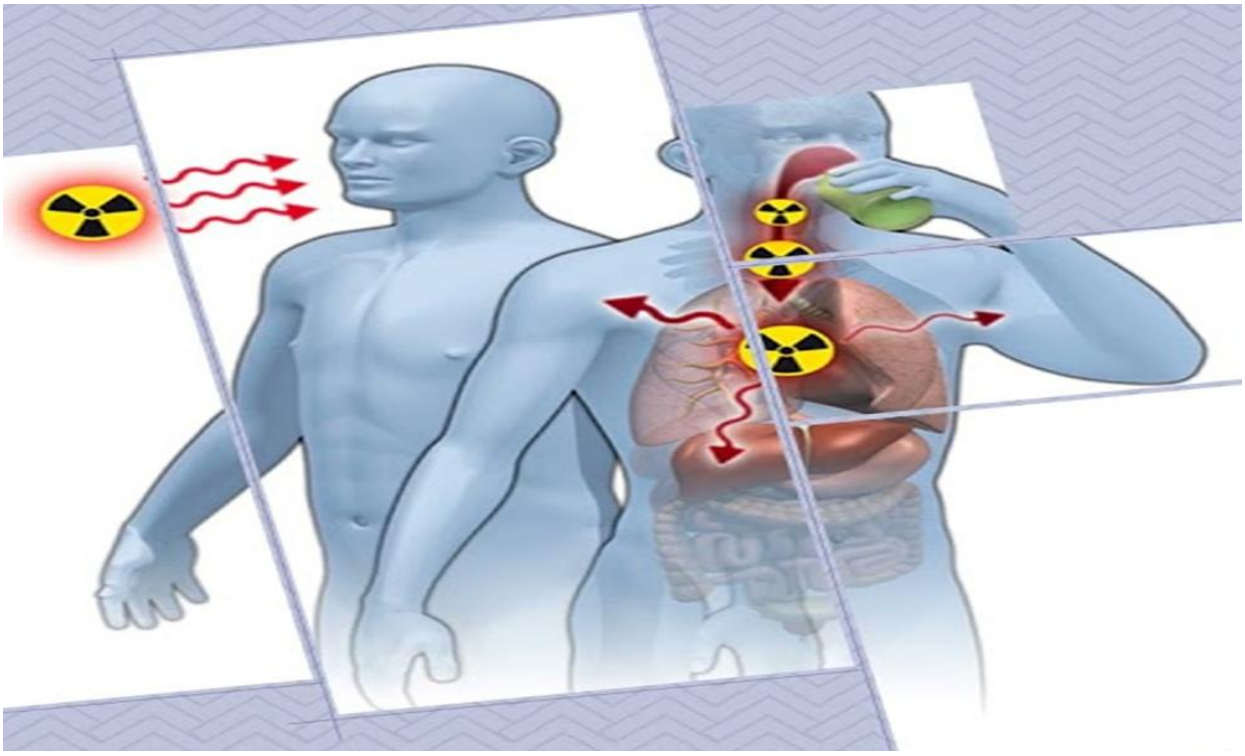
Biological Effects of Radiation
4th Lecture



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3rd year, 1st course

Teaching of Biological Radiation hazards

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Biological Effects of Radiation

When ionizing radiation interacts with living tissue, the effects occur in three successive stages**:**

Stage 1: Atomic Level (Physical Stage)

- **Time frame:** 10^{-15} to 10^{-12} seconds after exposure
- **Event:** Radiation interacts with atoms in cells, particularly in water (which makes up ~70% of the body).
- **Result:**
  - Ionization (removal of electrons)
  - Excitation (raising electrons to higher energy levels)
  - Production **of** ion pairs **(e.g.,** $H_2O \rightarrow H_2O^+ + e^-$)
- **Outcome:** Formation of unstable atoms and free electrons.

Physical and Prechemical Changes in Irradiated Water

-The initial changes produced by radiation in water are the creation of ionized and excited molecules, H_2O^+, H_2O^*, and free, sub-excitation electrons. They are produced in $<10^{-15}$s in local regions of the track.

-Water begins to adjust to the sudden physical appearance of the three species even before the molecules can move appreciably in their normal thermal agitation.

-After ~10^{-12}s from the passage of the charged particle, ordinary, diffusion-controlled chemical reactions started around the particle's path.

The time between 10^{-15}s to 10^{-12}s are called the **pre-chemical stage**.

Pre-Chemical Stage

-A free radical is a molecule or atom, which is not combined to anything (ie. free) and carries an unpaired electron in its outer shell, i.e. it's looking for something to interact with, or in purely scientific terms, it is in a state associated with a high degree of chemical reactivity.

-Imagine that some radiation has entered a body and interacts with a water molecule, of which there are plenty. If the water molecule is ionized

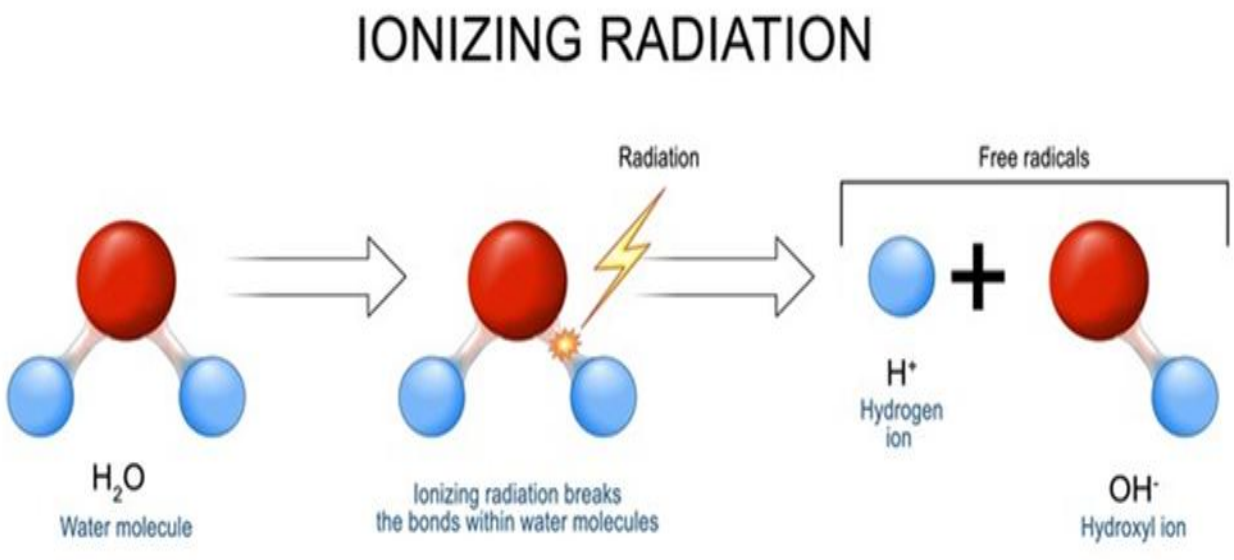
$$H_2O = H_2O^+ + e^-$$

-H_2O^+ is an ion radical – ion meaning it is electrically charged because it has lost an electron and a radical because it has an unpaired electron in the outer shell, making it very reactive.

$$e^- \rightarrow e^-_{aq},$$

$$H_2O^* \rightarrow \begin{cases} H_2O^+ + e^- \\ H + OH \end{cases}$$

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH.$$



Stage 2: Chemical Interaction (Chemical Stage)

- **Time frame:** 10^{-12} to 10^{-3} seconds
- **Event:** The ions and free radicals produced react with other molecules.
- **Result:**
  - Formation of **reactive free radicals** such as:
    - Hydroxyl radical (•OH)
    - Hydrogen radical (•H)
    - Hydrogen peroxide (H_2O_2)
  - These highly reactive species can damage critical biomolecules.
- **Outcome: Chemical alteration** of DNA, proteins, and cell membranes.

Chemical Stage

-The diffuse controlled chemical stage can be viewed as a random walk.

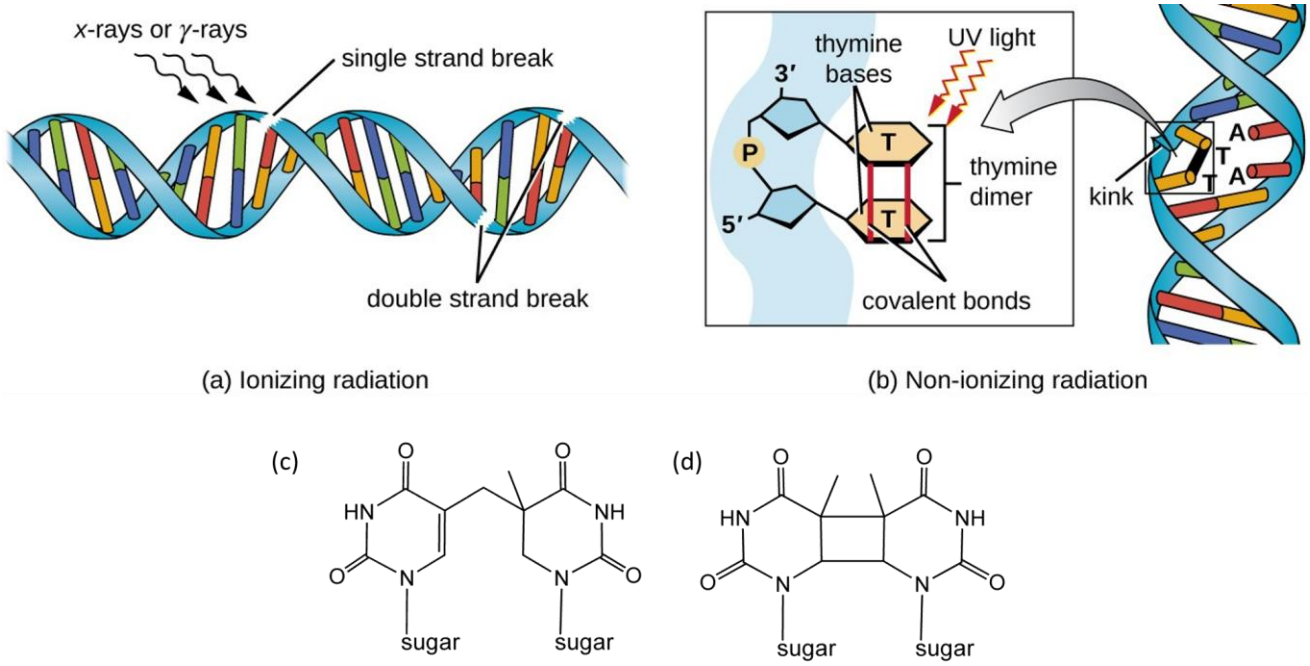
-The distance a particle traveled λ is related to time τ and the diffusion constant D by

$$\frac{\lambda^2}{6\tau} = D$$

-Two species that are closer than the sum of their reaction radii will have a chance to interact.

-After ~10^{-12} s, the four chemically active species H_2O^+, OH, e^-_{aq}, and H are located near the positions of the original H_2O^+, H_2O^*, and e^- that triggered their formation.

-Three of the new reactants, OH, e^-_{aq}, and H are free radicals. They begin to migrate in thermal motion. Individual pairs of these reactants may get sufficiently close to induce chemical reactions.



-As time passes, the reactions proceed until the remaining reactants diffused so far away from one another that the probability of additional chemical reaction becomes very small.

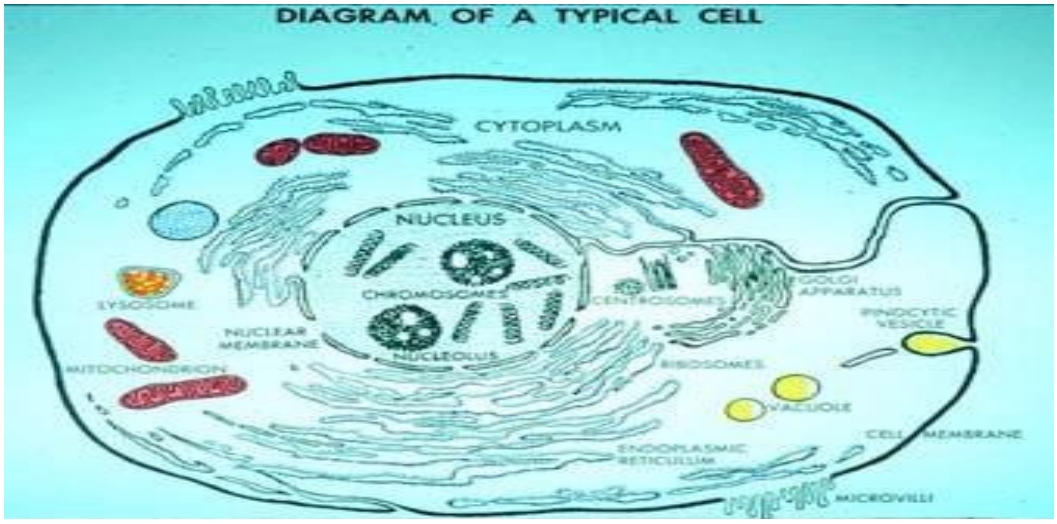
- These happen typically within 10^{-6} s, by which the chemical development of the track in pure water is essentially over.

Stage 3: Cellular and Whole-Body Changes (Biological Stage)

- **Time frame:** Minutes to years after exposure
- **Event:** The chemical changes manifest as biological effects at the cellular, tissue, and organism level.
- **Result:**
  - **Cellular effects:** DNA damage, mutation, chromosome aberrations, cell death
  - **Tissue/organ effects:** Inflammation, fibrosis, cancer
  - **Whole-body effects:** Radiation sickness, genetic effects, carcinogenesis
- **Outcome: Biological responses** depending on:
  - Type and dose of radiation
  - Rate of exposure
  - Sensitivity of the tissue

Critical Target is DNA

- Alpha particles through nucleus are lethal but particles through cytoplasm are not lethal.
- Cells with nucleus removed are not killed by radiation but if an irradiated nucleus is put into a cell, the cell will die.
- Microbeams can kill a cell by hitting the nucleus.



Radiation can produce a variety of lesions in DNA

- Rupture of the strand
- Alteration to bases
- Destruction of sugars
- Crosslinks and formation of dimers

THESE DAMAGES CAN LEAD TO:

-Slowdown in the cell synthesizing copies of its DNA, so that there is a delay in one cell dividing into two cells

-Delays (to allow repair) as the cell progresses towards its next cell division (delay in cell cycle progression)

-Decrease in the overall rate of cell proliferation (increase in cell number) of a population of cells

-Death of the cell

-Mutation of the cell