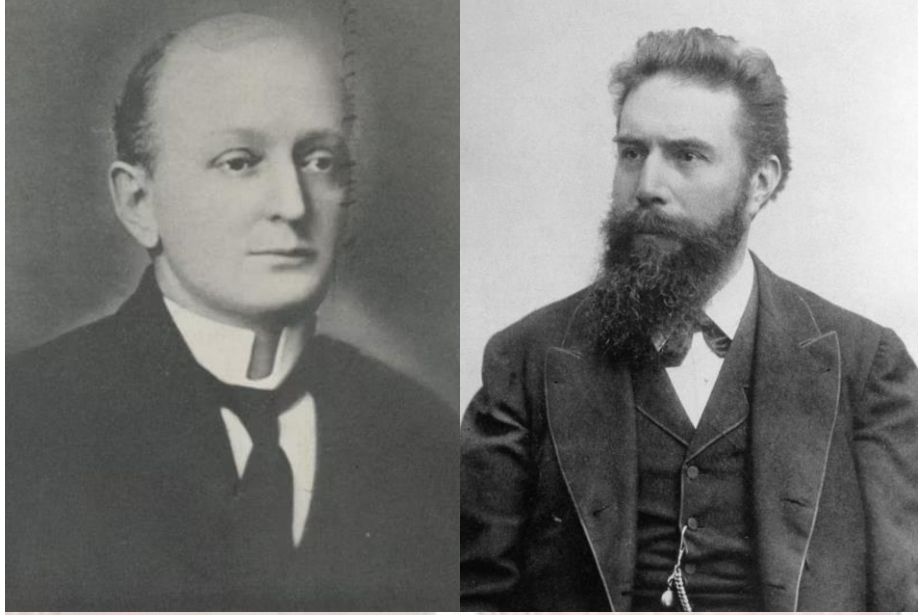
- Explain the fundamentals of radiobiology.
- Describe the physical and chemical interactions of radiation.
- Understand the radiolysis of water and differentiate between direct and indirect effects of radiation on cellular components.
- Identify and describe eukaryotic cell structures and types, and explain their relevance to radiation sensitivity and cellular repair mechanisms.

Introduction to Radiobiology

- **Radiobiology** is the **qualitative and quantitative** study of how ionizing radiation affects living organisms.
- Radiation can cause **cell death**, **alter cellular function**, or even **induce malignant transformation**.
- **The main goal of radiobiology is to understand the mechanisms of interaction between radiation and biological tissues.**
- Both **physical** (**type, dose, energy**) and **biological** (**cell type, oxygen level, repair capacity**) factors influence the radiobiological response of tissues.
- This field is essential for assessing the risks of low-dose radiation exposure and developing protective strategies in medicine and research.

History of Radiation Biology

- **1895** – Wilhelm Conrad Roentgen discovered **X-rays**, marking the birth of radiology.
- **Late 1890s** – The Dean of Vanderbilt University underwent one of the first skull X-rays; his hair fell out three weeks later, an **early sign of radiation injury**.
- **1904** – Clarence Dally, assistant to Thomas Edison, died from **metastatic carcinoma** caused by repeated X-ray exposure and severe radiation burns.
- Following his death, Edison halted all X-ray research, warning of its dangers.
- **1906** – Scientists Bergonie and Tribondeau identified the law of differential radiosensitivity, explaining why some tissues are more sensitive to radiation than others.



Jean Alban BERGONIE
(1857-1925)

Louis TRIBONDEAU
(1872-1918)

History of Radiation Biology

- **Mihran Kassabian** (1870–1910), one of the early pioneers of radiology, carefully documented his own radiation-induced injuries through journals and photographs.

- He suffered from progressive tissue necrosis in his hands, which eventually led to multiple **amputations**.

- Kassabian intended that his observations and records would serve as valuable scientific evidence to help future generations understand the **hazards of radiation exposure**.

Importance, Goals, and Applications of Radiobiology

Importance in Radiology

- Explains how radiation affects **cells, tissues, and organs**.
- Forms the scientific foundation for **safe medical imaging** and **radiation therapy**.
- Guides radiation protection standards for both **patients and healthcare professionals**.

Major Goals of Radiobiology

- Identify the mechanisms of **radiation-induced damage**.
- Understand **cellular repair** and **recovery processes following exposure**.
- Establish **dose–response relationships** in biological systems.

Applications

- Radiation therapy for the **treatment of cancer**.
- **Diagnostic imaging** safety and optimization.
- **Nuclear medicine practices** and **radiation protection strategies**.

Radiation Chemistry

- **Radiation chemistry** is the study of **chemical changes** in matter that occur due to the **absorption of ionizing radiation**.
- It explains how radiation **energy** interacts with **atoms and molecules**, leading to new chemical species and biological effects.

Types of Ionizing Radiation

- **Particulate Radiation:**

α-particles, β-particles, neutrons.

- **Electromagnetic Radiation:**

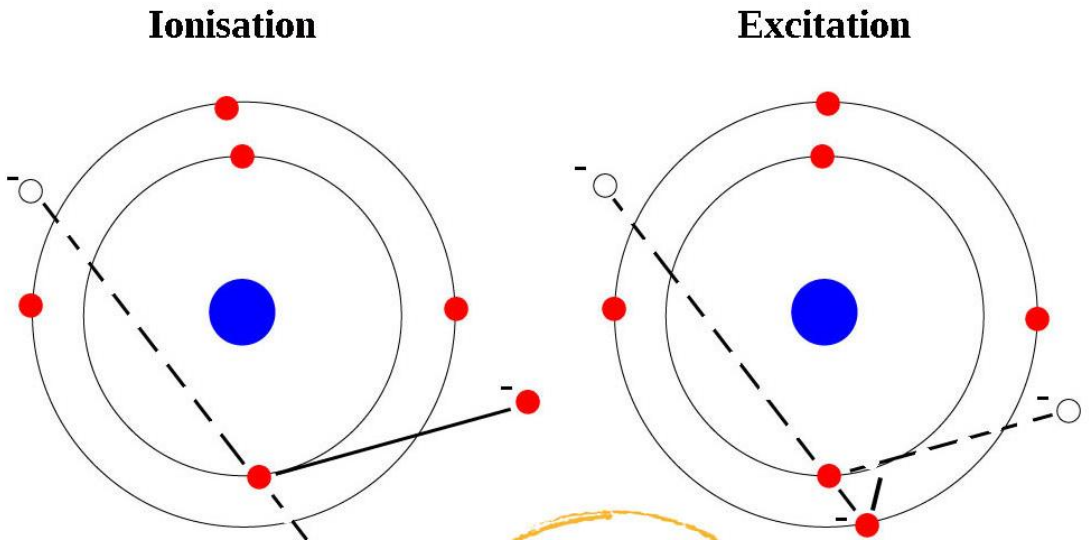
X-rays, γ-rays (gamma rays).

PARTICULATE RADIATION	ELECTROMAGNETIC RADIATION
Particulate radiation involves the emission of particles such as alpha or beta particles, which are charged or uncharged subatomic particles	Electromagnetic radiation consists of photons, which are massless particles with no charge
Particulate radiation particles may carry a positive (alpha) or negative (beta) charge	Electromagnetic radiation, such as light or radio waves, carries no net charge
Involves physical particles	Characterized by wave-like behavior
Tends to have lower penetration ability	Tends to have higher penetration ability

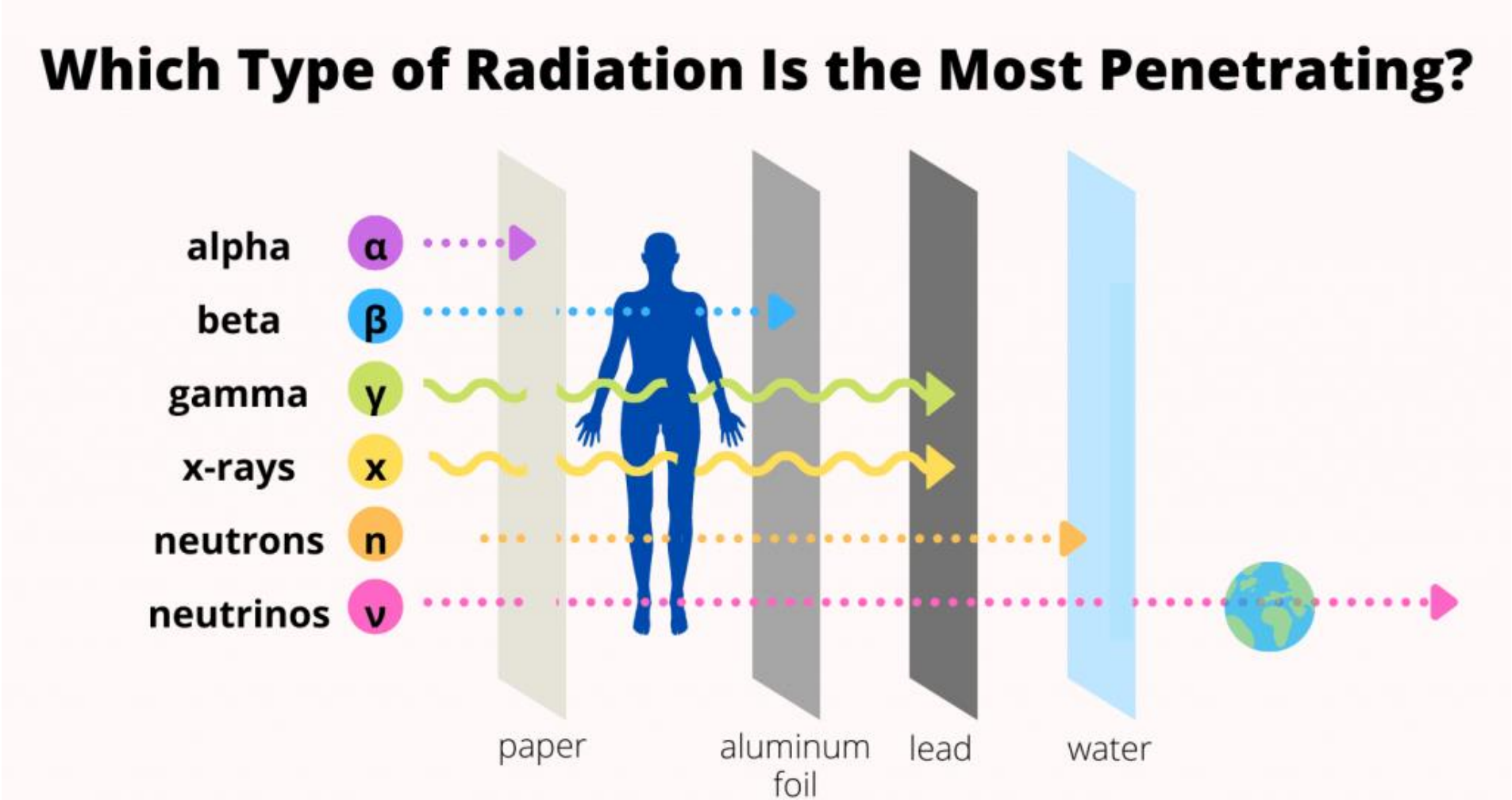
Radiation Chemistry

When ionizing radiation interacts with matter, it transfers energy that causes:

- **Ionization:** Removal of electrons from atoms or molecules.
- **Excitation:** Elevation of electrons to higher energy states.
- **Formation of free radicals and ions:** Highly reactive species that initiate chemical and biological changes.



Radiation Chemistry



Initial Physical Effect of Radiation

- The first interaction between **ionizing radiation and matter** occurs within **10^{-15} seconds** after exposure.
- The sequence of events following radiation exposure can be divided into **four stages**:

1- Physical Stage (10^{-15} - 10^{-12} s)

- Energy deposition occurs in the target material.
- Atoms and molecules become **ionized or excited**.

2- Physicochemical Stage (10^{-12} - 10^{-6} s)

Formation of **free radicals** and **reactive species** from the initial ionizations.

Initial Physical Effect of Radiation

3- Chemical Stage (10^{-6} s - seconds)

- Radicals interact with nearby biomolecules (**DNA**, **proteins**, **water**, etc.).
- Leads to **chemical changes** in the cell.

4- Biological Stage (minutes – years)

- Observable effects appear: **cell death**, **mutations**, **carcinogenesis**, or **tissue damage**.

Initial Physical Effect of Radiation

The first interaction occurs within 10^{-15} seconds after exposure.

Physical Stage
10^{-16} to 10^{-12} s
Energy deposition
atoms/molecules ionized

Physicochemical Stage
10^{-12} to 10^{-6} s
Free radicals
& reactive species

Chemical Stage
10^{-6} s - seconds
Reactions between *radicals*
and biomolecules

Biological Stage
minutes - to years
Observable biological effects
cell death, mutation, etc.

Radiolysis of Water

Key Concepts

- Since cells are **70 - 80% water**, most biological effects of radiation occur through the **radiolysis of water**, **the breakdown of water molecules by ionizing radiation**.

1. **Ionization of the water molecule**: $H_2O \rightarrow H_2O^+ + e^-$
2. **Formation of reactive species**: $H_2O^+ \rightarrow H^+ + OH\cdot$

$$e^- + H_2O \rightarrow H_2O^- \rightarrow H\cdot + OH^-$$

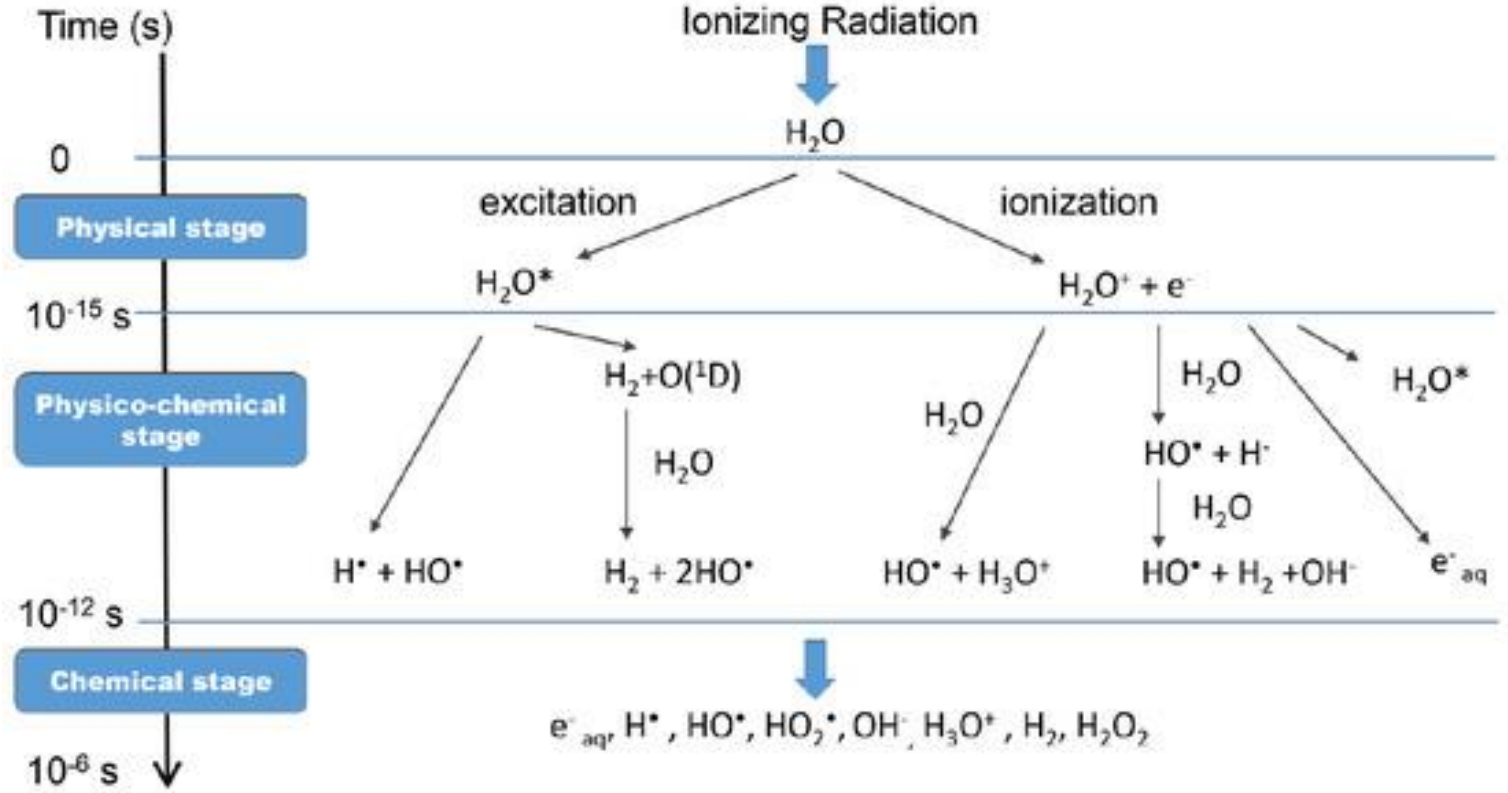
Reactive Products

- Free radicals: H· , OH·
- Molecular products: H_2 , H_2O_2

Radiolysis of Water

Biological Importance

- **Hydroxyl radicals (OH·):** Highly reactive; cause DNA strand breaks and protein damage.
- **Hydrogen peroxide (H_2O_2):** Contributes to oxidative stress and may induce cell death.



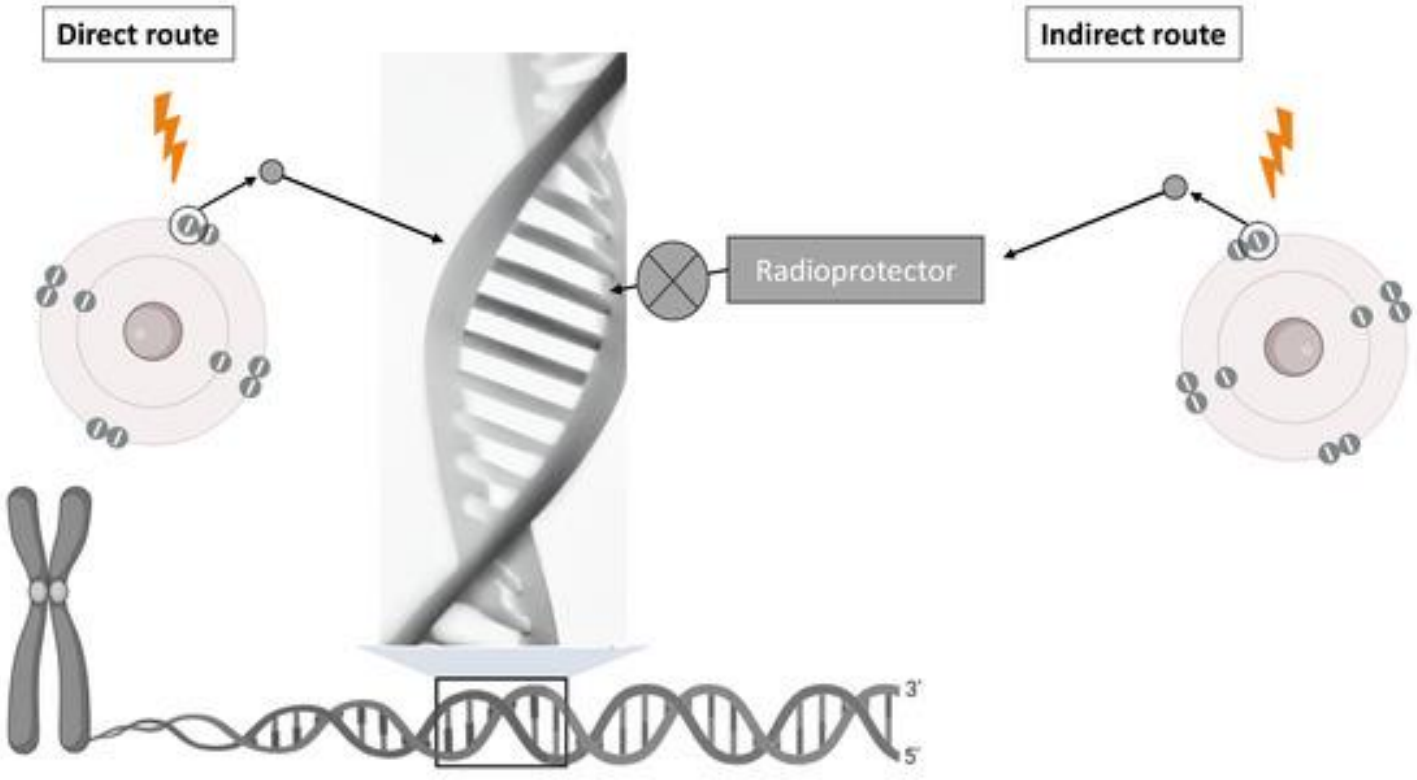
Direct and Indirect Effects of Radiation

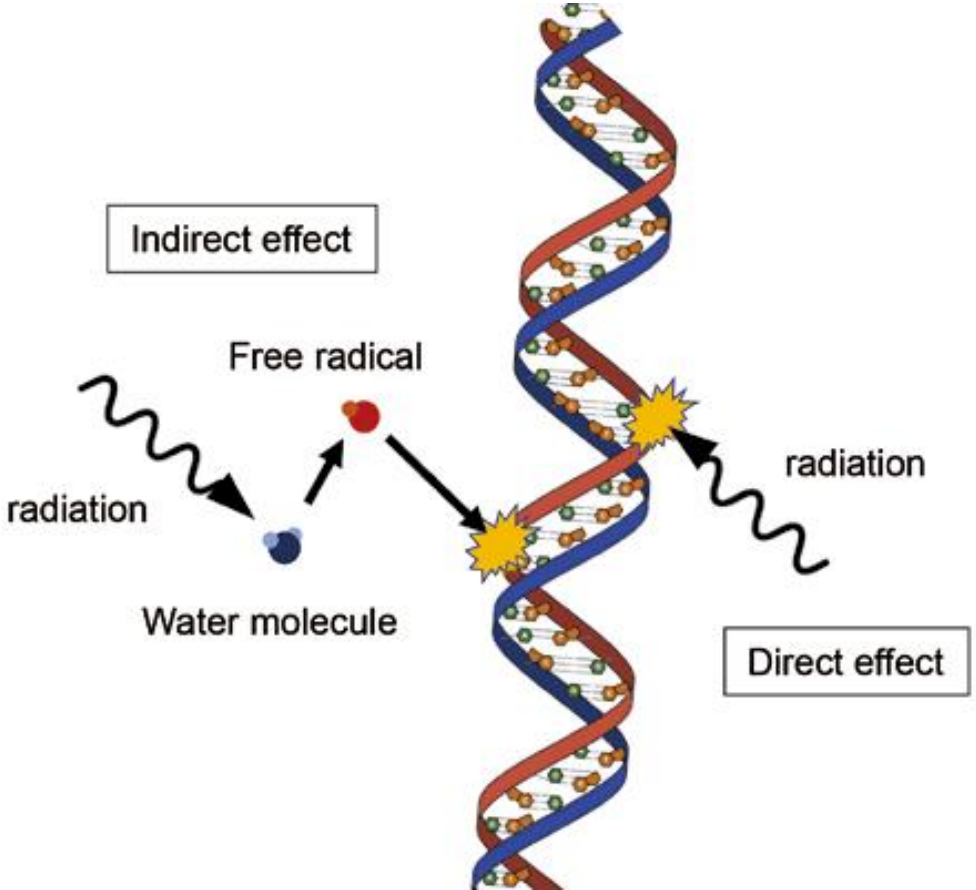
Type	Mechanism	Primary Target	Common Radiation
Direct Effect	Radiation directly ionizes critical biomolecules (DNA, proteins).	Nucleus or essential cell structures	High-LET radiation (α-particles, neutrons)
Indirect Effect	Radiation reacts with water, generating free radicals that damage biomolecules.	Cytoplasm or nucleus (via radicals)	Low-LET radiation (X-rays, γ-rays)

Direct and Indirect Effects of Radiation

Examples:

- **Direct:** DNA strand breaks caused by **ionization**.
- **Indirect:** DNA damage from **hydroxyl radicals** produced during **water radiolysis**.





Eukaryotic Cell Structure and Types

- **Eukaryotic cells** are the fundamental structural and functional units of life.
- They are characterized by a **true nucleus and membrane-bound organelles**, which coordinate complex cellular activities.

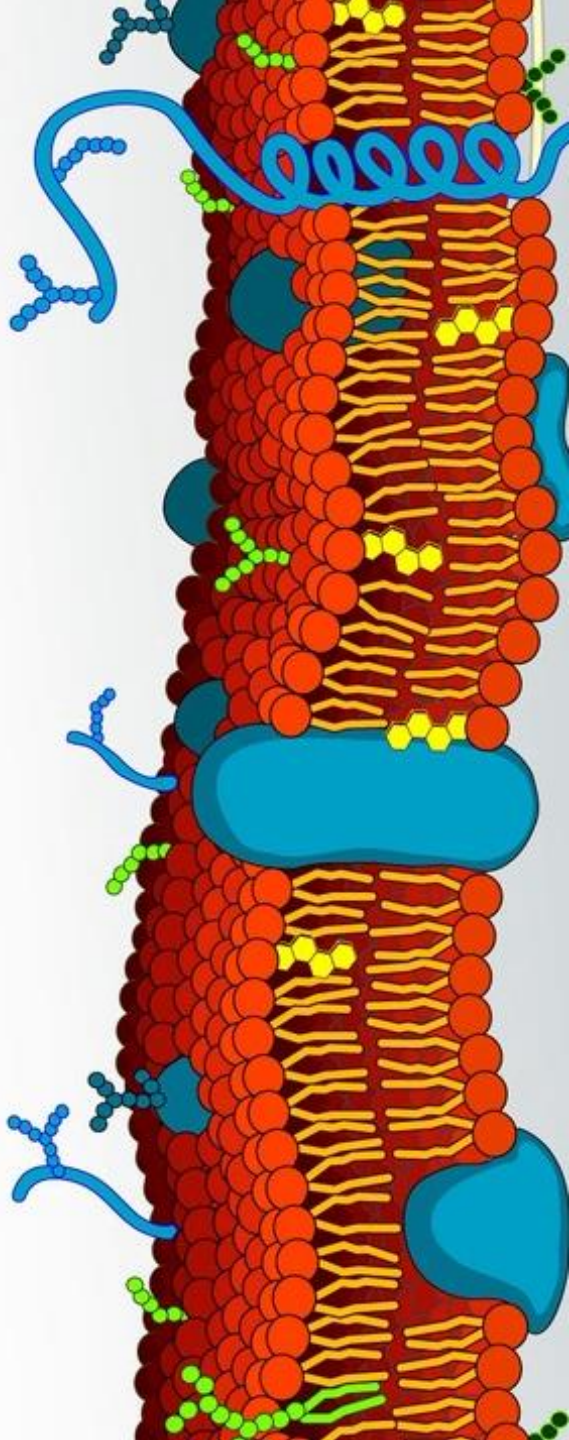
Main Components:

1. Cell Membrane:

- A Semipermeable barrier that controls the entry and exit of substances.
- Maintains the cell's internal environment and supports communication with other cells.

2. Cytoplasm:

- Gel-like substance that fills the cell and houses organelles.
- Provides a medium for enzymatic reactions and molecular transport.



Eukaryotic Cell Structure and Types

3. Nucleus:

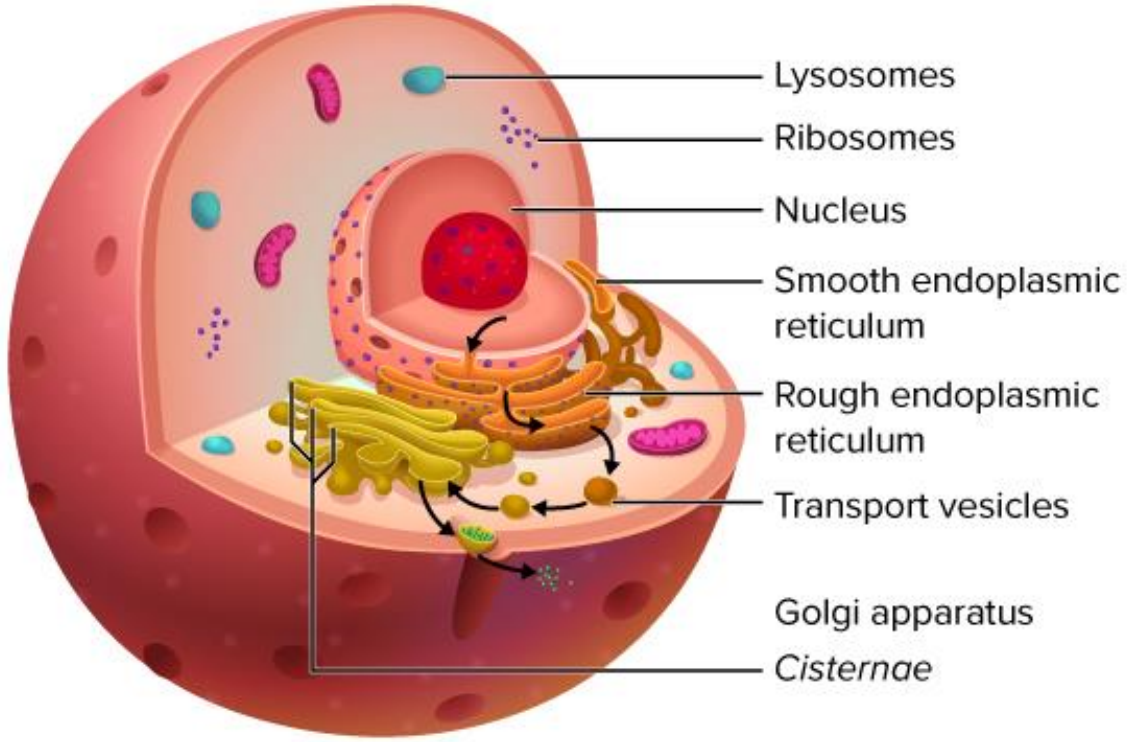
- The control center of the cell, containing DNA.
- Directs cell growth, metabolism, and reproduction.

4. Organelles:

- **Mitochondria:** Generate energy through cellular respiration (the "powerhouse" of the cell).
- **Endoplasmic Reticulum (ER):**

1. Rough ER: Synthesizes proteins.
2. Smooth ER: Synthesizes lipids and detoxifies substances.

- **Golgi Apparatus:** Modifies, packages, and transports proteins and lipids.
- **Lysosomes:** Digest cellular waste, foreign particles, and damaged organelles.



Eukaryotic Cell Structure and Types

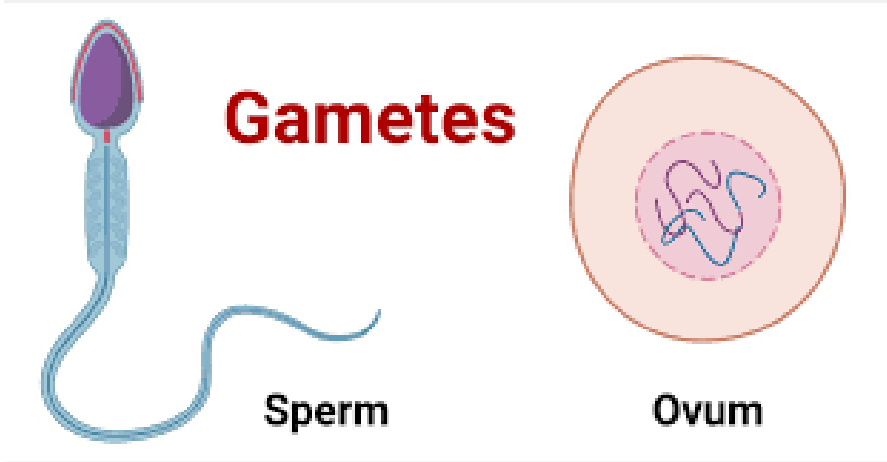
Cell Types

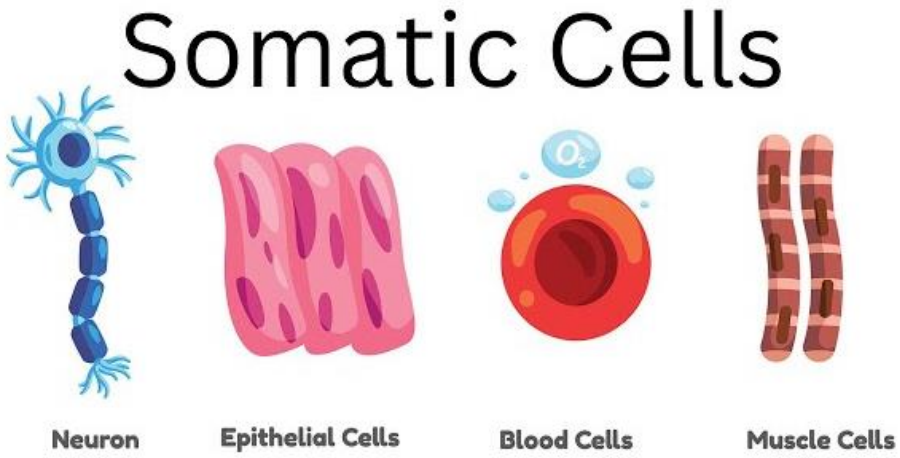
1. Somatic Cells

- Make up the body’s tissues and organs.
- Radiation exposure can cause mutations or cell death.
- Effects are limited to the individual and are not passed to offspring.

2. Germ Cells

- Reproductive cells (sperm and eggs).
- Radiation damage can lead to hereditary effects, potentially affecting future generations.





Summary

- Radiobiology studies how radiation interacts with living organisms and affects cellular function.
- Radiation chemistry explains how absorbed energy produces ionization and reactive free radicals.
- Radiolysis of water is the primary mechanism behind indirect radiation effects in cells.
- Direct and indirect radiation actions can damage critical cellular components, particularly DNA.
- Knowledge of eukaryotic cell structure helps predict cellular sensitivity to radiation and potential repair responses.

Questions? Comments?

Thank you!