Introduction to Health Physics

1. Introduction

Health Physics is a branch of applied physics concerned with the protection of people and the environment from the harmful effects of ionizing radiation, while allowing its beneficial uses in medicine, industry, and research.

With the widespread use of radiation in medical imaging, nuclear power, research laboratories, and industry, understanding radiation safety has become essential for physicists, engineers, and health professionals.

2. What Is Health Physics?

Health Physics can be defined as:

The science of radiation protection, involving the measurement, evaluation, and control of radiation exposure to humans and the environment.

Objectives of Health Physics:

- Protect workers, patients, and the public from unnecessary radiation exposure
- Ensure radiation is used safely and effectively
- Apply scientific principles to minimize biological damage

3. Types of Radiation

Radiation is energy transmitted through space or matter.

3.1 Non-Ionizing Radiation

- Does not have enough energy to remove electrons from atoms for examples:
  - Radio waves
 - Microwaves
  - Infrared
  - Visible light

Example:
Mobile phone radiation is non-ionizing and mainly causes heating effects, not ionization.

3.2 Ionizing Radiation

- Has enough energy to ionize atoms and molecules

- More dangerous biologically

Main types:

Radiation	Charge	Penetration	Shielding
Alpha (α)	+2	Very low	Paper, skin
Beta (β)	−1	Medium	Plastic, aluminum
Gamma (γ)	0	Very high	Lead, concrete
Neutrons	0	Very high	Water, concrete
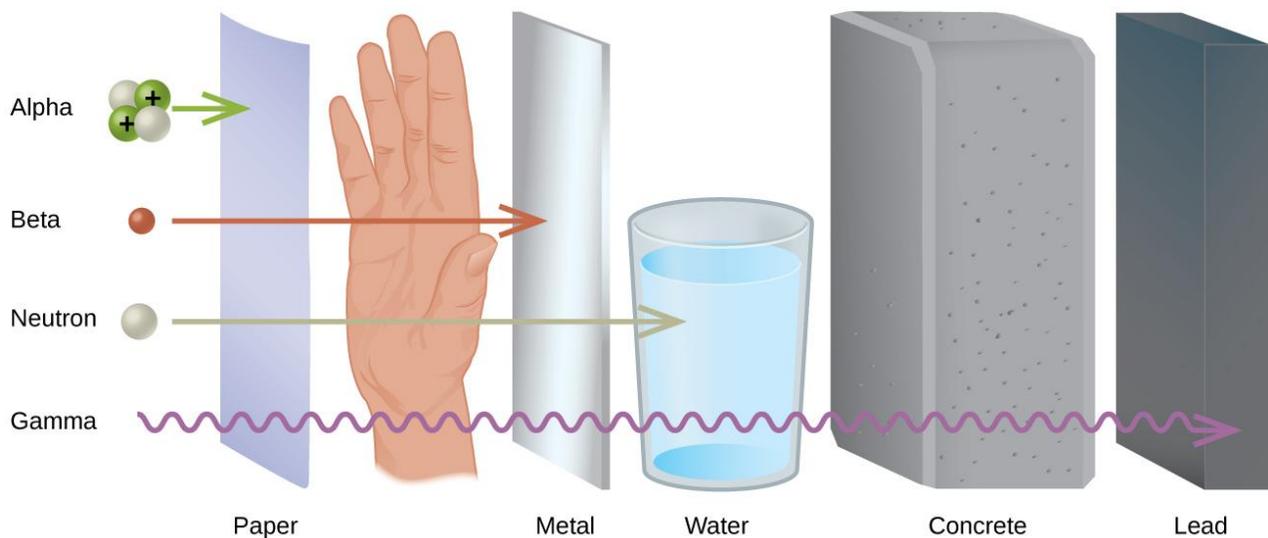
The ability of different types of radiation to pass through material is shown. From least to most penetrating, they are alpha < beta < neutron < gamma.

Example:
Alpha particles cannot penetrate skin, but if inhaled (e.g., radon gas), they can cause serious lung damage.

4. Sources of Radiation

4.1 Natural Sources

- Cosmic rays

- Radon gas

- Natural radioactive elements in soil and food

Example: Radon contributes the largest fraction of natural radiation dose to humans.

4.2 Artificial Sources

- Medical X-rays and CT scans

- Nuclear reactors

- Industrial radiography

- Research laboratories

Example: A CT scan delivers a much higher dose than a standard chest X-ray, but provides detailed diagnostic information.

5. Interaction of Radiation with Matter

Ionizing radiation transfers energy to atoms in biological tissue, causing:

- Ionization

- Excitation

- Molecular bond breakage

These interactions can damage **DNA**, proteins, and cells.
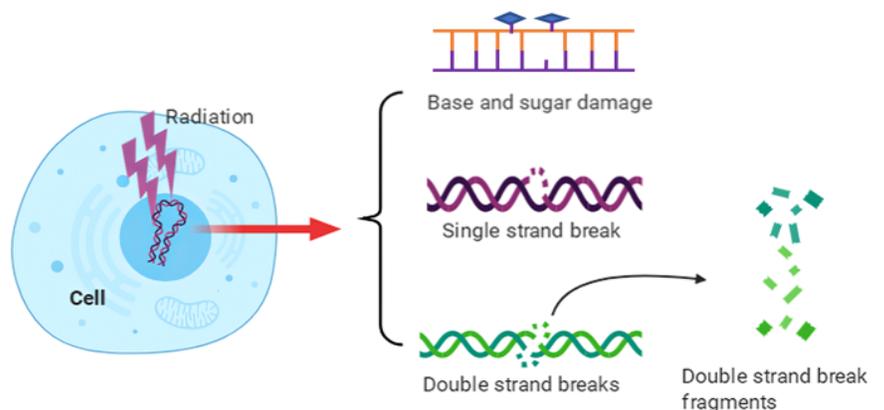
DNA damage induced by ionizing radiation. The major types of DNA damage induced by IR include base and sugar damage, single-strand breaks, double-strand breaks, clustered DNA damage, and covalent interstrand or interstrand crosslinking.

x-ray and γ-ray interactions.

(A) Primary, unattenuated beam does not interact with material.

(B) Photoelectric absorption results in total removal of incident x-ray photon with energy greater than binding energy of electron in its shell, with excess energy distributed to kinetic energy of photoelectron.

(C) Rayleigh scattering is interaction with electron (or whole atom) in which no energy is exchanged and incident x-ray energy equals scattered x-ray energy with small angular change in direction.
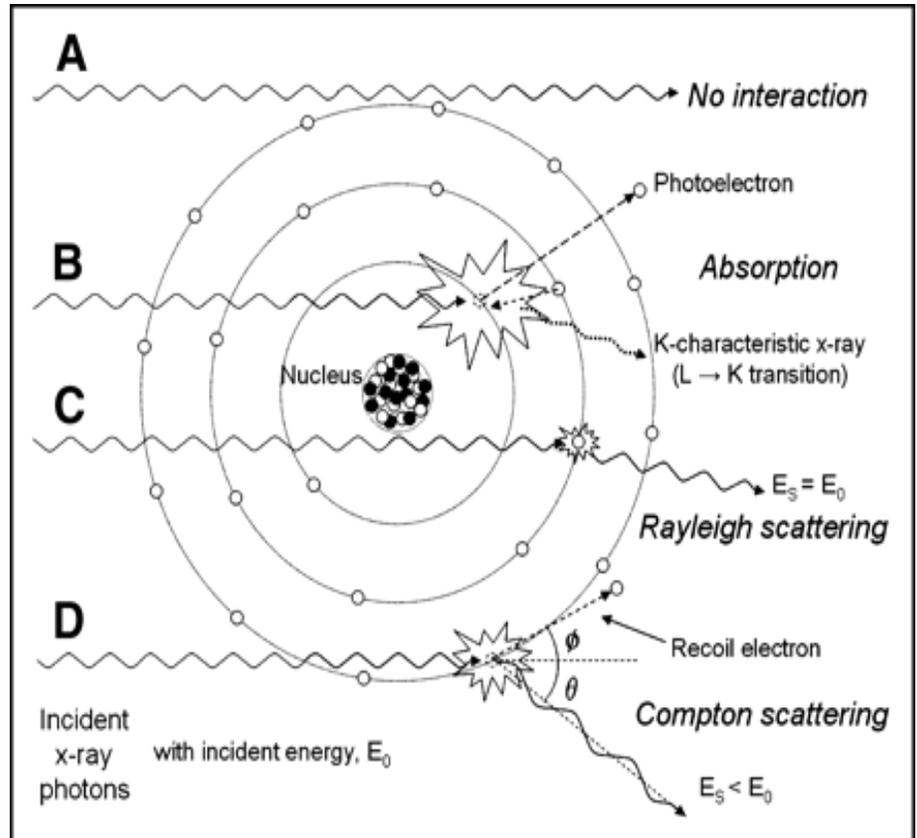
(D) Compton scattering interactions occur with essentially unbound electrons, with transfer of energy shared between recoil electron and scattered photon, with energy exchange described by Klein–Nishina formula.

6. Biological Effects of Radiation

6.1 Deterministic Effects

- Have a threshold dose
- Severity increases with dose

6.2 Stochastic Effects

- No threshold
- Probability increases with dose

Even small doses may increase cancer risk, which is why dose minimization is critical.

Deterministic effects
(Hair loss, cataract, skin injury, etc.)

When a number of people were exposed to the same dose of radiation and certain symptoms appear in 1% of them, said dose is considered to be the threshold dose.
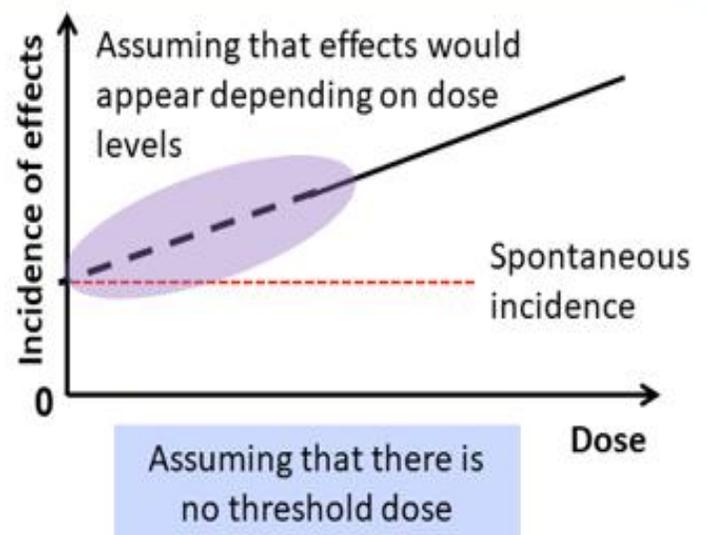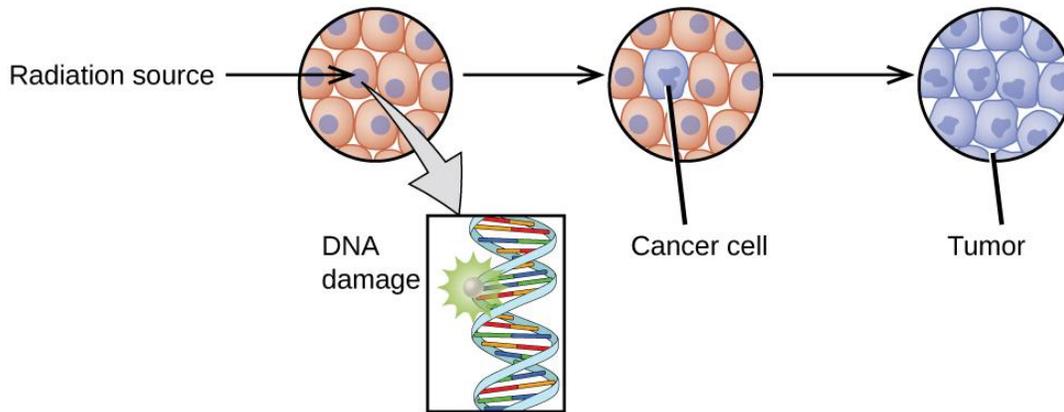(2007 Recommendations of the International Commission on Radiological Protection (ICRP))

Incidence of effects

No effects

0

Threshold dose
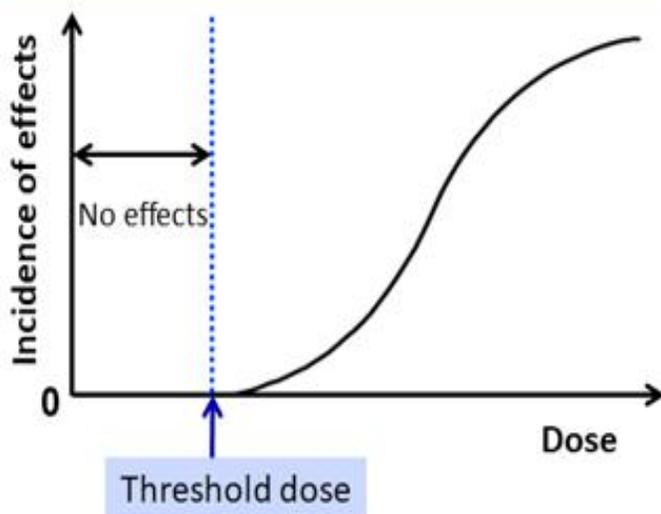
Dose

Stochastic effects
(Cancer, leukemia, hereditary effects, etc.)

Effects of radiation exposure under certain doses are not clear because effects of other cancer-promoting factors such as smoking and drinking habits are too large. However, the ICRP specifies the standards for radiological protection for such low-dose exposures, assuming that they may have some effects as well.

Incidence of effects

Assuming that effects would appear depending on dose levels

Spontaneous incidence

0

Assuming that there is no threshold dose

Dose

Radiation can harm biological systems by damaging the DNA of cells. If this damage is not properly repaired, the cells may divide in an uncontrolled manner and cause cancer.

7. Radiation Dose and Units

7.1 Absorbed Dose

- Unit: Gray (Gy)
- Measures energy absorbed per unit mass

7.2 Equivalent Dose

- Unit: Sievert (Sv)
- Takes radiation type into account

7.3 Effective Dose

- Also in Sievert (Sv)
- Considers tissue sensitivity

Example: The lungs are more radiosensitive than muscles, so the same absorbed dose leads to a higher effective dose.

8. Principles of Radiation Protection

8.1 ALARA Principle (As Low As Reasonably Achievable)

- Radiation exposure should be minimized considering economic and social factors.

8.2 Time

- Reduce time near radiation sources

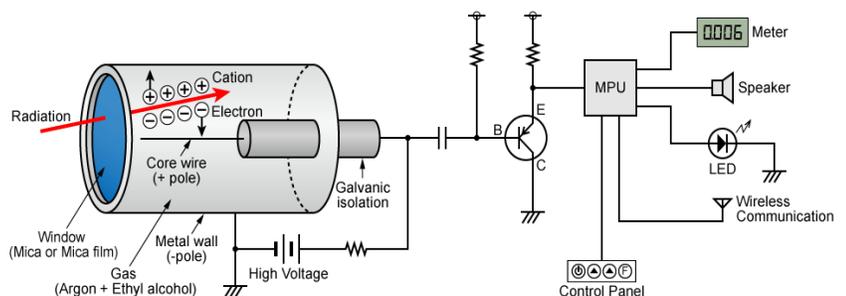Example: Radiology staff rotate duties to limit individual exposure.

8.3 Distance

- Radiation intensity decreases with distance

- Follows the inverse square law

Example: Standing twice as far from a source reduces exposure to one-quarter.

8.4 Shielding

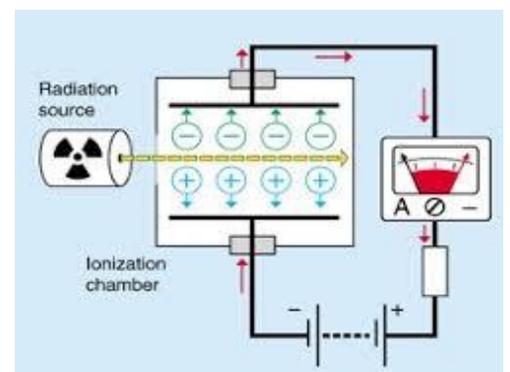| Radiation	Shield
Alpha	Paper
Beta	Plastic
Gamma	Lead
Neutrons	Water

9. Radiation Monitoring and Detection

Common instruments:

- Geiger-Müller counters

- Ionization chambers

- Thermoluminescent dosimeters (TLDs)

Example: Workers wear personal dosimeters to track

cumulative radiation exposure.

Numerical Problems in Health Physics (with Solutions)

Problem 1: Absorbed Dose Calculation

A tissue of mass 2 kg absorbs 0.01 J of energy from ionizing radiation.

Solution

Absorbed dose is given by: $\mathbf{D = \dfrac{E}{m}}$

Where:

- $\mathbf{E = 0.01\ J}$, $\mathbf{m = 2\ kg}$ **then** $\mathbf{D = \dfrac{0.01}{2} = 0.005\ Gy}$

- $\boxed{\mathbf{D = 5 \times 10^{-3}\ Gy}}$

Problem 2: Equivalent Dose

An organ receives an absorbed dose of 0.02 Gy from alpha particles.

Radiation weighting factor for alpha particles: $\mathbf{w_R = 20}$

Solution

Equivalent dose: $\mathbf{H = D \times w_R}$

$$\mathbf{H = 0.02 \times 20 = 0.4\ Sv}$$

Problem 3: Effective Dose

The lungs receive an equivalent dose of 0.1 Sv.

The tissue weighting factor for lungs is: $\mathbf{w_T = 0.12}$

Solution

Effective dose: $\mathbf{E = H \times w_T}$

$$\mathbf{E = 0.1 \times 0.12 = 0.012\ Sv}$$
$$\boxed{\mathbf{E = 12\ mSv}}$$

Problem 4: Inverse Square Law

A radiation intensity of 800 µSv/h is measured at a distance of 1 m from a point source.

What is the intensity at 4 m?

Solution

Inverse square law: $I_2 = I_1 \left(\frac{r_1}{r_2}\right)^2$

$$I_2 = 800 \left(\frac{1}{4}\right)^2$$

$$I_2 = 800 \times \frac{1}{16} = 50 \text{ µSv/h}$$

Problem 5: Time Reduction Principle

A worker is exposed to a radiation field of 200 µSv/h for 3 hours.

(a) Calculate the received dose

(b) What is the dose if exposure time is reduced to 30 minutes?

Solution

(a) Dose = Dose rate × time

$\qquad = 200 \times 3 = 600 \text{ µSv}$

(b) $\qquad = 200 \times 0.5 = 100 \text{ µSv}$

Problem 6: Annual Dose Comparison

The average annual natural background radiation dose is 2.4 mSv.

A patient receives:

- One chest X-ray: 0.1 mSv

- One CT scan: 7 mSv

(a) Total medical dose

(b) How many times larger is this than the annual background dose?

Solution

(a) $0.1 + 7 = 7.1$ mSv

(b) $\frac{7.1}{2.4} \approx 2.96$

> $\approx$ **3 times background dose**

Problem 7: Shielding and Protection Conceptual Numerical

A gamma radiation field of 10 mSv/h is reduced by a lead shield that attenuates the intensity by 90%.

Solution

Remaining intensity:

$$I = 10 \times (1 - 0.90) = 1 \text{ mSv/h}$$

Problem 8: Worker Dose Limit

The recommended occupational dose limit is 20 mSv/year.

A worker receives 2 mSv/month.

(a) Annual dose

(b) Is the limit exceeded?

Solution

(a) $2 \times 12 = 24$ mSv/year

(b) $24 > 20 \Rightarrow$ limit exceeded