Madenat Alelem University College

Medical physics dept.

Fourth stage

Radiation Biology

Lecture 1

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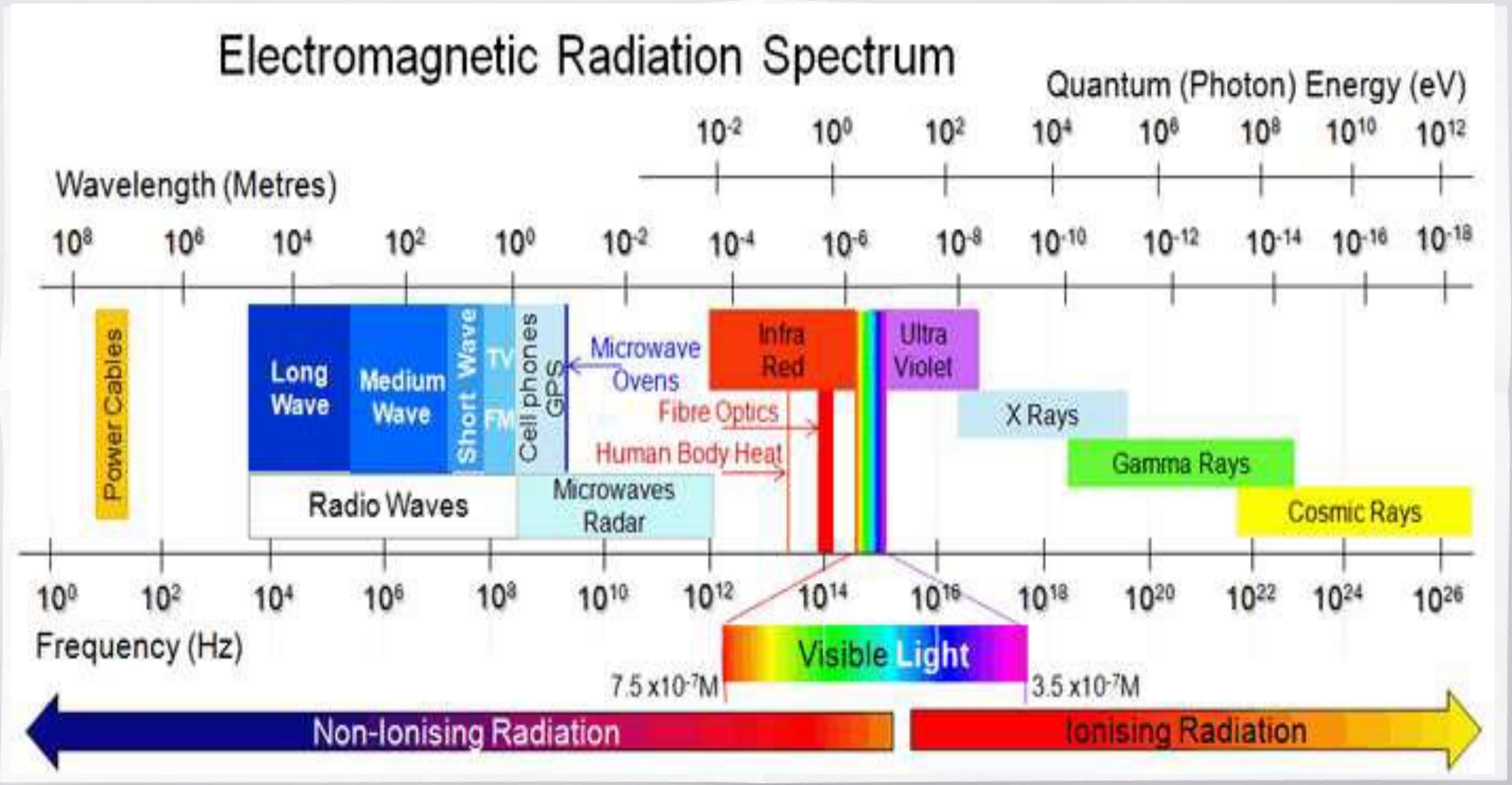
Introduction to radiation biology

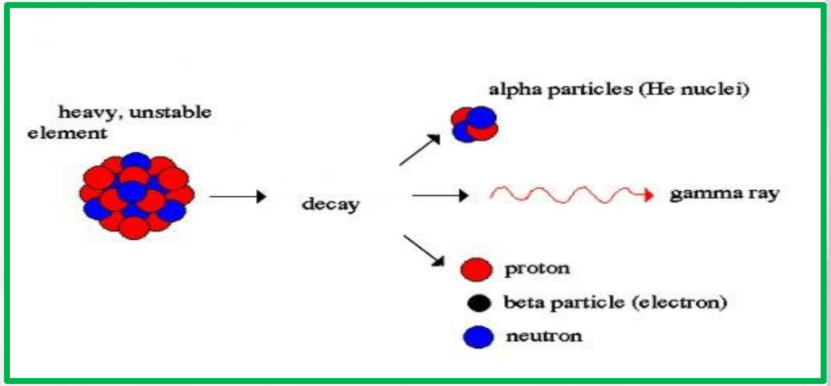
Radiation biology or Radiobiology is a branch of science concerned with the action of ionizing radiation on biological tissues and living organisms.

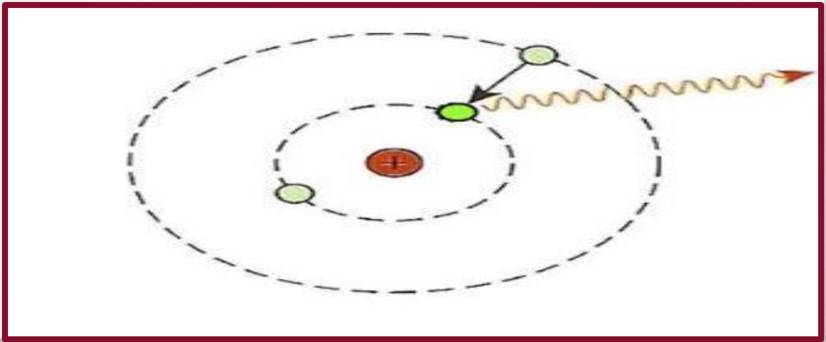
Radiation as defined as the emission and propagation of energy through space or a substance in the form of waves or particles.


Electromagnetic Radiation Spectrum
Quantum (Photon) Energy (eV)
10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} 10^{10} 10^{12}
Wavelength (Metres)
10^{8} 10^{6} 10^{4} 10^{2} 10^{0} 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14} 10^{-16} 10^{-18}
Power Cables
Long Wave
Medium Wave
Short Wave
TV
FM
Cell phones
GPS
Microwave Ovens
Infra Red
Ultra Violet
Fibre Optics
Human Body Heat
X Rays
Gamma Rays
Radio Waves
Microwaves Radar
Cosmic Rays
10^{0} 10^{2} 10^{4} 10^{6} 10^{8} 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20} 10^{22} 10^{24} 10^{26}
Frequency (Hz)
Visible Light
7.5×10^{-7}M
3.5×10^{-7}M
Non-Ionising Radiation
Ionising Radiation

Sources of ionizing radiation

Ionizing radiations may be emitted in the decay process of unstable nuclei or by de-excitation of atoms and their nuclei in nuclear reactors, X ray machines and other devices.





When a nucleus emits an α or β particle, the daughter nucleus is sometimes left in an excited state which after de-excitation, returns to a lower energy level by emitting a γ ray in much the same way that an atomic electron can jump to a lower energy level by emitting visible light.

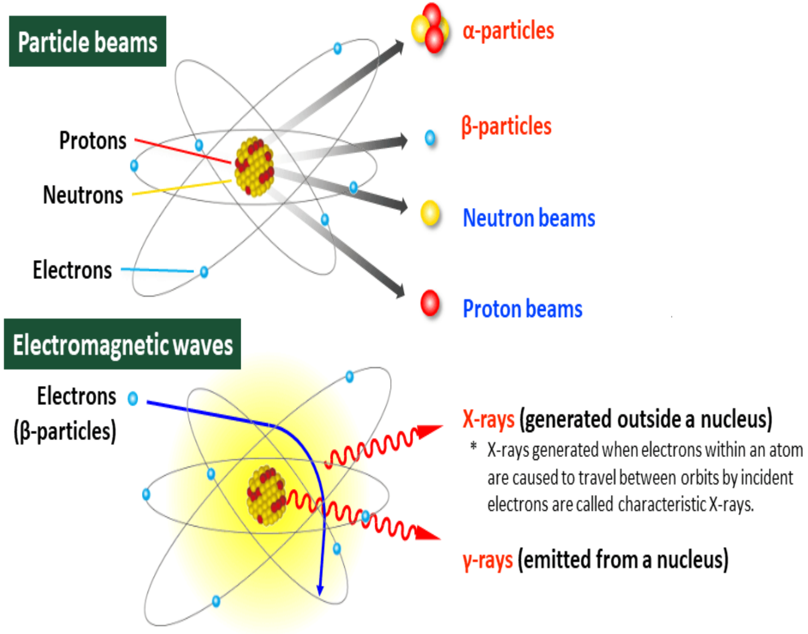
Both natural radiation sources (cosmic rays, and terrestrial sources that come from radionuclides in the earth's crust, air, food and water and the human body itself) and man-made radiations (medical uses of radiation and radioisotopes in health care, professional sources in the generation of electricity from nuclear power reactors, industrial uses of nuclear techniques, and in the past from nuclear weapons testing) cause ionization of atoms or molecules, which may cause injury to cells.

Types of ionizing radiation

Ionizing radiation may be divided into indirectly and directly ionizing for the understanding of biological effects.

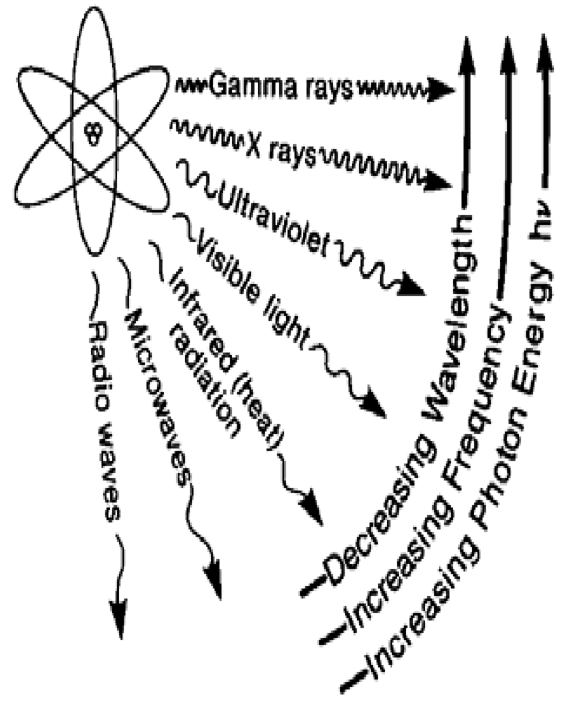
electromagnetic radiations, are indirectly ionizing because they do not produce chemical and biological damage themselves but produce secondary electrons (charged particles) after energy absorption in the material.

In contrast, Most of the particulate types of radiation are directly ionizing can directly disrupt the atomic structure of the absorbing medium through which they pass producing chemical and biological damage to molecules.



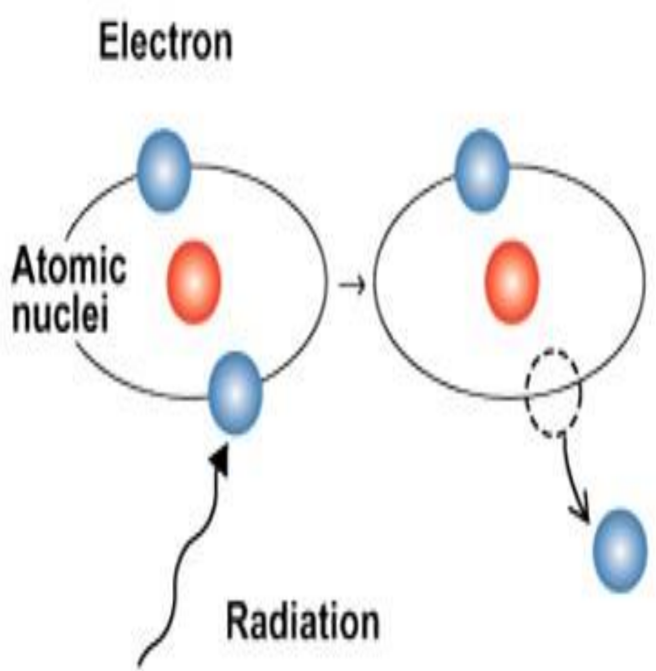
1. Electromagnetic radiation

- Electromagnetic radiation can be defined as the propagation of wave like energy (without mass) through space or matter.
- These waves are essentially characterized by their energy which varies inversely with the wavelength.

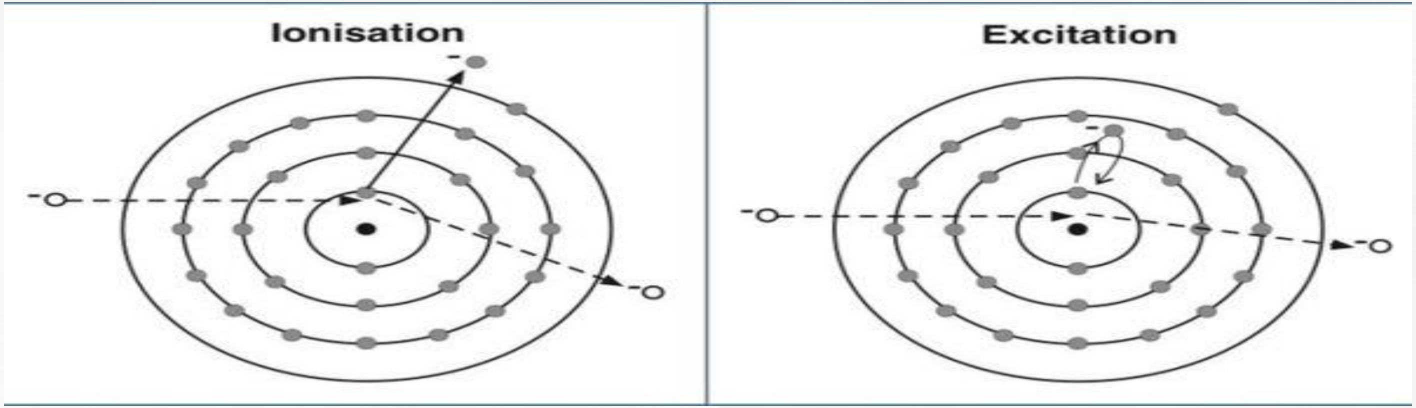


X and γ ray photons have the ability to eject an electron from its orbit in an atom (are ionizing radiations).

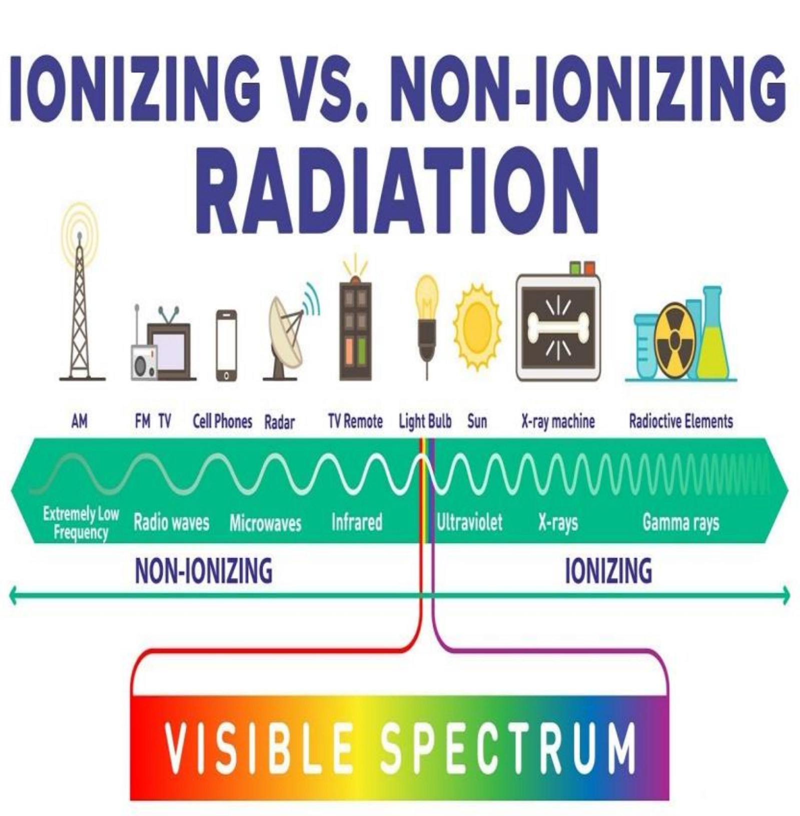
Ionization is the process of removing one or more electrons from atoms by the incident radiation leaving behind electrically charged particles (an electron and a positively charged ion).



The ionized or excited atom or molecule may either fragment producing free radicals or return to the parent state. If the energy transferred by ionizing radiation to the atom is insufficient to eject orbital electrons, the electrons may be raised from lower to higher orbitals and the atom is said to be excited.



Non-ionizing radiations are generally considered harmless to biological tissues, although there remain arguments in this area and research is ongoing cellular phones, radar, infrared, radiowaves, microwaves, visible light, ultrasound fall into this category because of the longer wavelengths and therefore, smaller energy per quanta.



When electromagnetic radiation travels through matter, it can be transmitted without transferring any energy or its intensity may be reduced by interaction with the traversed material. Biological effects arise when electromagnetic radiations (mainly X rays or γ rays) are either scattered or absorbed by the atoms of tissues/organs.

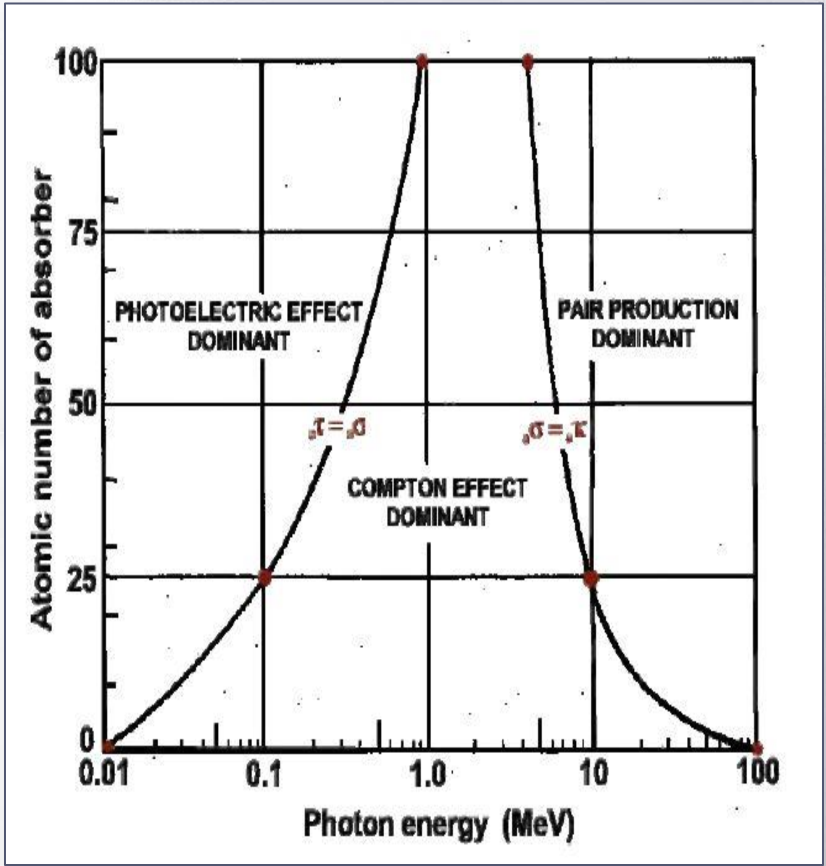
Quantum theory considers electromagnetic radiation as streams of packets of energy called photons. The energy of a photon of electromagnetic radiation is given by Planck's equation, where:

$$\mathbf{E = h\nu = hc/\lambda}$$

E is the photon energy, h is Planck's constant, and ν is the photon frequency. Wave velocity is obtained by the product of frequency and wavelength, $c = \lambda\nu$, where c is the velocity of light.

Biological effects of radiation arise when ionizing radiation interacts with an organism/tissue and leaves some energy behind.

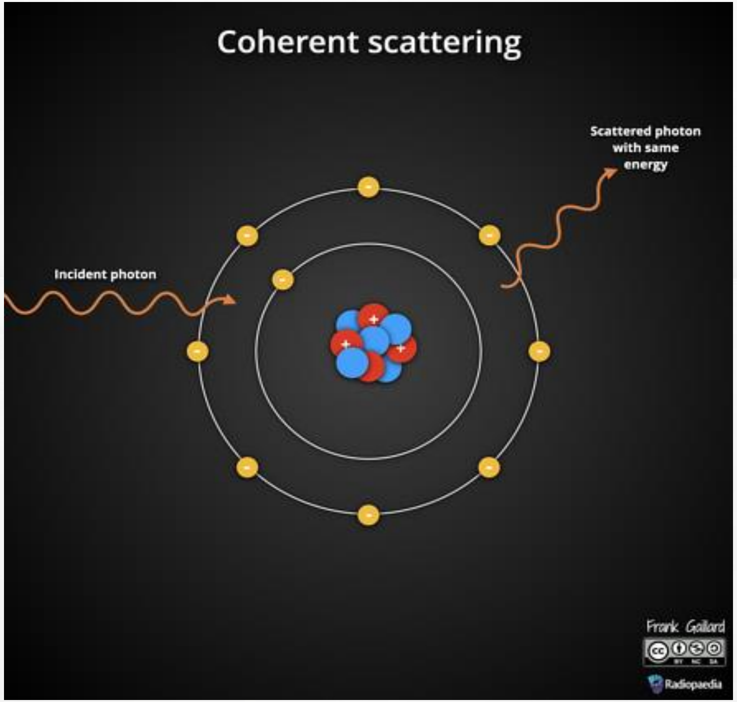
Photons passing through matter transfer their energy through the following three main processes: photoelectric absorption, Compton scattering, and pair production.



Coherent (Rayleigh) scattering

Occur at low energy about 10 keV or below.

Scattered photon is emitted with the **same incident energy** (No loss of energy) but in different direction (doesn't produce ionization).



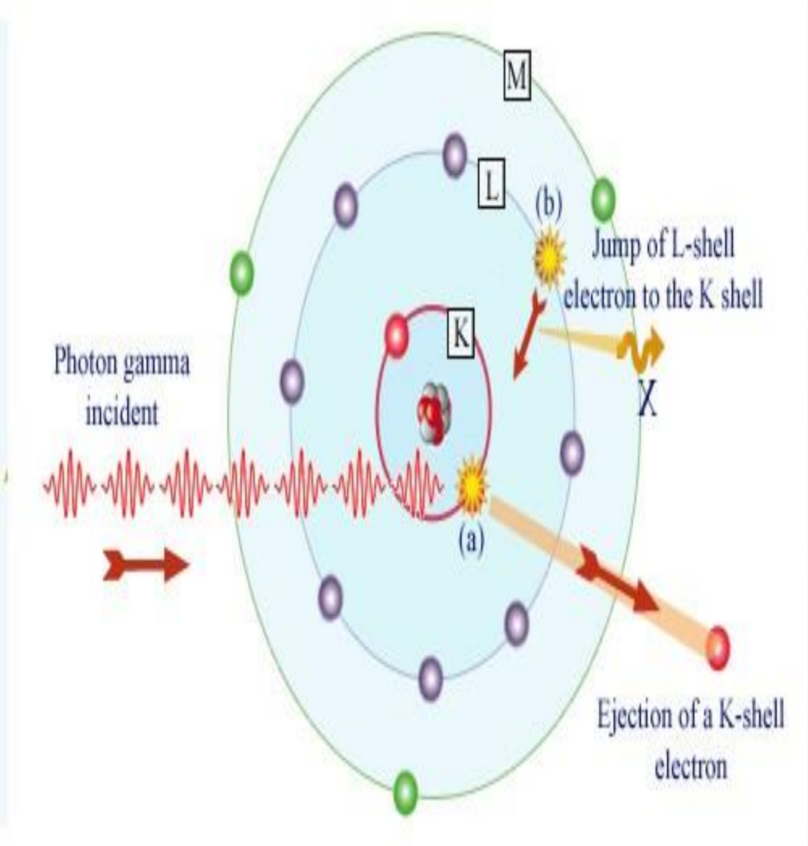
Photoelectric absorption

In photoelectric absorption, the photon interacts with a bound inner shell electron in the atom of the absorbing medium and transfers its entire energy to the electron ejecting it from the occupied atomic shell. The energy transferred is used to overcome the binding energy of the electron and the remainder appears as kinetic energy of the resulting photoelectron.

Kinetic Energy (e) = hν – E b

Where hν is the energy of incident photon, and E b is the binding energy of the electron.

As a result, an atom that participated in photoelectric interaction is left ionized. The vacancy created due to ejection of the electron is instantly filled by an electron from an outer orbital of the same atom.

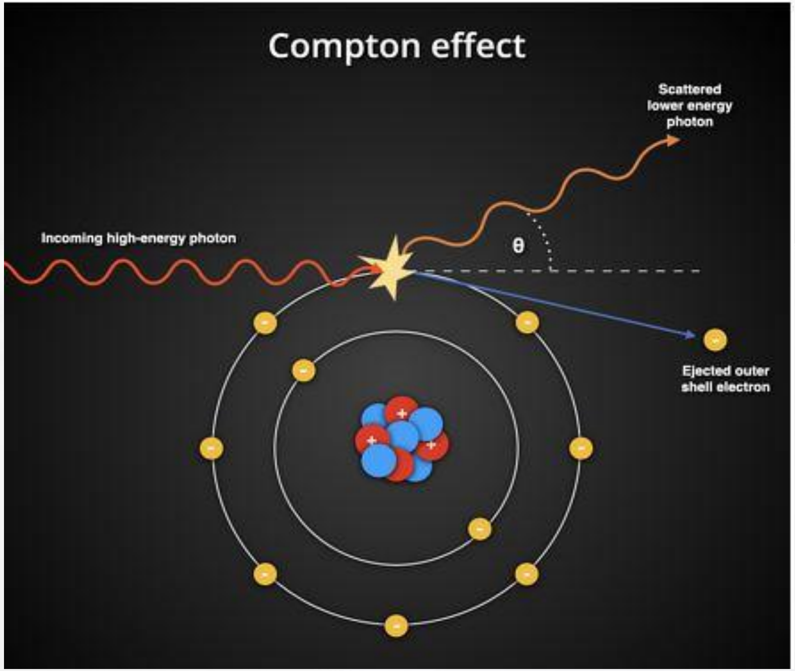


The ejected photoelectron travels a distance within the absorber and loses its energy through secondary ionizations. In this way, the entire photon energy of the incident photon is deposited in the tissue irradiated.

The photoelectric effect is the energy transfer mechanism for X and γ ray photons having energies below 50 keV in biological tissues, but it is much less important at higher energies.

Compton scattering

- The process of Compton Effect occurs when the incident photon interacts with the outer orbital electron whose binding energy is very low compared with that of the incident photon.



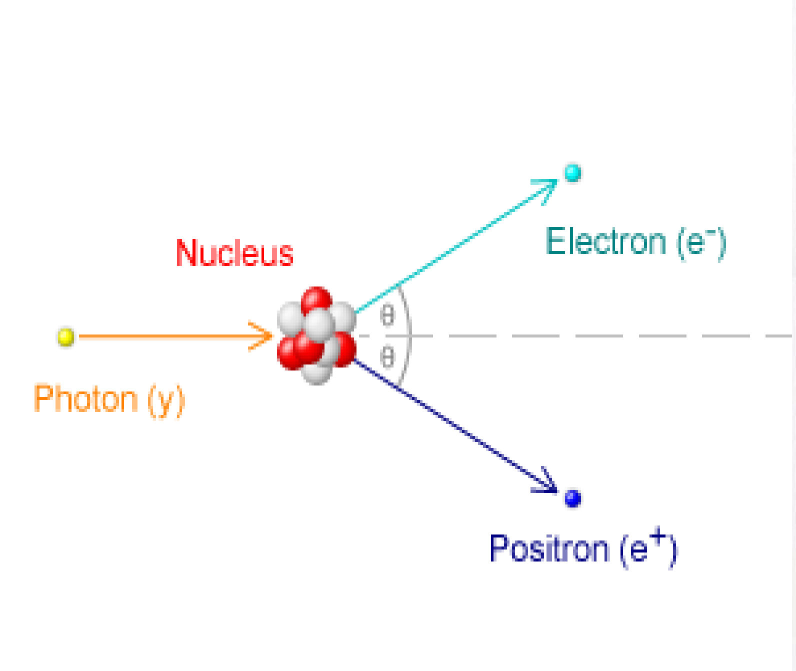
In this interaction, the incident photon transfers energy to an atomic electron causing its ejection from the atom. The photon is scattered with the remainder of the original energy in a different direction to that of the incident photon. Compton scatter thus causes ionization of the absorbing atom due to loss of an electron.

The scattered electron (a secondary charged particle) travels some distance in matter and eventually loses energy by further ionization and excitation events.

It is the principal absorption mechanism for X and γ rays in the intermediate energy range of 100 keV to 10 MeV. This range is in the therapeutic radiation range.

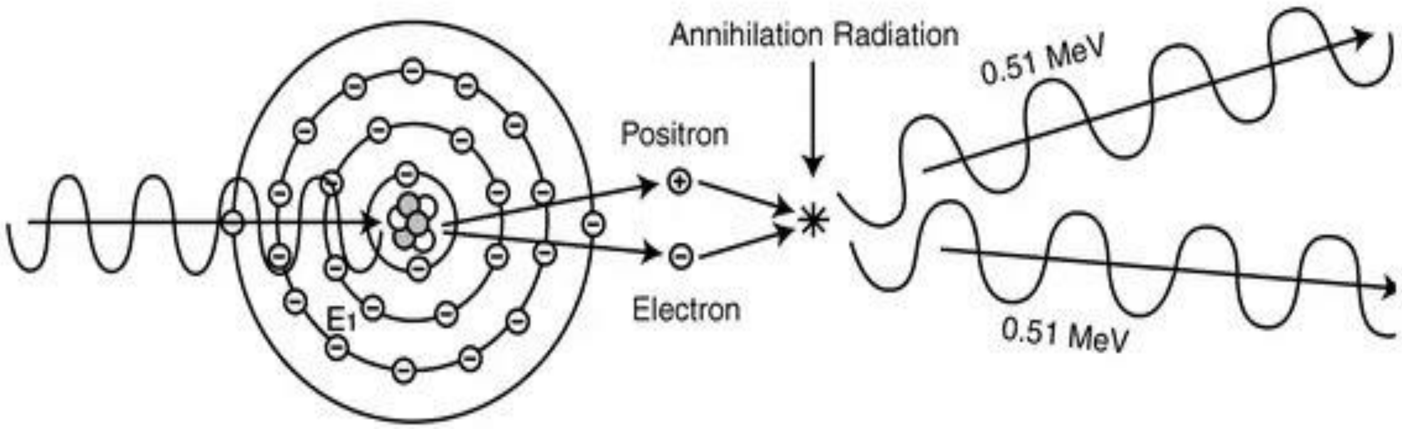
Pair production

When a photon of high energy (>1.02 MeV) interacts with atoms of the medium, the incident photon can be spontaneously converted into the mass of an electron and positron pair by interaction of the Coulomb force near the nucleus.



The oppositely charged particles are emitted in opposite directions to each other and cause damage as secondary charge particles.

A **positron** is the anti-matter equivalent of an electron and it has the same mass as an electron, but it has a positive charge equal in strength to the negative charge of an electron. The positron has a very short lifetime and at the end of its range it combines with a free electron. The entire mass of these two particles is then converted into two γ photons each of 0.51 MeV.



c) Pair Production

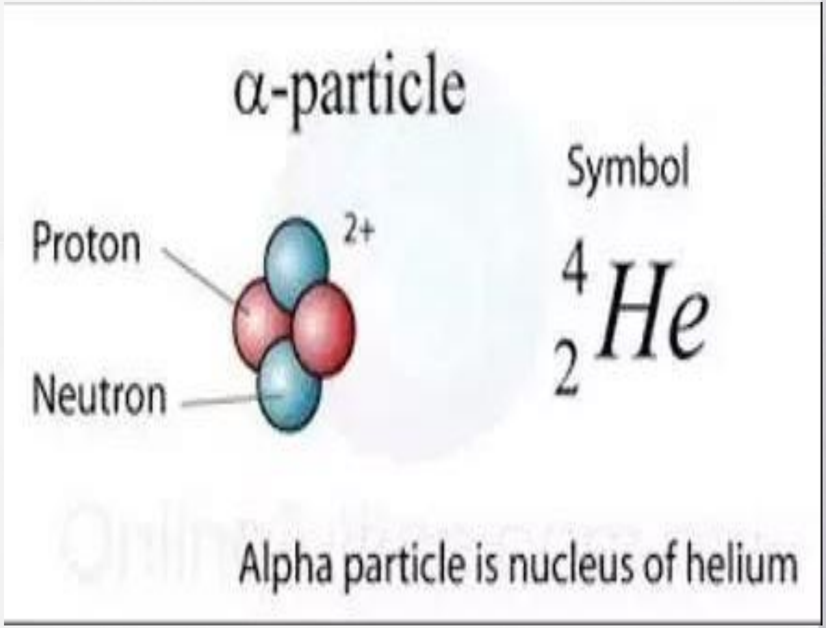
2. Particulate radiations

Particulate radiations (e.g. α, β particles, protons, neutrons, ions), also produce their effects by causing ionization and excitation processes randomly in the atoms or molecules of the traversed material.

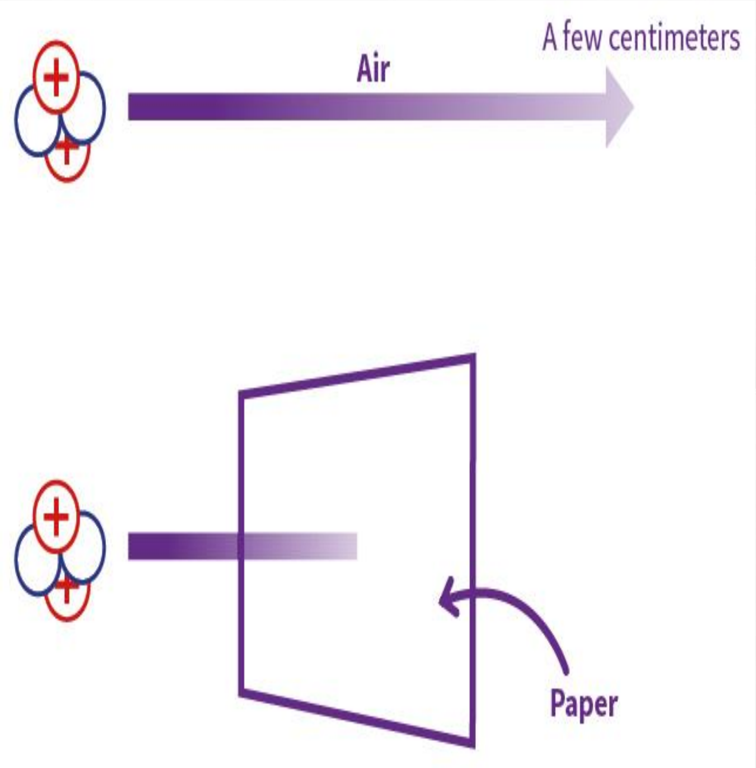
The passage of charged particles, electrons and positively charged ions causes intense damage (energy deposition) to molecules along the path in living tissue due to strong electrostatic interactions between the travelling particle and the electrons of the atoms of the medium.

a. Charged particles

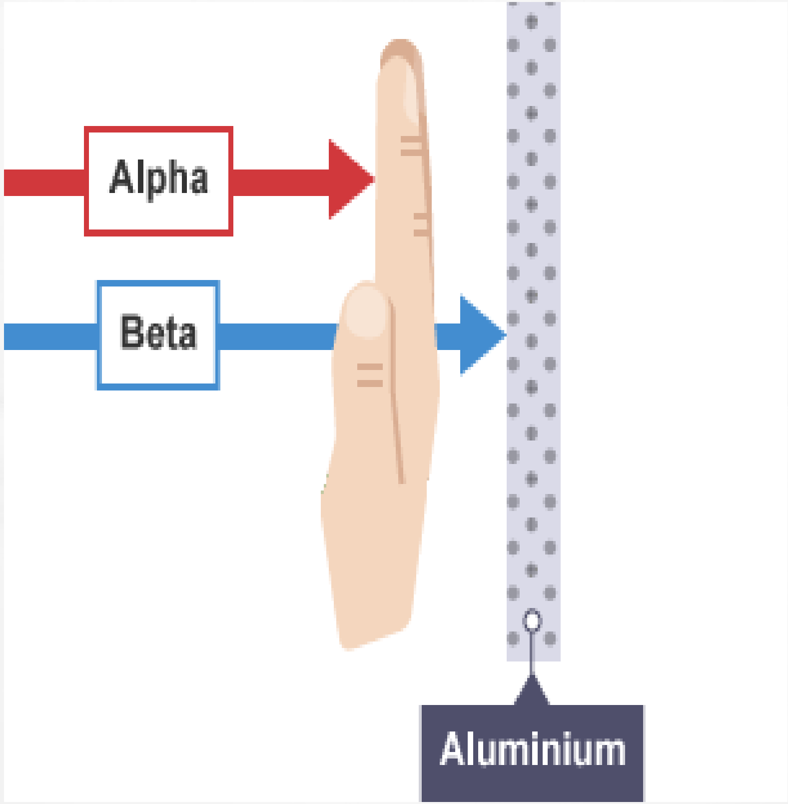
Protons with one unit mass and one positive charge cause less damage than α particles (helium nuclei). At the same energy α particles have lower velocity because of their higher mass and carry twice the charge of a proton.



Radioactive materials often release α particles and because they are a highly ionizing form and they usually have low penetration. They quickly lose their energy and they penetrate only a few tens of microns in body tissue.



Beta particles (β, electrons) are also emitted by radioactive nuclei, as well as being produced from atoms and molecules by X and γ rays. Generally, beta particles do not penetrate further than the skin of the human body.

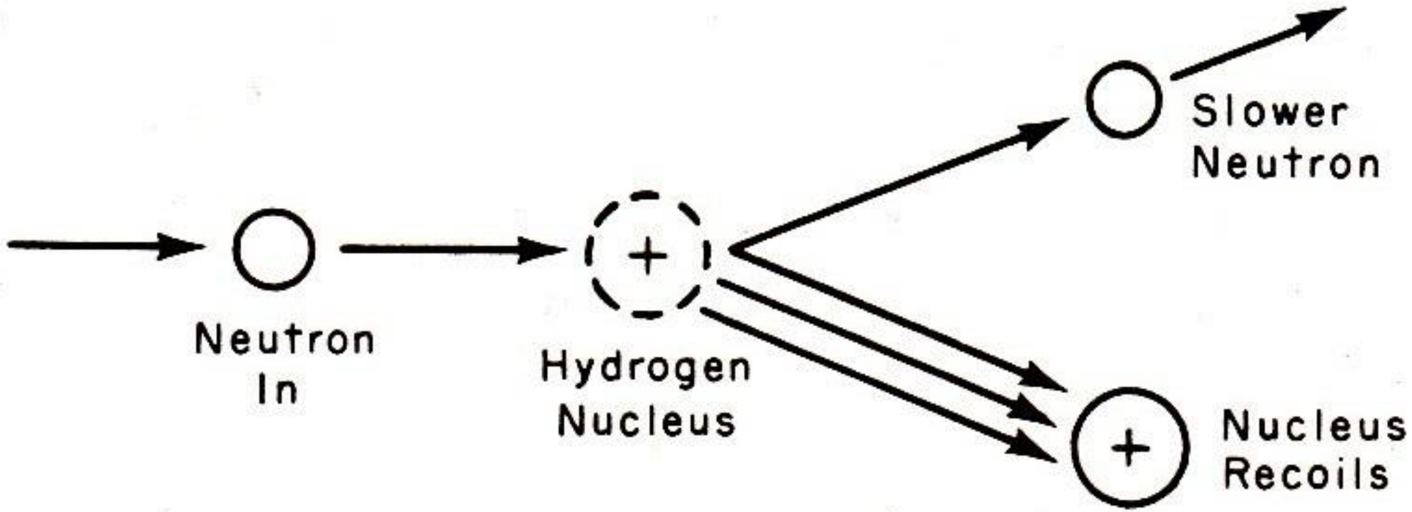


b. Uncharged particles

Neutrons (n) are uncharged particles with a mass very similar to that of a proton and are an indirectly ionizing radiation because without a charge they cannot participate in electrostatic interactions. neutrons are more penetrating than are charged particles.

Although neutrons do not interact strongly with electrons of atoms and do not directly ionize atoms, they do cause a density of ionization that is far greater than in the case of X rays. Neutrons interact with the atomic **nuclei** of the medium and they lose energy by different interaction processes depending on their energy (velocity) and the mass of the encountered nucleus.

In soft tissues, because of the existence of protons, Fast neutrons (>1 MeV) can be scattered by nuclei with kinetic energies <1 eV. With each collision, the fast neutron mostly transfers a part of its kinetic energy to the scattering nucleus by elastic scattering . And the fast neutron is slowed until it reaches thermal equilibrium with the material in which it is scattered, through collision processes producing high energy recoil protons, which in turn deposit energy in the tissue.



Elastic scattering

Fast neutrons can be made into thermal neutrons via a process called moderation. In reactors, typically heavy water, light water, or graphite are used to moderate neutrons. Thermal neutrons have a much larger effective cross-section than fast neutrons, and therefore, can be absorbed more easily by any atomic nuclei with which they collide.

Ions

The nuclei of carbon, neon, silicon and argon atoms form charged ions when one or more orbital electrons have been stripped off. High energy charged ions offer special advantages in cancer radiotherapy because of the energy distribution along their track. This allows the possibility of depositing high energy densities at depth in tissue but these facilities are as yet very limited on account of high costs and developed technical requirements.

Applications of Radiation

Diagnostic

Medical imaging (Radiology): creating images of internal human body or its functions

– X-rays travel through the body and are absorbed in different amounts by different tissues. Radiological density is determined by both the density and the atomic number of the materials being imaged.

For example, structures such as bone contain calcium, which has a higher atomic number than most tissues. Because of this property, bones easily absorb x-rays and produce high contrast on the x-ray detector. As a result, bony structures appear whiter than other tissues. This property enables detectors to find broken bones and locate cancers that may be growing in the body.

Communications

Cell phones, AM and FM radio, microwave towers all radiate electromagnetic energy. These waves surround humans daily.

Treatment

Radiotherapy treatment are use radiation to kill cancer cell by creating positively charged ions and electrons in the cells of tissue that which pass through or change genes so tumor cells can't grow.

Radiation has many other areas can they uses in (sterilization, industrial and research purposes).

Human response to radiation

- A high level of radiation exposure delivered over a short period of time can cause biological effects within hours, days or weeks and can sometimes result in death. This is known as **acute radiation syndrome**, "**radiation sickness**" or **early effects of radiation**.
- If the biological effects of radiation can be appear after years or decays after exposure, its known as "**late effects of radiation**".
- If the biological effects of radiation appear on a new generation, its called "**genetic effects of radiation**".

Mass-Energy equivalence

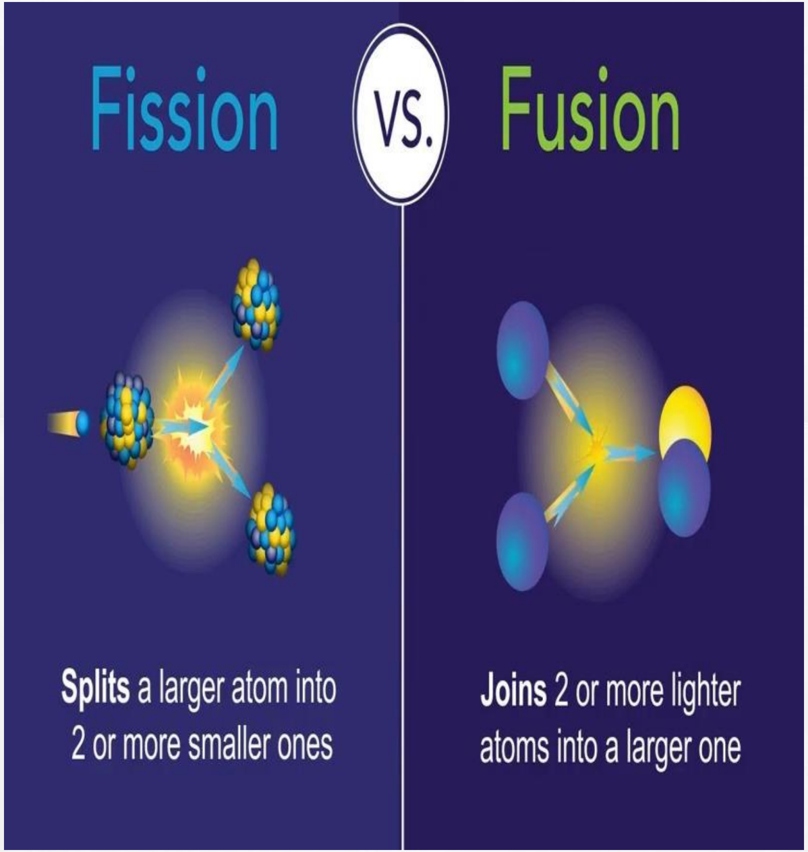
- Is the famous concept in physics represented mathematically by:

$$E = mc^2$$

- The formula indicates that a small amount of rest mass corresponds to an enormous amount of energy. **Rest mass** is the mass that is measured when the system is at rest and it remains independent of momentum, even at extreme speeds approaching the speed of light.

- Massless of free particles such as photons have zero rest mass, but have both momentum and energy. When energy is lost in chemical reactions, nuclear reactions, and other energy transformations, the system will also lose a corresponding amount of mass.
- Nuclear reactions can be release so much more energy than chemical reactions because of the mass changes (Δm).

Small amounts of mass are turned into energy from the breaking up (fission) or combination (fusion) of the nuclei of atoms. Even spontaneous radioactive decay converts a bit of mass into incredible amounts of energy.



Radiation units

Quantity	SI unit	Older unit	Conversion factor (traditional/SI)	Conversion factor (SI/traditional)
Activity	becquerel (Bq); 1 Bq = 1 nuclear transformation s^{-1}	curie (Ci)	1 Ci = 3.7 10^{10} Bq	1 Bq = 2.7 10^{-11} Ci
Absorbed dose	gray (Gy) 1 Gy = 1 J kg^{-1}	rad	1 rad = 0.01 Gy	1 Gy = 100 rad
Equivalent dose or effective dose	sievert (Sv) 1 Sv = 1 J kg^{-1}	rem	1 rem = 0.01 Sv	1 Sv = 100 rem
Exposure	coulomb per kilogram of air (C kg^{-1})	roentgen (R)	1 R = 2.58 10^{-4} C kg^{-1}	1 C kg^{-1} = 3876 R

Radiation Activity

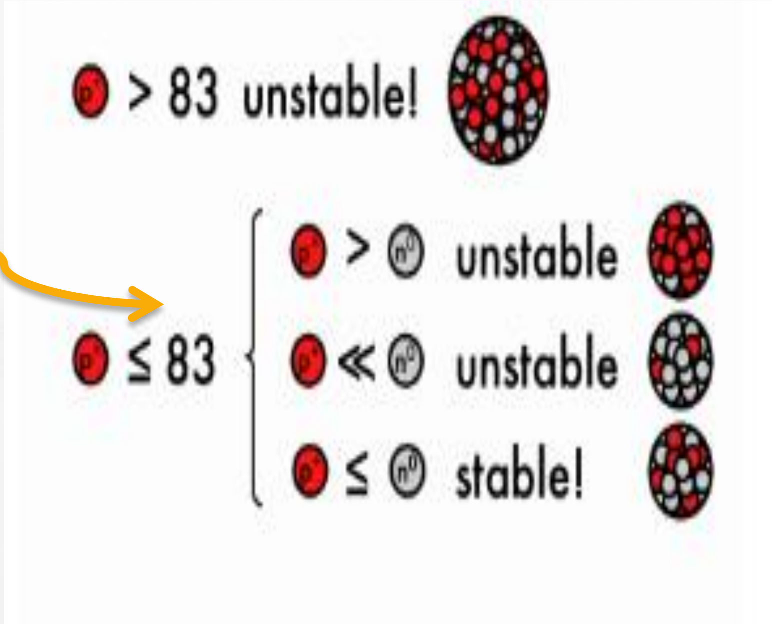
Is the number of particles which are emitted from nuclei as a result of nuclear instability (**disintegration per second** (**dps**)).

$$A = -\frac{dN}{dt}$$

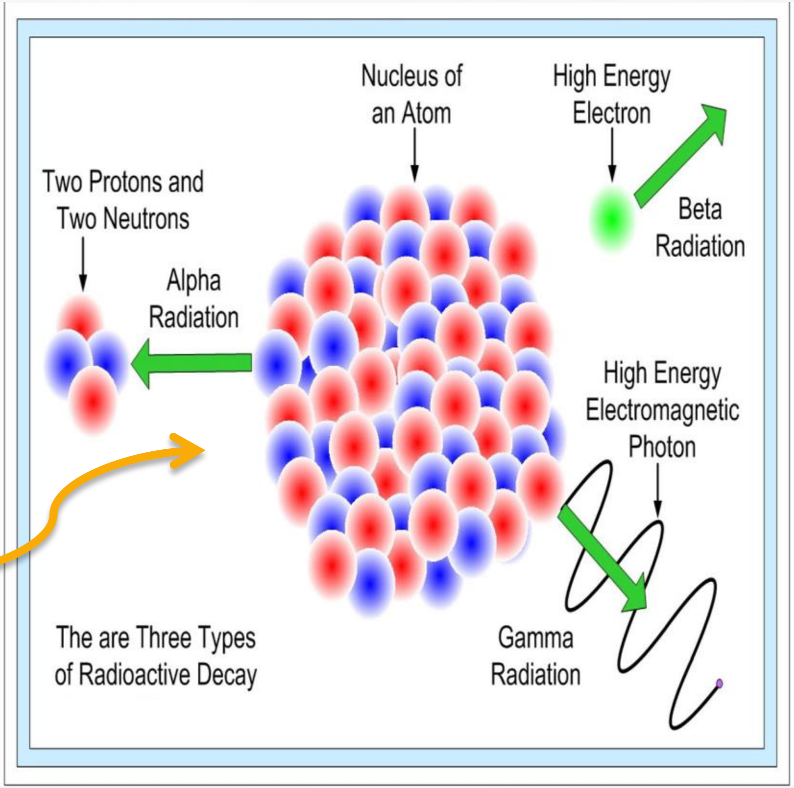
The majority nuclei found on Earth is stable because almost all short-lived radioactive nuclei have decayed by time. There are ≈ 270 stable isotopes and 50 (radioactive isotopes) and Thousands of radioisotopes have been made in the laboratory.

Radioactive decay

- Not all nuclei are stable and the stability conditions is



- Unstable nuclei are spontaneously split to emit particles or radiations.
- This process called radioactivity.
- There are three types of radiation emitted during nuclei decay



- The rate of decay of nuclei is proportional to the total number of nuclei in the sample at a particular time:

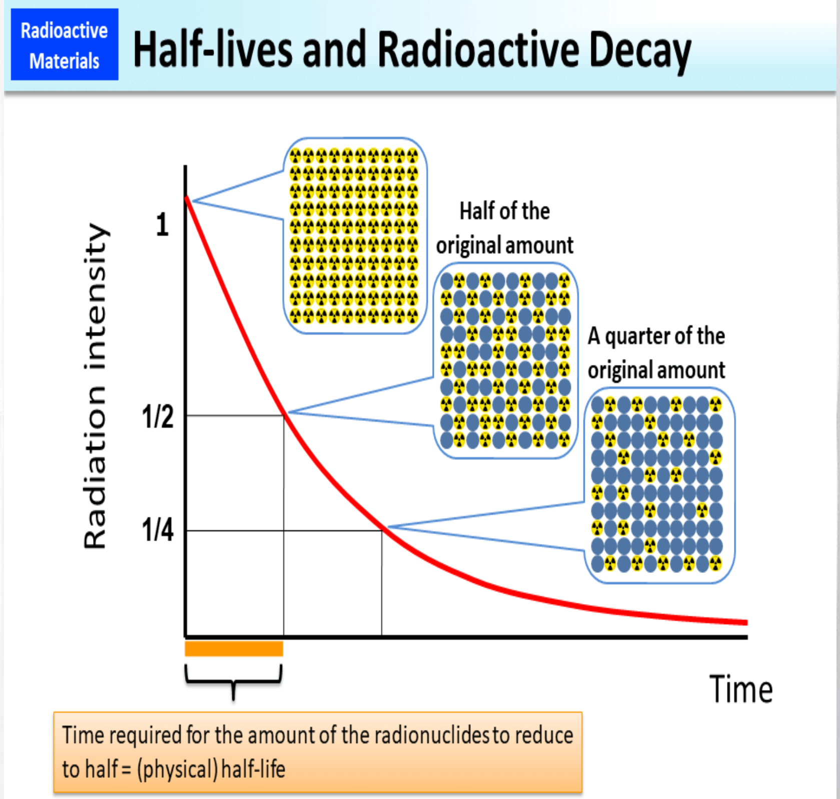
(radioactivity is exponentially slow down by time)

$$N = N_o \, e^{-\lambda t}$$

Where λ is radioactive decay constant, **N** is number of nuclei at time t, **No** is number of nuclei at time t=0

After a certain time, the radioactivity becomes half of the original amount, then the time is known as a **half life** $T_{1/2}$ of radioactive reaction:

$$\lambda = \frac{0.693}{T_{1/2}}$$



CHAPTER 2
ENERGY TRANSFER PROCESS

MECHANISMS OF ENERGY TRANSFER FROM ɣ-RAYS

The photon beams interact with matter by three ways:

- ✗ Absorption (E_{abs})
- ✗ Scattering ($E_{\gamma'}$)
- ✗ Penetration (unaffected)

And the three ways **depends on**:

- ❖ Density, thickness and atomic number of the absorbing medium.
- ❖ Energy of incident photon.

LINEAR ENERGY TRANSFER (LET)

When a radiation interact with matter: it will lose kinetic energy to any solid, liquid, or gas through which it passes; this occurs by several mechanisms and at different rates.

The amount of energy that the radiation transfers per unit of path length is called its **linear energy transfer** (LET) (E_{Tr}).

$$\text{LET} = \text{Stopping power (S)} = \frac{dE}{dL} \quad (\text{keV}/\mu\text{m})$$

Where dE is the average energy in kev and dL is the distance that radiation pass in µm.

This feature reflects a radiation's ability to produce biological damage.

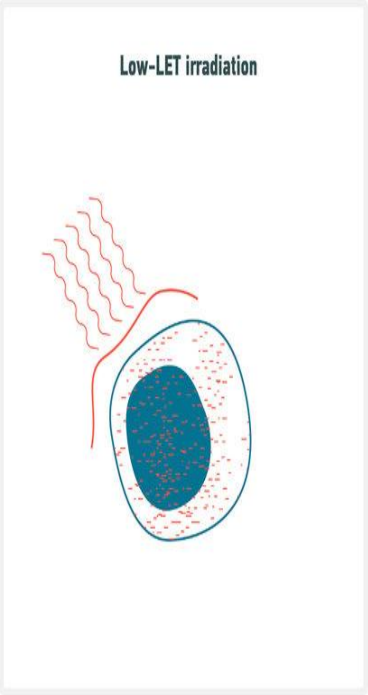
LET is proportional to the squared charge and inversely proportional to the energy $\frac{{Z_e}^2}{E}$

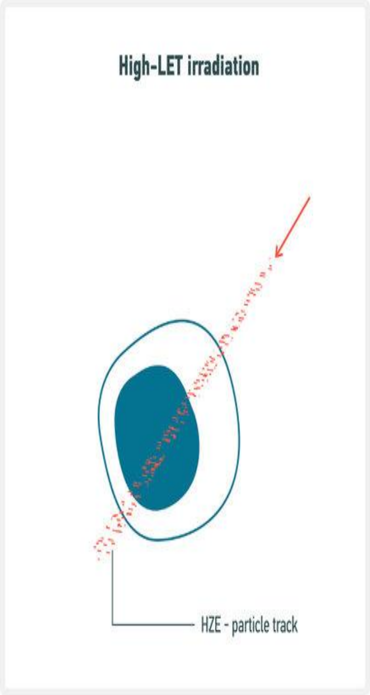
- Both high and low LET interactions can cause significant damage to the DNA and can result in a wide array of biological effects. Radiation can also react with molecules other than DNA (lipids, proteins, water, etc.) to produce free radicals, which can then go on to adversely react with the DNA molecule.

Regardless of the method of energy transfer, DNA is the primary molecule that affected from low level radiation because DNA damage from radiation and from other sources is cumulative and can (but does not always) result in carcinogenesis after months or years after exposure.

Types of LET

Radiation is classified as either high linear energy transfer (high LET) or low linear energy transfer (low LET) ≈ 3 **keV/μm**, based on the amount of energy it transfers per unit path length it travels. (e.g.) Alpha radiation is high LET; beta, X and gamma radiation are low LET.





DIFFERENCES BETWEEN HIGH AND LOW LET ENERGY

✗ **High LET (> 10-100 keV/μm) or more**

- Such as n and α radiation.
- Produce densely ionization.
- Deposited its energy uniformly.
- Cause internal radiation.
- Cause direct damage to the target and they are lethal.
- Produce double-strand break of DNA.

DIFFERENCES BETWEEN HIGH AND LOW LET ENERGY

- **Low LET (3-10 keV/ μm)**
- Such as X and γ and β particles.
- Produce lightly ionization.
- Interact with medium randomly.
- Cause external radiation hazard.
- Cause indirect damage to the target and they are sub-lethal.
- Produce single-strand break of DNA.

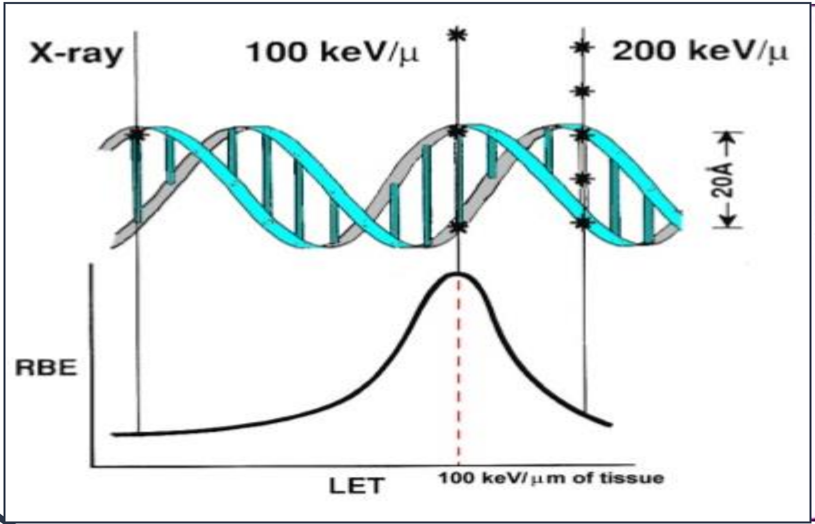
RELATIVE BIOLOGICAL EFFECTIVNESS (RBE)

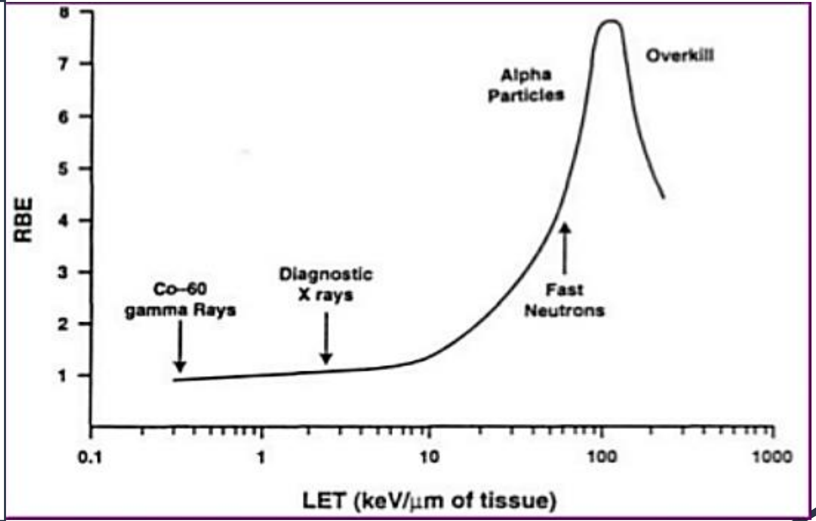
The RBE for any radiation is defined as the ratio of the dose from 200 keV X-rays required for a given biological effect to the dose that would produce the same effect with that radiation.

$$\text{RBE} = \frac{\text{Dose of X-rays required to produce an effect}}{\text{Dose of test radiation required to produce the same effect}}$$

RBE is depend on the types of radiation and energies.

- When LET of radiation is increases RBE is increases.
- The Maximum biological damage (higher ionization) response occurs at 100 keV/μm for α-particles and then decreased.





- The RBE of diagnostic X ray, γ and β particles is 1
- Radiation with lower LET than diagnostic X ray have RBE is less than 1
- Radiation with higher LET than diagnostic X ray have RBE is higher than 1
- The RBE ranges is from less than 1 to 20 for

LET and RBE of Various Ionizing Radiation.

Type of Radiation	LET (keV/um)	RBE
25 MeV X-rays	0.2	0.8
Co-60 gamma rays	0.3	0.9
1 MeV electrons	0.3	0.9
Diagnostic x-rays	3.0	1.0
10 MeV protons	4.0	5.0
Fast neutrons	50.0	10.0
5 MeV alpha particles	100.0	20.0

ATTENUATION OF RADIATION

- Is define as the reduction of radiation intensity (number of passing photons) when they pass through matter either by absorption or scattering.
- There are two attenuation coefficient linear (μ_l) and mass (μ_m) attenuation coefficient.

1) LINEAR ATTENUATION COEFFICIENT (μ_l)

- Part of photons removed from a mono-energetic beam of x- or gamma rays per unit thickness of material, typically expressed by cm^{-1} or mm^{-1}

$$\mu = \mu_{rayleigh} + \mu_{photoelectric} + \mu_{compton} + \mu_{pair\ production}$$

- ✓ The number of photons removed from the beam (n) can be calculated by:

$$n = \mu N \Delta x$$

Number removed from beam

Attenuation coefficient

Number of photons incident on the material

Material Thickness

- 100 keV photons, 1 mm of thickness.
- μ is 0.016/mm.
- 16% removed for every 1,000 photons.

- 100 keV photons, 6 cm of thickness.
- μ is 960/mm.
- 96% removed for every 1,000 photons.

For mono-energetic beam of photons incident on either thick or thin slabs of material, an exponential relationship exists between Number of incident photons (N_o) and those transmitted (N) through thickness x :

$$N = N_o \, e^{-\mu x}$$

Example: Find the value of attenuation coefficient (μ) for Aluminum if 0.45cm thickness of Aluminum reduces the radiation level by 50%

Solution:

$$N = N_o\, e^{-\mu x}$$

$$\frac{N}{N_o} = e^{-\mu x}$$

$$50\% = e^{-\mu(0.45\ cm)} \quad] * \mathrm{Ln}$$

$$\mathrm{Ln}\ 0.5 = -\mu(0.45\ cm)$$

$$-\ 0.693 = -0.45\mu$$

$$\mu = 1.54\ cm^{-1}$$

- For a given thickness of material, probability of interaction **depends on** number of atoms the x- or gamma rays encounter per unit distance.

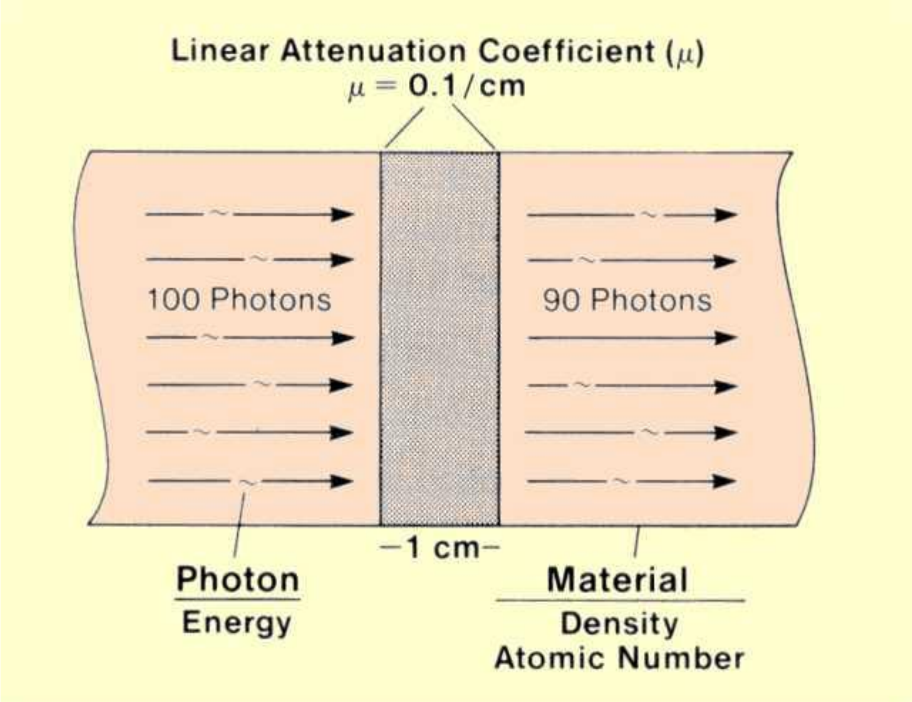
- Density (ρ) of material affects this number.
- Linear attenuation coefficient is proportional to the density of the material:

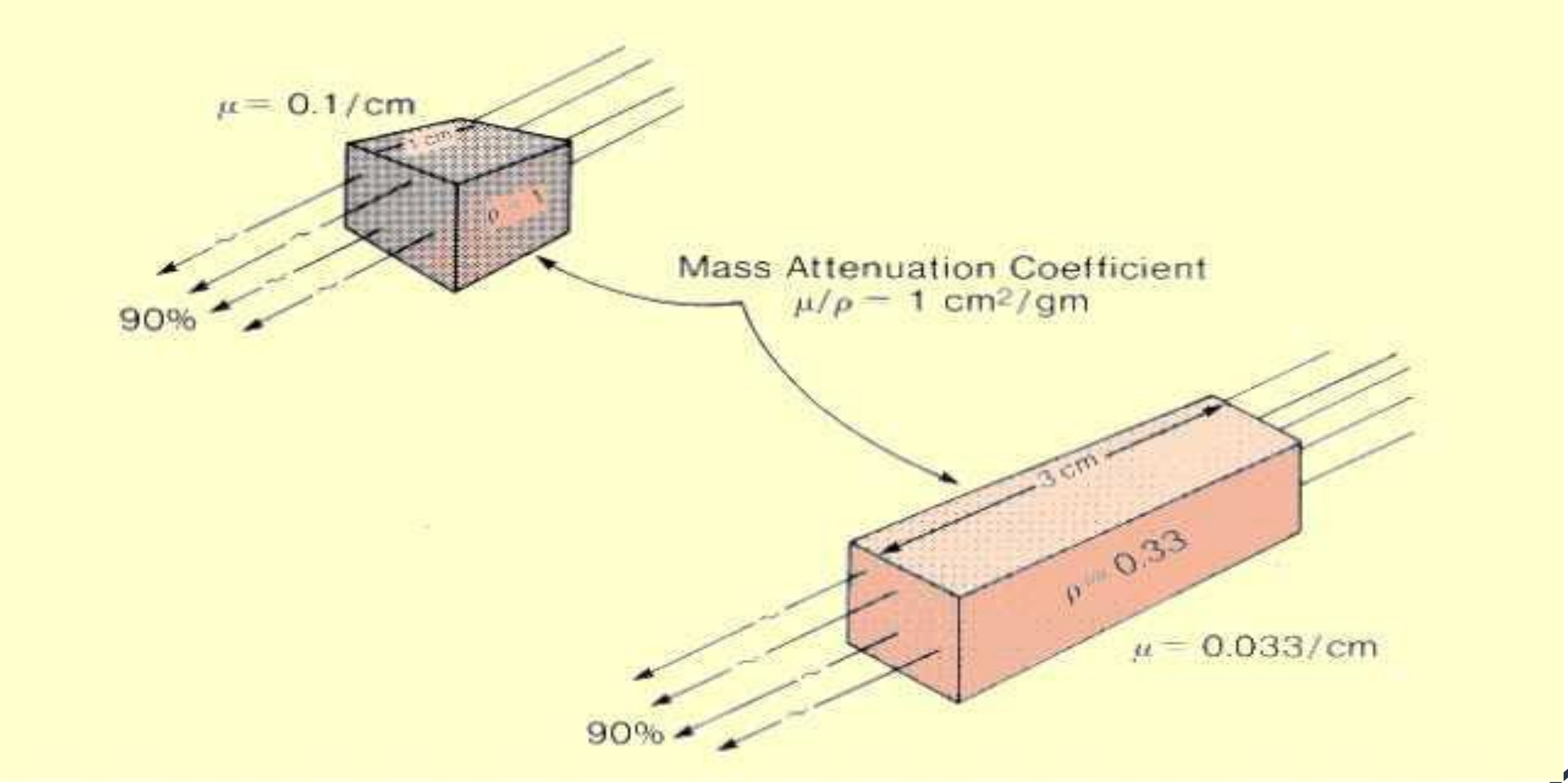
$$\mu \;\alpha\; \frac{\rho Z}{E_{\gamma}}$$

2) MASS ATTENUATION COEFFICIENT (μ_m)

- The linear attenuation divided by the density, typically expressed by $\frac{cm^2}{g}$ or $\frac{m^2}{kg}$ where:

$$\mu_m = \frac{\mu_l}{\rho}$$





μ = 0.1/cm
1 cm
ρ = 1
90%
Mass Attenuation Coefficient
μ/ρ = 1 cm²/gm
3 cm
ρ = 0.33
μ = 0.033/cm
90%

- **Mass thickness (x_m)** is the mass per unit area

$$x_m = x\rho \quad \left(\frac{g}{cm^2}\right)$$

- **Half Value Layer (HVL)** is the thickness of material that reduces the initial intensity of radiation to 50%

$$HVL = \frac{0.693}{\mu} \quad (cm)$$

- **Tenth Value Layer (TVL)** is the thickness of material that transmits only one tenth of the initial intensity of radiation

$$TVL = \frac{2.303}{\mu} \quad (cm)$$

Example: If a 2mm thickness of material transmits 25% of a mono-energetic beam of photons, calculate the HVL of the beam

Solution:

$$N = N_o\, e^{-\mu x}$$

$$\frac{N}{N_o} = e^{-\mu x}$$

$$25\% = e^{-\mu(0.2\ cm)} \quad] * \text{Ln}$$

$$\text{Ln } 0.25 = -\mu(0.2\ cm)$$

$$-1.38 = -0.2\mu$$

$$\mu = 6.93\ cm^{-1}$$

$$\text{HVL} = \frac{0.693}{6.93} = 0.1 \text{ cm}$$

MEAN FREE PATH (MFP)

MFP is defined as the average distance traveled before interaction.

$$\text{MFP} = \frac{1}{\mu}$$

$$= \frac{1}{0.693/HVL}$$

$$= 1.44\ \text{HVL}$$

Chapter Three

Charged particles Energy Absorption in Tissues

BIOLOGICAL EFFECTS OF IONIZING RADIATION

The fact that ionizing radiation produces biological damage has been known for many years.

Radiation damage starts at the cellular level. Radiation which is absorbed in a cell has the potential to effect on a variety of critical targets in the cell, the most important of which is the **DNA**. Evidence indicates that damage to the DNA is what causes cell death, mutation, and carcinogenesis.

- Radiation interactions within the body may produce macroscopically effects on specific organs or tissues, such as the skin, eye lenses, and thyroid.
- Irradiation of biological tissue cause a series of intracellular ionization of a molecule, and which may lead to cellular injury. Injury to a large number of cells may, in turn, lead to further injury to the organ and to the organism.

- Many factors may affected the response of a living organism to a given dose of radiation.
  1. The dose rate.
  2. The energy and type of radiation.
  3. The time of the exposure.
  4. Biological species, sex and age.
  5. The portion of the body tissues exposed.
  6. repair mechanisms.

The **DNA** is the primary target molecule for radiation toxicity. DNA damage, can occur in one of two ways from an exposure to radiation:

1. Direct Action

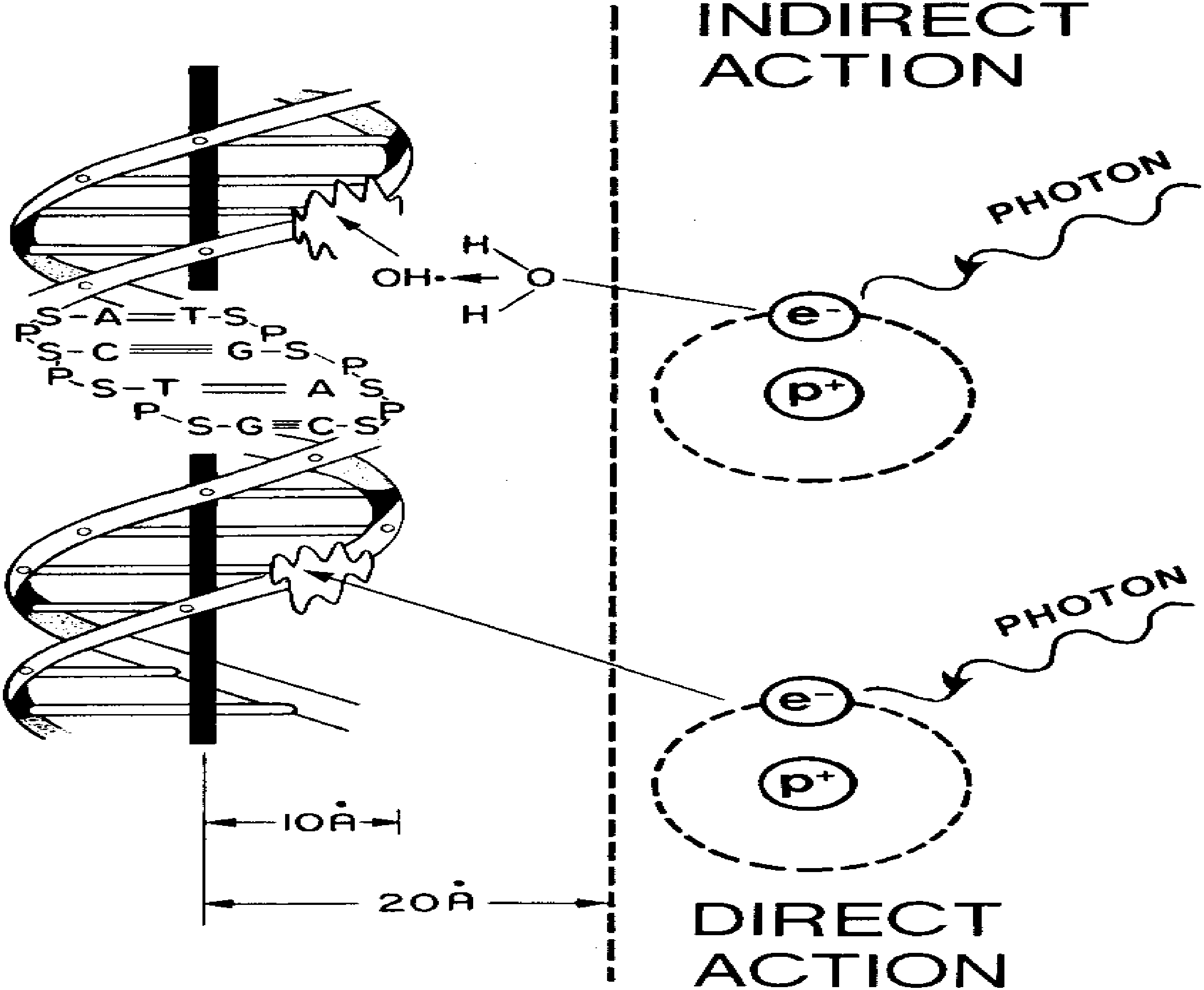
In the first scenario, radiation may impact the DNA directly, causing ionization of the atoms in the DNA molecule. and thus is a fairly **uncommon** occurrence due to the small size of the target.

The diameter of the DNA helix is only about **2 nm**. It is estimated that the radiation must produce ionization within a few nanometers of the DNA molecule in order for this action to occur.

2. Indirect Action

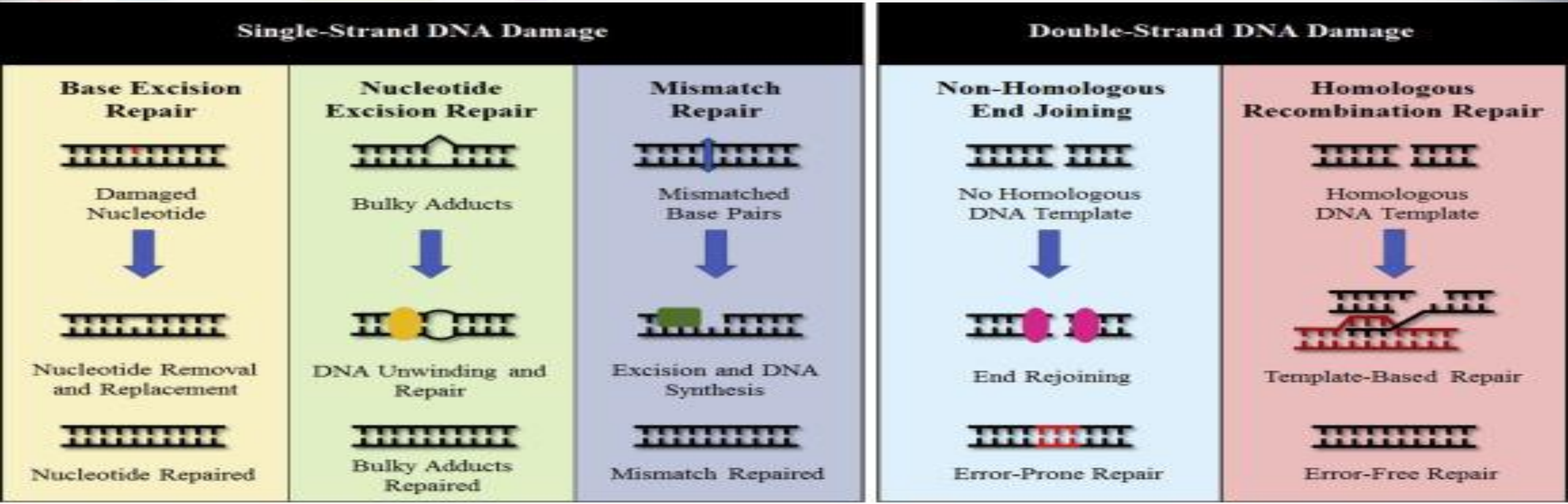
In the second scenario, the radiation interacts with non-critical target atoms or molecules, usually **water**. This results in the production of free radicals, which are atoms or molecules that have an unpaired electron and thus are highly reactive.

These free radicals can then attack critical targets such as the DNA Because they are able to diffuse some distance in the cell, **the initial ionization event does not have to occur so close to the DNA in order to cause damage**. Thus, damage from indirect action is much **more common** than damage from direct action, especially for radiation that has a low specific ionization.



INDIRECT ACTION
PHOTON
H
OH•
O
H
e⁻
p⁺
S-A=T-S
P
S-C≡G-S
P
P-S-T=A-S
P
P-S-G≡C-S
PHOTON
e⁻
p⁺
10Å
20Å
DIRECT ACTION

When the DNA is attacked, either via direct or indirect action, damage is caused to the strands of molecules that make up the double-helix structure. **Most** of this damage consists of breaks in only one of the two strands and is **easily repaired** by the cell, using the opposing strand as a template.



FREE RADICAL REACTIONS

Free radicals may be defined as the species that contain one or more unpaired electrons. This state is associated with a high degree of chemical reactivity, therefor; they are generally less stable and react in fraction of seconds with another species.

Free radicals such as H_2O^+ (water ion) and $OH^{\cdot}$ (hydroxyl radical), that break the chemical bonds and produce the chemical changes that lead to biological damage are highly reactive molecules because they have an unpaired valence electron.

Since **80% of a cell** is composed of **water**, as a result of the interaction with a photon or a charged particle, the water molecule may become **ionized**:

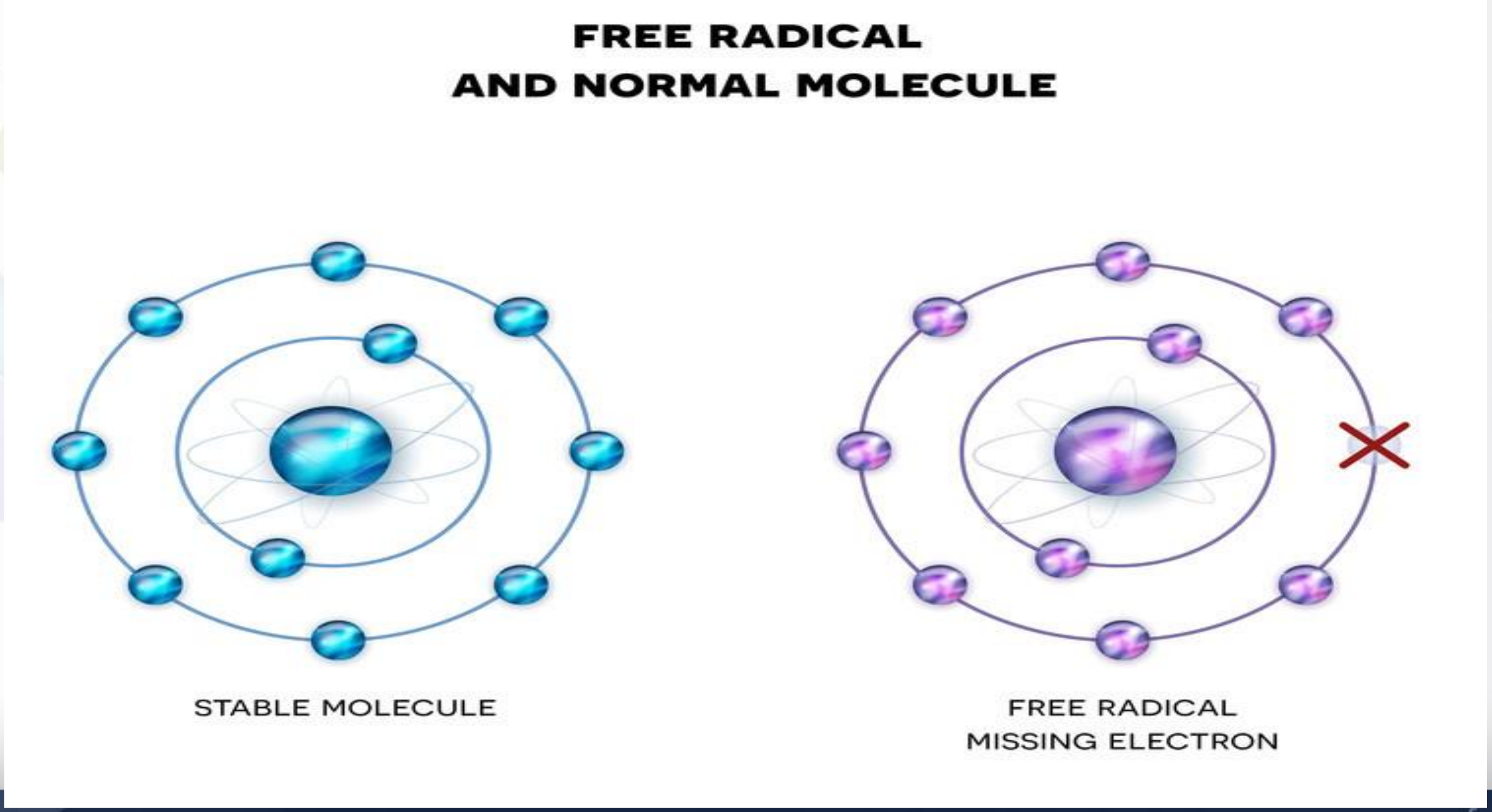
$$H_2O \longrightarrow H_2O^+ + e^-$$

H_2O^+ is an ion radical with a lifetime of ~ 10^{-10} s; it decays to form highly reactive hydroxyl free radical OH ·

$$H_2O^+ + H_2O \longrightarrow H_3O^+ + OH\cdot$$

The ionized atoms and molecules which may convert into free radicals in 10^{-12} to $^{-15}$ s, These radicals react with neighboring molecules and produce secondary radicals. Chain reactions occur and play a role in damage to cell membranes and breakage of chemical bonds in molecules.

These radicals are highly reactive and found in a number of biological processes, metabolism, oxidation, reduction and cancer induction.



Water Radiolysis

- The primary mechanism of biological damage to macromolecules from ionizing radiation is an indirect interaction that begins with the radiolysis of water.
- The net products of radiolysis of water molecules are the formation of highly reactive free radicals, namely

❑ hydrogen free radical ($H^{\cdot}$)

❑ hydroxyl free radical ($OH^{\cdot}$)

❑ hydroperoxyl radical ($HO_2^{\cdot}$)

Diffusion constant for radical species

Species	D (10^{-5} cm^2 s^{-1})
OH	2
e^-_{aq}	5
H_3O^+	8
H	8

Radiolysis stages

- Radiolysis occur in three main stages taking place on different time scales:

1. The physical stage

Which is achieved about 1 fs after the initial matter-ionizing radiation interaction, consists in energy deposition followed by fast relaxation processes. This leads to the formation of ionized water molecules (H_2O^+), excited water molecules ($H_2O^\cdot$) and sub-excitations electrons ($e-$).

2. Physico-chemical stage

During the physico-chemical stage (10^{-15} – 10^{-12}s), numerous processes occur including:

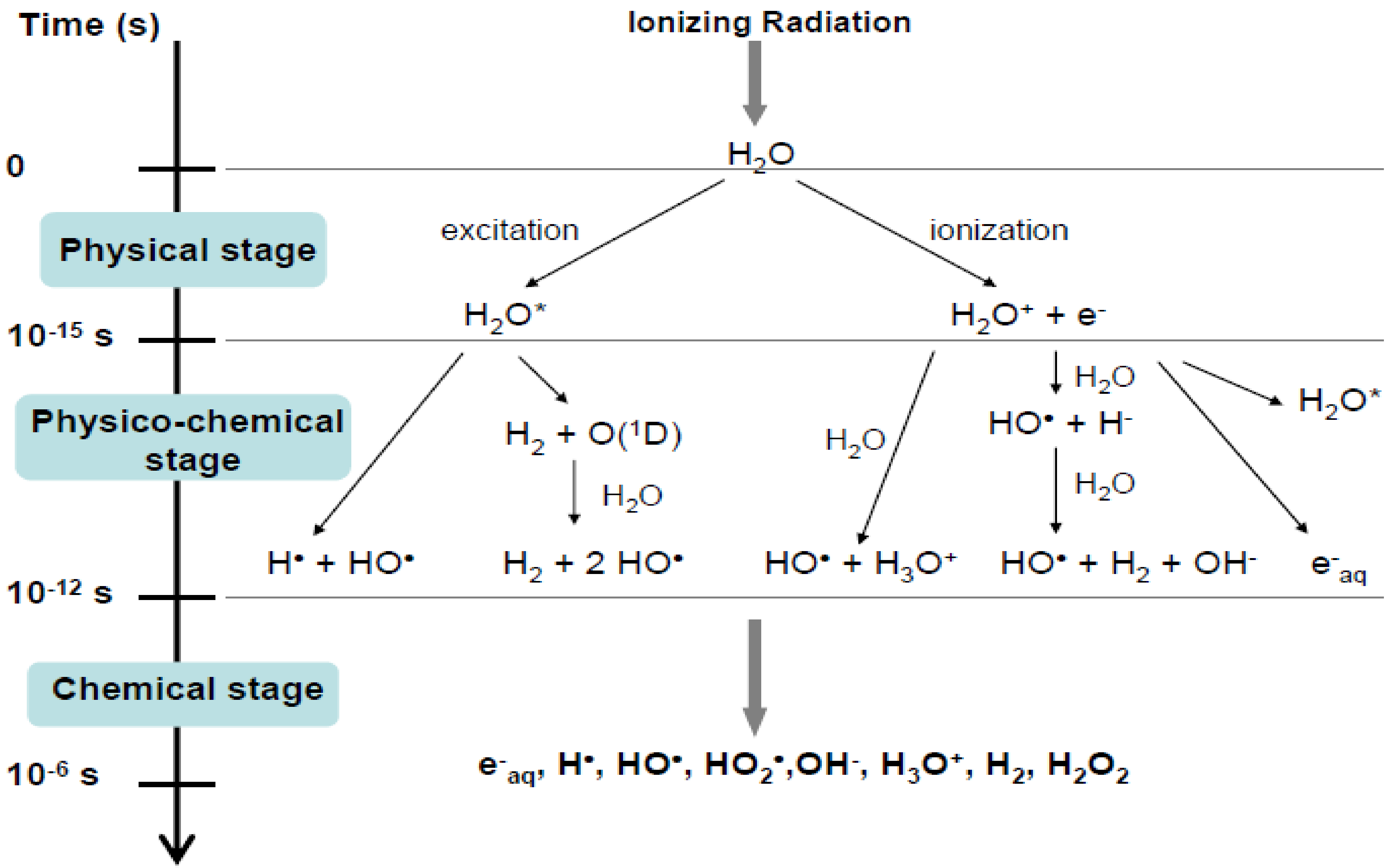
$$H_2O^+ + H_2O \longrightarrow H_3O^+ + OH^\cdot$$

$$H_2O^* \longrightarrow OH^\cdot + H^\cdot$$

$$e^- \longrightarrow e_{aq}^-$$

3. Chemical stage

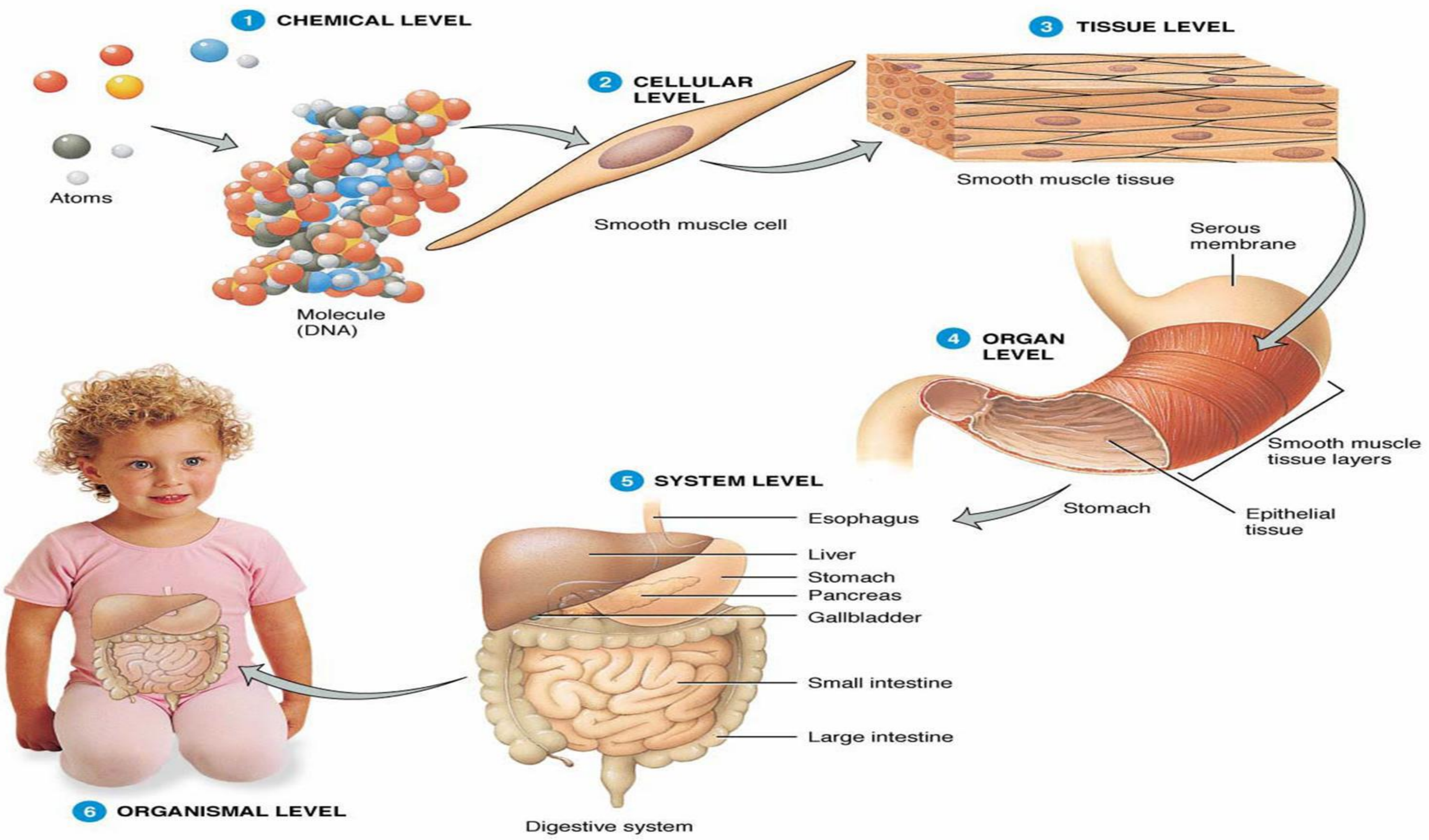
During the chemical stage $(10^{-12} - 10^{-6}\text{s})$, the species react in the tracks and then diffuse in solution. They can thus react with each other and also with surrounding molecules (in the solute). The track of the particles expands because of the diffusion of radicals and their subsequent chemical reactions.


Time (s)
Ionizing Radiation
H_2O
0
excitation
ionization
Physical stage
H_2O^*
$H_2O^+ + e^-$
10^{-15} s
H_2O
H_2O^*
Physico-chemical stage
$H_2 + O(^1D)$
H_2O
$HO^\bullet + H^-$
H_2O
H_2O
$H^\bullet + HO^\bullet$
$H_2 + 2\ HO^\bullet$
$HO^\bullet + H_3O^+$
$HO^\bullet + H_2 + OH^-$
e^-_{aq}
10^{-12} s
Chemical stage
10^{-6} s
e^-_{aq}, $H^\bullet$, $HO^\bullet$, $HO_2^\bullet$, OH^-, H_3O^+, H_2, H_2O_2

OXIDATION AND REDUCTION

- **Oxidation:** the loss of electrons. The electrons are transferred to the oxidizing agent.
- **Reduction:** the addition of electrons. May involve the addition of electron only, or the addition of hydrogen together with an electron.

HUMAN CELLS


1 CHEMICAL LEVEL
Atoms
Molecule (DNA)
2 CELLULAR LEVEL
Smooth muscle cell
3 TISSUE LEVEL
Smooth muscle tissue
Serous membrane
4 ORGAN LEVEL
Smooth muscle tissue layers
Stomach
Epithelial tissue
5 SYSTEM LEVEL
Esophagus
Liver
Stomach
Pancreas
Gallbladder
Small intestine
Large intestine
Digestive system
6 ORGANISMAL LEVEL

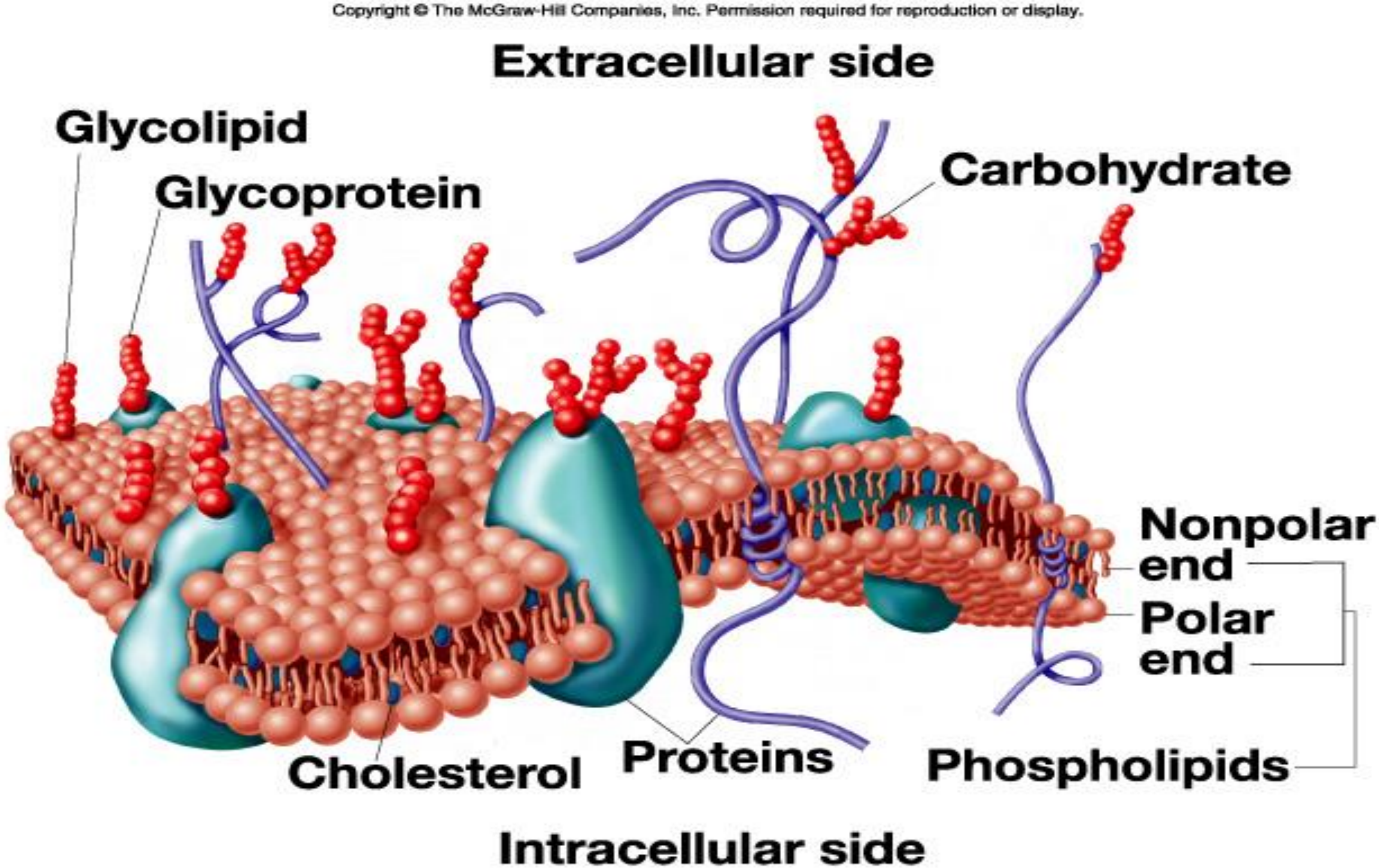
Cell is the basic unit of structure and function of the body. About 200 different types of specialized cells carry out a multitude of functions that help each system contribute to the homeostasis of the entire body. The principal parts of cells are:

- Plasma membrane.
- Nucleus.
- Cytoplasm and organelles.

1. PLASMA MEMBRANE

Is the selectively permeable outer coating of the cell and contains the cytoplasm, substances and the organelle within it. It Consist of:

1. **Double layer of phospholipids** due to hydrophobic/hydrophilic parts they restrict passage of H_20 and H_20 soluble ions.
2. **Proteins** span or partially span the membrane they provide structural support, transport molecules, serve as receptors.
3. **Negatively charged carbohydrates** attach to the outer surface.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Extracellular side
Glycolipid
Glycoprotein
Carbohydrate
Nonpolar end
Polar end
Cholesterol
Proteins
Phospholipids
Intracellular side

2. NUCLEUS

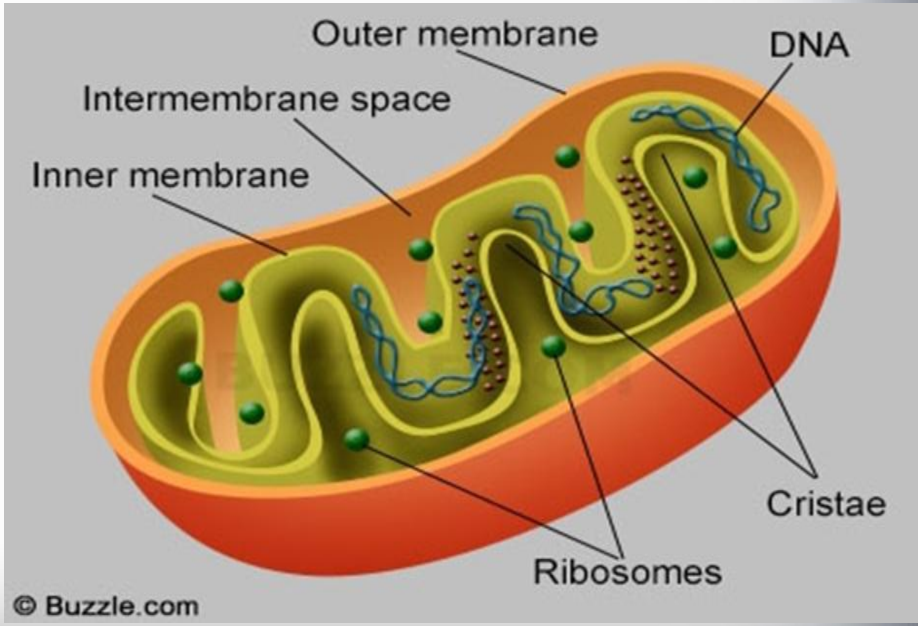
- Its a large spheroid body and the largest of the organelles.
- It contains genes, collections of DNA. The DNA which allows for replication of the cell. Within the nucleus is an area known as the **nucleoli**. It is not enclosed by a membrane but is centers for production of ribosomes.

3. Cytoplasm and Organelles

- Consists of all the cellular contents between the plasma membrane and the nucleus.
- This part has two components: cytosol and organelles.
- **Cytosol**: means the fluid portion of cytoplasm. That contains (water, dissolved solutes, and suspended particles). Surrounded by cytosol are several different types of organelles.

MITOCHONDRIA

- Sites for **energy** production of all cells; its produces a high-energy compound called **ATP** (adenosine triphosphate) which can be used as a simple energy source elsewhere, they contain **own DNA** and can reproduce themselves. They have:
- Outer membrane: smooth.
- Inner membrane: cristae.



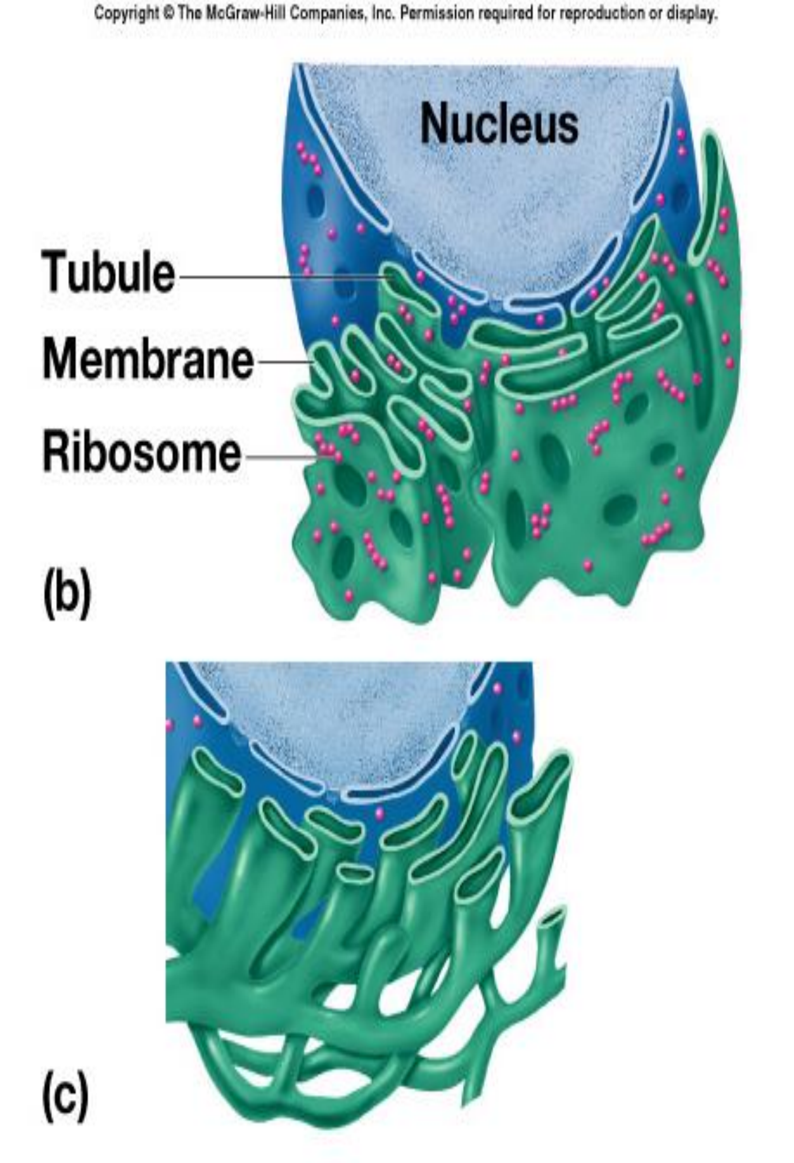
Endoplasmic Reticulum (ER)

✓ Granular (rough) ER:

- holds ribosomes on surface.
- active the protein synthesis in cells.

✓ Agranular (smooth) ER:

- Provides site for enzyme reactions in steroid hormone production and inactivation.
- Storage of Ca^{+2} in striated muscle cells



Ribosomes

- Protein factories: The proteins produced according to genetic information contained in mRNA.
- Located in cytoplasm and on the surface of endoplasmic reticulum ER.

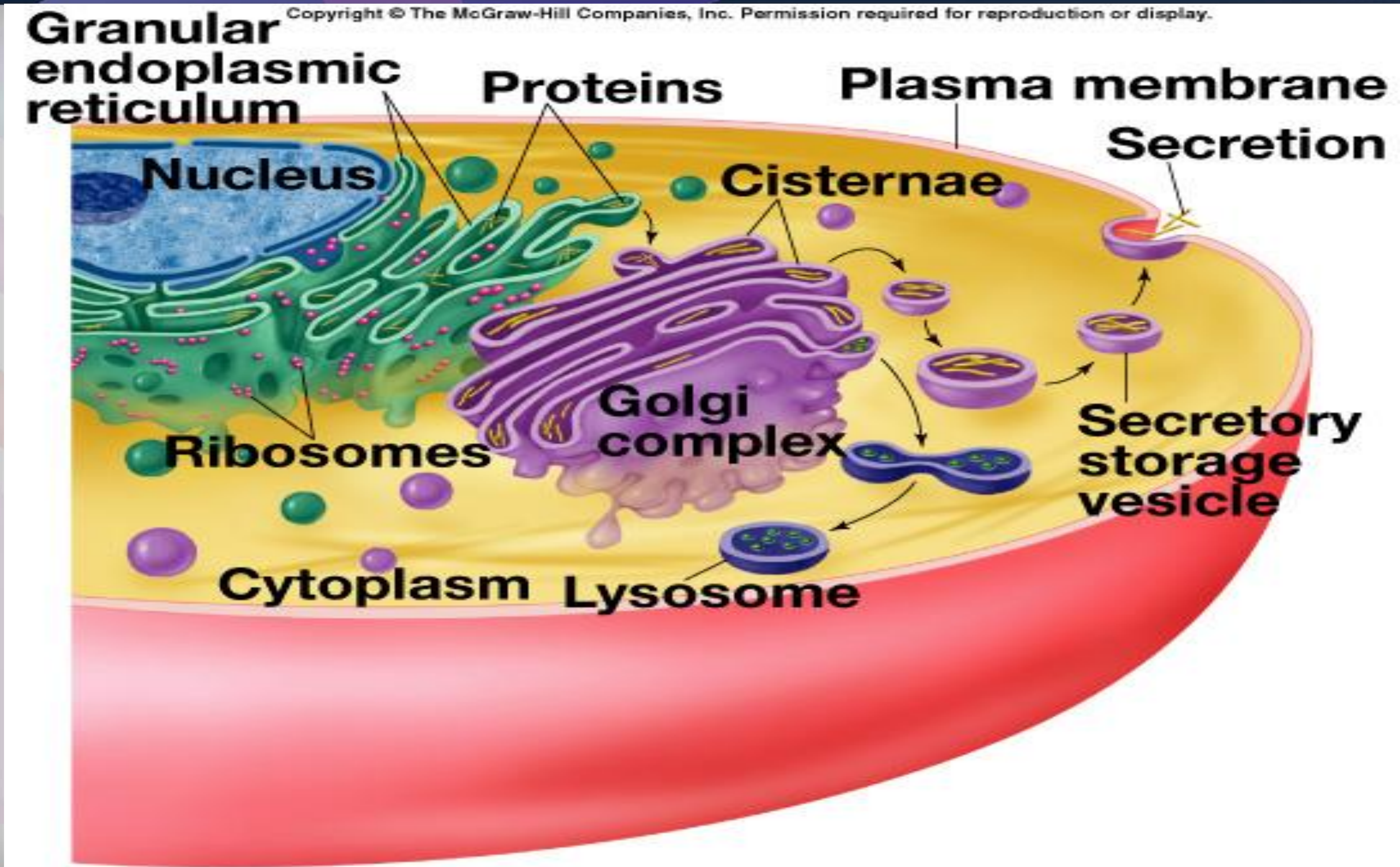
GOLGI APPARATUS

- Is a collection of flat vesicles. It is closely associated with the ER, the substances produced in the ER are transported to the Golgi apparatus.

❖ One side for entry of vesicles from ER that contain cellular products.

❖ Other site faces towards plasma membrane and releases vesicles of chemically modified products.

- Modifies proteins, separates according to destination, and packages into vesicles.



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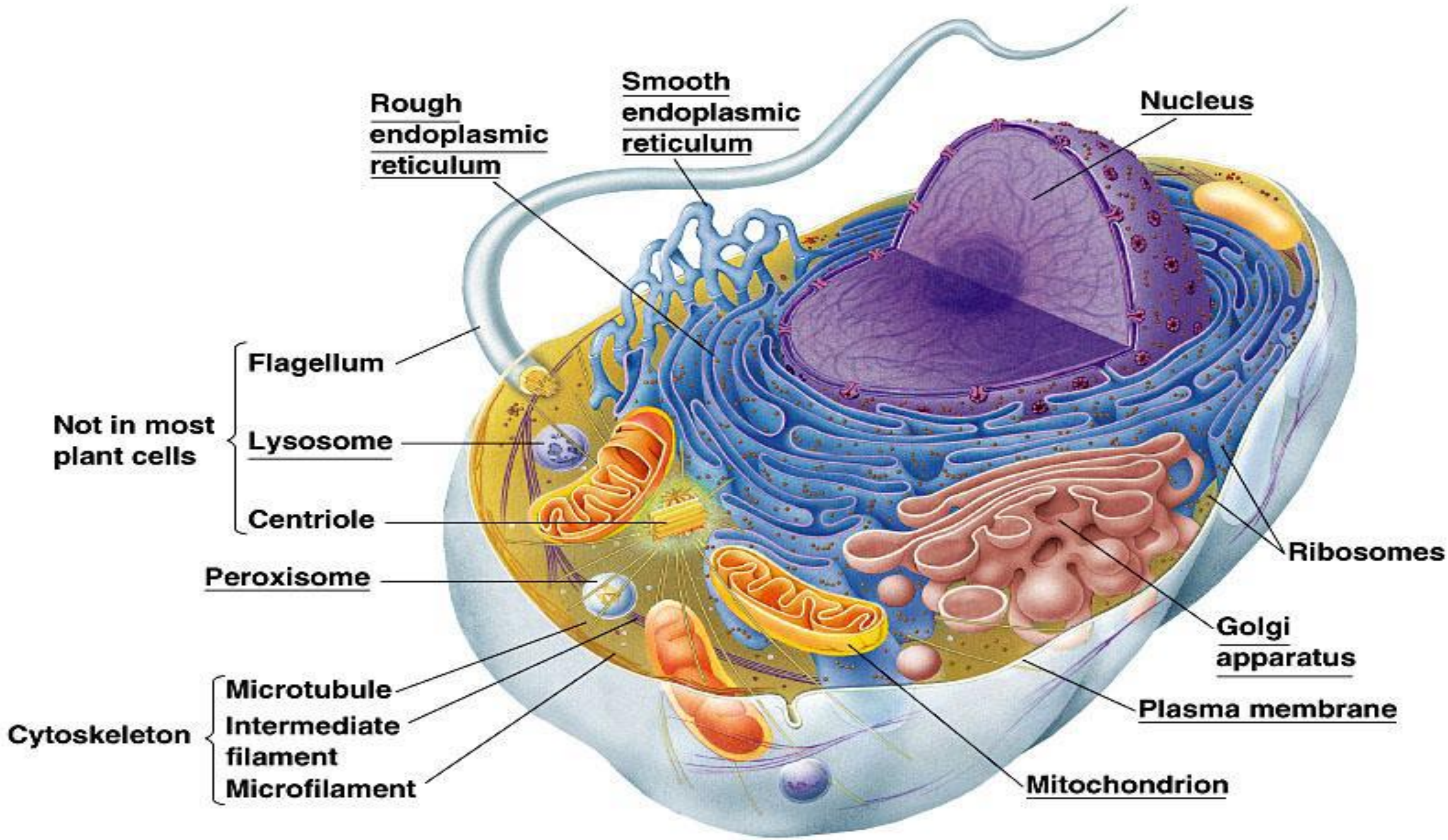
Granular endoplasmic reticulum
Proteins
Plasma membrane
Secretion
Nucleus
Cisternae
Golgi complex
Secretory storage vesicle
Ribosomes
Cytoplasm
Lysosome

LYSOSOMES

Are vesicles that break off from the Golgi apparatus. Lysosomes contain enzymes that help with the digestion of nutrients in the cell and break down any cellular debris or invading microorganisms like bacteria.

For example the secretory vesicles of the pancreatic cell release digestive enzymes which help with the digestion of nutrients in the gut.


Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Nucleus
Flagellum
Not in most plant cells
Lysosome
Centriole
Peroxisome
Microtubule
Cytoskeleton
Intermediate filament
Microfilament
Ribosomes
Golgi apparatus
Plasma membrane
Mitochondrion

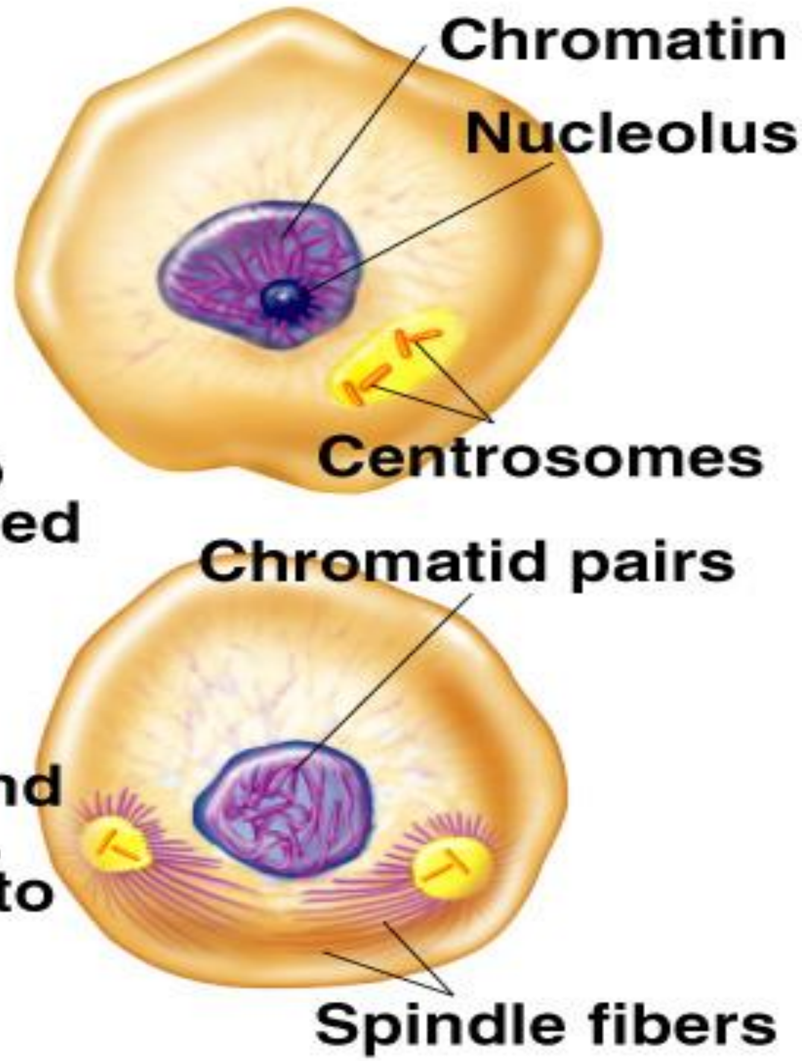
CELL MITOSIS

(a) Interphase

- The chromosomes are in an extended form and seen as chromatin in the electron microscope.
- The nucleus is visible

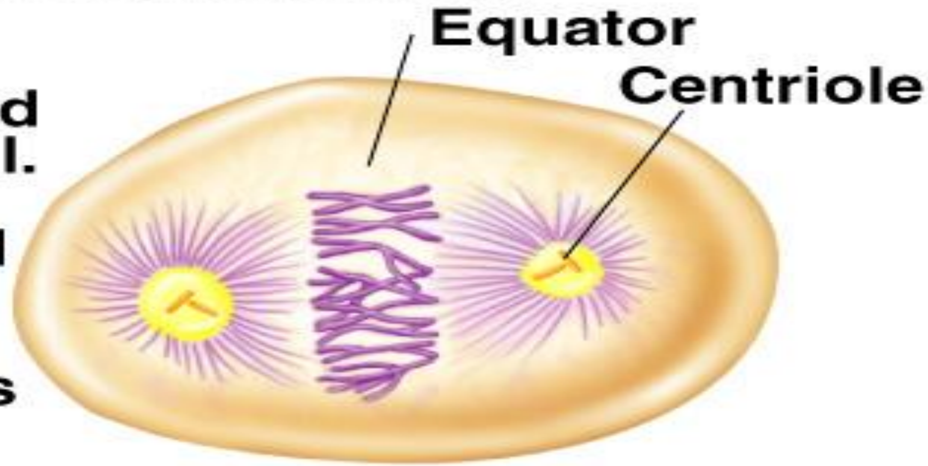
(b) Prophase

- The chromosomes are seen to consist of two chromatids joined by a centromere.
- The centrioles move apart toward opposite poles of the cell.
- Spindle fibers are produced and extend from each centrosome.
- The nuclear membrane starts to disappear.
- The nucleolus is no longer visible.



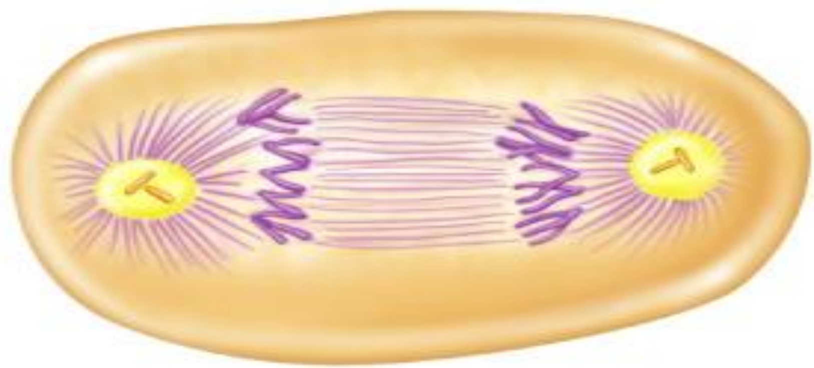
(c) Metaphase

- The chromosomes are lined up at the equator of the cell.
- The spindle fibers from each centriole are attached to the centromeres of the chromosomes.
- The nuclear membrane has disappeared.



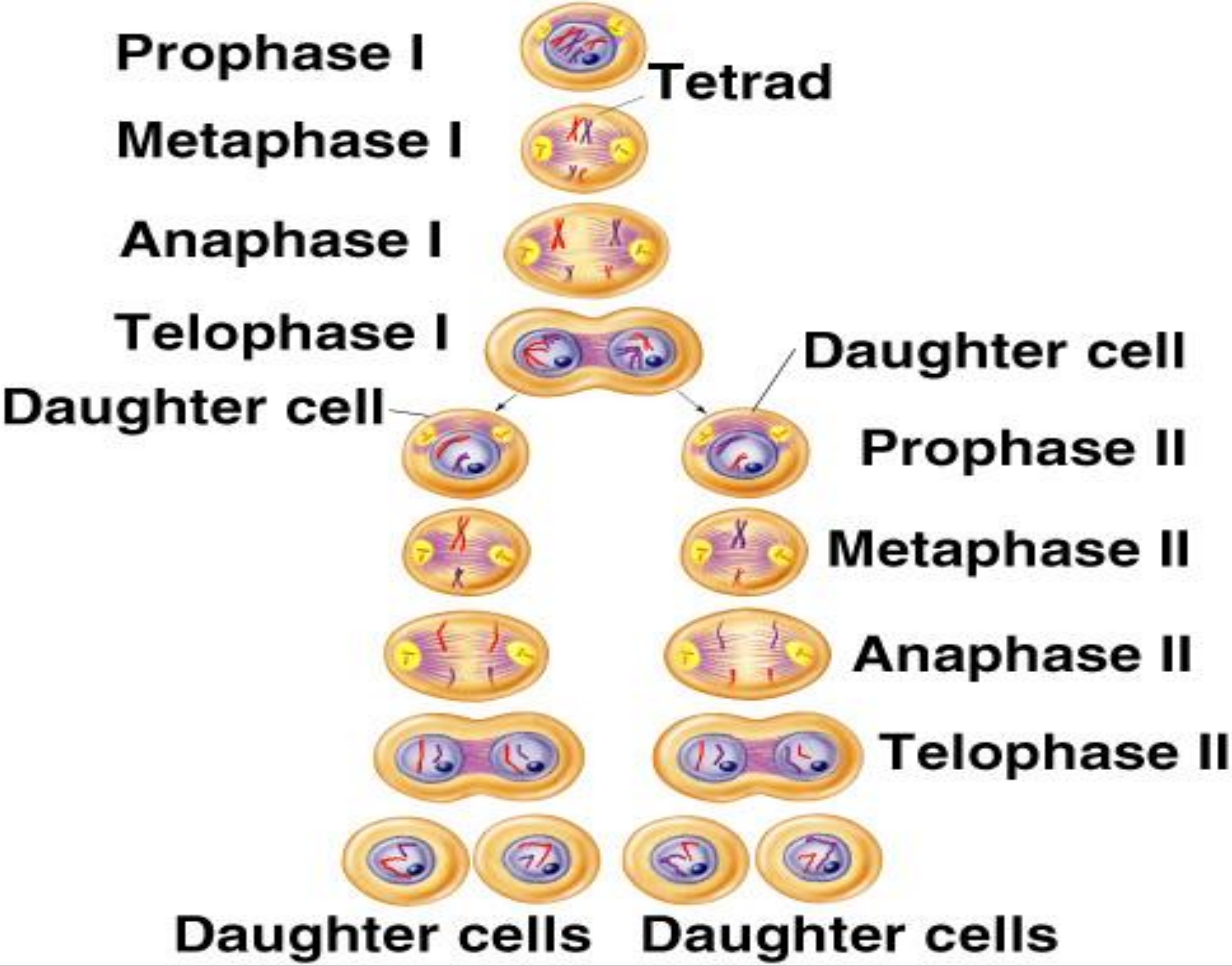
(d) Anaphase

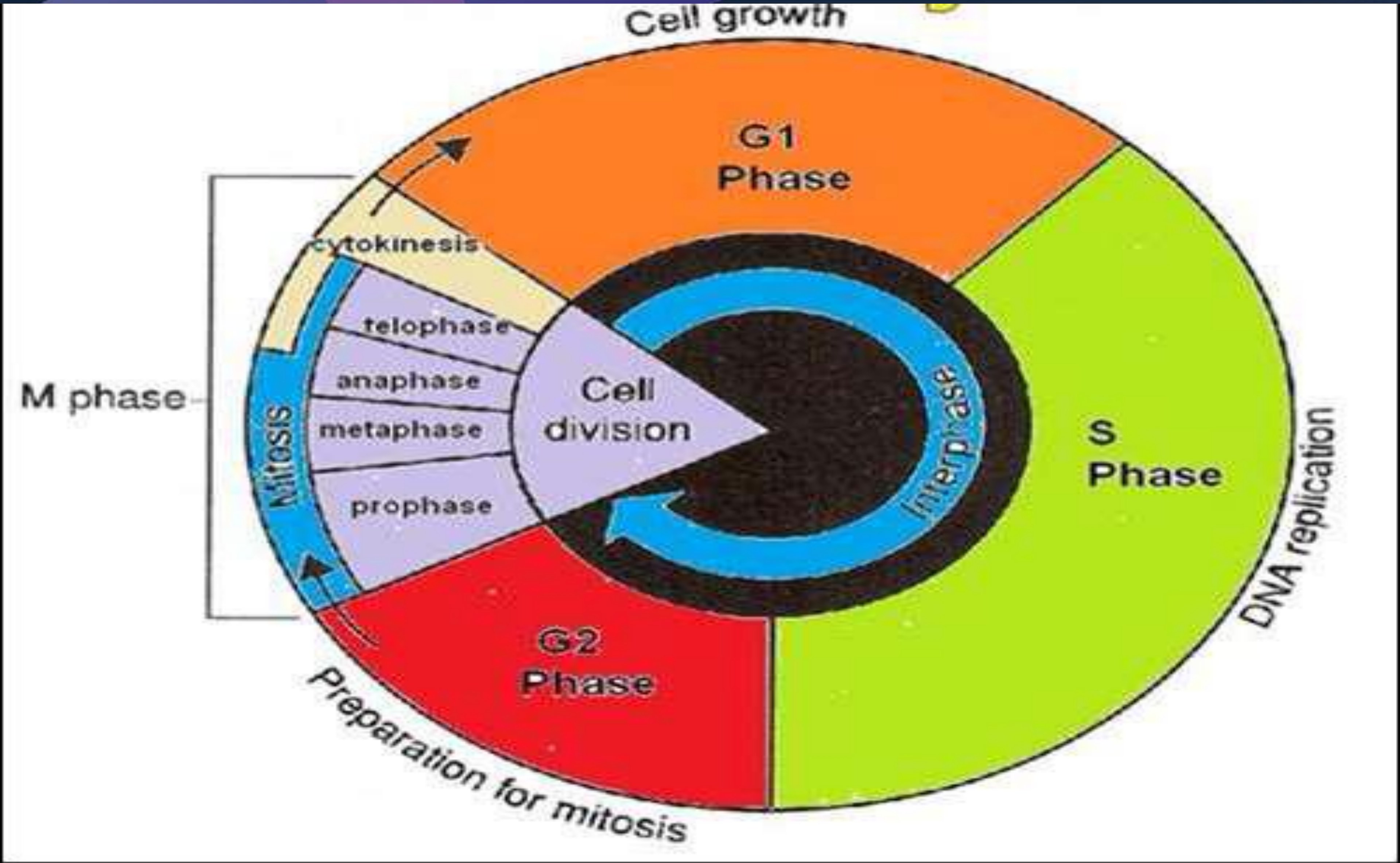
- The centromere split, and the sister chromatids separate as each is pulled to an opposite pole.



(e) Telophase:

- Division of cytoplasm, producing 2 daughter cells.


Prophase I
Tetrad
Metaphase I
Anaphase I
Telophase I
Daughter cell
Daughter cell
Prophase II
Metaphase II
Anaphase II
Telophase II
Daughter cells
Daughter cells


Cell growth
G1
Phase
S
Phase
DNA replication
G2
Phase
Preparation for mitosis
M phase
cytokinesis
telophase
anaphase
metaphase
prophase
Mitosis
Cell
division
Interphase

Radiation Effects on Cell Cycle

- The potential biological effect and damages caused by Radiation depend on condition of Radiation exposure.
- Radiation can cause immediate effect but also long-term effect which may occur in years or several generations later. Biological effect of Radiation results from both direct and indirect action of Radiation. Direct action is based on direct interaction between Radiation particles and complex body molecule.

Indirect is more complex and depend heavily on energy lose effect of Radiation in the body, tissue and the subsequent chemistry. Biological Effects are of two types

a)Deterministic Effect

b)Stochastic Effect

DETERMINISTIC EFFECT

These effects depend on time of exposure, doses, type of Radiation. It **has a threshold** of doses below which the effect does not occur the threshold may be vary from person to person. Deterministic effects are those responses which increase in severity with increased dose if the dose increases the severity of an effect increases. All early effect and most tissue late effect is deterministic. deterministic effect includes Acute radiation Sickness and chronic radiation Sickness

STOCHASTIC EFFECT

Is those effect which occur when a person receives a high dose of radiation. These effects have an increase probability of occurrence with increase dose. There **is no threshold dose** below which is a stochastic effect cannot occur. Severity does not depend on magnitude of absorbed doses these effects occur by chance.

Stochastic effect is of two types (somatic stochastic effect and Genetic effect)