MEDICAL PHYSICS (24PH203)

UNIT 1

UNIT I: EFFECT OF IONIZING RADIATION

Production, properties and classification of electromagnetic radiation- Different sources of radiation - Photoelectric effect- Compton Scattering- Coherent scattering- Infrared radiation and its biological applications-UV radiation and its applications- damaging effects of UV light - Radiometry and photometry- Electrical impedance and Biological Impedance-- Artificial Intelligence in Radiotherapy.

Q1. Production of Electromagnetic Radiation

Electromagnetic radiation (EMR) is produced when charged particles, such as electrons, are accelerated or decelerated. This process results in the generation of energy in the form of electromagnetic waves that travel through space. The production of EMR can occur through various mechanisms, each with its own characteristics and applications. The most common processes include: acceleration of charged particles, atomic and molecular transitions, and thermal radiation.

1. Acceleration of Charged Particles:

When charged particles, such as electrons, accelerate or decelerate, they disturb the electromagnetic field around them, which results in the emission of electromagnetic radiation.

The key methods include:

a. Electromagnetic Radiation from Accelerating Electrons

When an electron moves through space and accelerates (e.g., in an electric field or due to external forces), it generates a disturbance in the electric and magnetic fields. This disturbance propagates outward as electromagnetic radiation.

Example: In radio transmitters, alternating current accelerates electrons back and forth in an antenna, producing radio waves.

Applications: Radio transmission, particle accelerators (e.g., synchrotrons), and broadcasting.

b. Bremsstrahlung Radiation (Braking Radiation)

When high-energy electrons are decelerated by the electromagnetic field of atomic nuclei, they lose kinetic energy, which is emitted as electromagnetic radiation, typically in the X-ray or gamma-ray regions.

Example: In X-ray tubes, electrons are accelerated and then suddenly decelerated upon hitting a target, emitting X-rays.

Applications: X-ray production in medical imaging, high-energy physics experiments.

2. Atomic and Molecular Transitions

Electromagnetic radiation is also produced when atoms or molecules undergo transitions between different energy states. These transitions can be caused by changes in the energy levels of electrons within atoms or by molecular vibrations and rotations.

a. Electron Transitions in Atoms

In atoms, electrons occupy specific energy levels. When electrons absorb energy (e.g., from heat or photons), they may jump to a higher energy level. When they fall back to a lower energy level, they release the excess energy in the form of electromagnetic radiation. This is often seen in the visible and ultraviolet (UV) spectra.

Example: Fluorescence and phosphorescence occur when electrons transition between energy levels in atoms.

Applications: Lasers, neon signs, and atomic spectroscopy.

b. Molecular Vibrations and Rotations

In molecules, electromagnetic radiation is often produced when atoms vibrate or rotate within a molecule. These transitions typically occur in the infrared (IR) and microwave regions.

Example: The vibrational modes of molecules, like those in carbon dioxide (CO_2), produce infrared radiation when they vibrate.

Applications: Infrared spectroscopy, microwave ovens, and thermal radiation.

c. Spontaneous and Stimulated Emission (Laser Production)

Electromagnetic radiation is also produced in lasers through processes called spontaneous emission (where an electron in a higher energy state naturally decays to a lower energy state, emitting a photon) and stimulated emission (where an external photon causes an electron to decay and release a photon of the same energy).

Example: Lasers that produce highly coherent light, like in CD players or medical lasers.

Applications: Communication systems, barcode scanners, medical devices, and entertainment (laser light shows).

3. Thermal Radiation

Any object with a temperature above absolute zero emits electromagnetic radiation in the form of thermal radiation. The type of radiation emitted depends on the object's temperature.

a. Blackbody Radiation

A blackbody is an idealized object that absorbs all incident radiation and emits electromagnetic radiation in a spectrum that depends only on its temperature. This radiation spans the infrared to visible spectrum as the temperature increases.

Example: The Sun emits a spectrum of electromagnetic radiation due to its high temperature (~5,500°C).

Applications: The study of blackbody radiation led to the development of Planck's law and Wien's displacement law, which are fundamental to understanding the radiation emitted by objects in various industries, including the study of stellar bodies.

4. Radiation Due to Accelerating Charges in External Fields

Electromagnetic radiation can also be produced by the interaction of charged particles with external electromagnetic fields.

a. Transition Radiation

This occurs when charged particles move through a boundary between two different materials. The acceleration of the particles at the boundary generates radiation.

Example: The production of transition radiation in particle detectors.

Applications: Particle physics, accelerator physics.

5. Non-Linear Optical Effects (Second Harmonic Generation, etc.)

When high-intensity electromagnetic radiation interacts with nonlinear optical materials, it can produce electromagnetic radiation at different frequencies. This can occur due to processes like second harmonic generation (SHG), where two photons combine to form a new photon with double the frequency (half the wavelength).

Example: Using a laser to generate ultraviolet light from an infrared source through second harmonic generation in crystals.

Applications: Laser technology, high-resolution spectroscopy, and nonlinear optics.

Q2. Properties of Electromagnetic Radiation

Electromagnetic radiation is a form of energy propagated in the form of electromagnetic waves. The important properties are given below:

1. Electromagnetic radiation consists of time varying electric field and magnetic field, which are mutually perpendicular to each other and also perpendicular to the direction of propagation.
2. Electromagnetic waves are transverse in nature and hence they can exhibit polarization.

3. Electromagnetic radiation does not require any material medium for its propagation and can travel through vacuum.
4. All electromagnetic waves propagate in vacuum with the same velocity, known as the velocity of light,

$$C=3 \times 10^8 \text{ m/s}$$

5. In a material medium, the velocity of electromagnetic radiation depends on the refractive index of the medium and is less than that in vacuum.
6. The electric field intensity E and magnetic field intensity B are related by

$$E = cB$$

7. Electromagnetic radiation carries energy and momentum, and the flow of energy is given by the Poynting vector.
8. Electromagnetic waves exert radiation pressure when incident on a surface due to the transfer of momentum.
9. Electromagnetic radiation exhibits wave–particle duality.
10. The energy of a photon is directly proportional to its frequency and is given by $E = h\nu$
11. Electromagnetic radiation covers a wide range of wavelengths and frequencies called the electromagnetic spectrum, extending from radio waves to gamma rays.
12. Electromagnetic radiation can undergo reflection, refraction, diffraction, interference and scattering.
13. High-frequency electromagnetic radiation such as X-rays and gamma rays has ionizing power.

Q3. Classification of Electromagnetic Radiation

Electromagnetic radiation consists of oscillating electric and magnetic fields which propagate through free space with the velocity of light. Based on wavelength (λ), frequency (ν), and energy, electromagnetic radiation is classified into different regions forming the electromagnetic spectrum.

Electromagnetic Spectrum

The electromagnetic spectrum is the complete range of electromagnetic waves arranged in order of increasing frequency or decreasing wavelength.

Electromagnetic radiation is classified as follows:

1. Radio Waves

Wavelength: > 1 m

Frequency: $< 3 \times 10^8$ Hz

Characteristics:

Longest wavelength

Lowest frequency and energy

Applications:

Radio broadcasting

Television transmission

Wireless communication

2. Microwaves

Wavelength: 1 mm to 1 m

Frequency: 3×10^8 to 3×10^{11} Hz

Characteristics:

Can penetrate clouds and fog

Applications:

RADAR

Satellite communication

Microwave ovens

3. Infrared Rays (IR)

Wavelength: 700 nm to 1 mm

Frequency: 3×10^{11} to 4×10^{14} Hz

Characteristics:

Emitted by hot bodies

Produces heating effect

Applications:

Thermal imaging

Night vision devices

Remote controls

4. Visible Light

Wavelength: 400 nm to 700 nm

Frequency: 4×10^{14} to 7.5×10^{14} Hz

Characteristics:

Only part of the spectrum visible to human eye

Consists of seven colours (VIBGYOR)

Applications:

Vision

Optical instruments

Photography

5. Ultraviolet Rays (UV)

Wavelength: 10 nm to 400 nm

Frequency: 7.5×10^{14} to 3×10^{16} Hz

Characteristics:

Higher energy than visible light

Causes fluorescence

Applications:

Sterilization

Detection of forged currency

Medical diagnostics

6. X-Rays

Wavelength: 0.01 nm to 10 nm

Frequency: 3×10^{16} to 3×10^{19} Hz

Characteristics:

High penetrating power

Ionizing radiation

Applications:

Medical imaging

Crystal structure analysis

Industrial radiography

7. Gamma Rays

Wavelength: < 0.01 nm

Frequency: $> 3 \times 10^{19}$ Hz

Characteristics:

Shortest wavelength

Highest energy

Highly penetrating

Applications:

Cancer treatment (radiotherapy)

Nuclear research

Sterilization of medical equipment

Q 4. Sources of Radiation

There are many natural sources of radiation which have been present since the earth was formed. The naturally occurring sources contribute about four to five times as much to your exposure as the man-made sources.

1. Natural Sources of Radiation:

The ionizing radiation from natural sources is called natural background radiation. The three major sources of naturally occurring radiation are:

(i) Cosmic Radiation:

Charged particles from the sun and stars interact with the earth's atmosphere and magnetic field to produce a shower of cosmic radiation consists of positively charged particles, as well as gamma radiation The exposure of an individual to cosmic rays is greater at higher elevations that at sea level.

(ii) Terrestrial Radiation:

There are natural sources of radiation in the ground, rocks, building materials and drinking water supplies. When the earth was formed, it contained many radioactive material such as natural radium, uranium and thorium. Some of these materials are ingested with food and water, while others, such as radon, are inhaled.

(iii) Internal Radiation:

In addition to the cosmic and terrestrial sources, all people also have radioactive potassium-40, tritium (H-3), Carbon-14, lead-210 and other isotopes inside their bodies from birth. The total average dose of natural radionuclides of potassium 40 in our body is about 40 mrem/year.

2. Man-made Sources of Radiation:

In addition to the naturally occurring sources, there are many aritificial sources of radiation. The people may be exposed to these sources either as public exposure or occupational exposure.

(i) public exposure:

Many of the people may be exposed to radiation for one or several times during their life from the following sources:

a) Medical x-ray: for diagnosis of several disease such as chest x-ray.

b) Nuclear medicine for therapy of cancer by using radioactive isotopes such as iodine-131, Cobalt-60 etc

c) Consumer products such as tobacco, building materials, Ophthalmic glass, smoke detectors etc.

d) Residual fallout from nuclear weapons testing, shipment and accidents.

(ii) Occupational exposure:

Workers are exposed to radiation used in x-ray machines, radiography and as nuclear fuel cycle at nuclear plant.

Q9: Ultraviolet and its Biological applications:

Ultraviolet radiation is part of the electromagnetic spectrum and lies between the visible and the x-ray regions. It is normally divided into three wavelength ranges (UV-A, UV-B, UV-C)

A : 315 – 400 nm

B : 280 – 315 nm

C : 100 – 280 nm

The sun provides ultraviolet (mainly UV-A and UV-B) as well as visible radiation. The UV radiation causes sun burn. The early effects of Sunburn are pain, erythema, swelling and tanning.

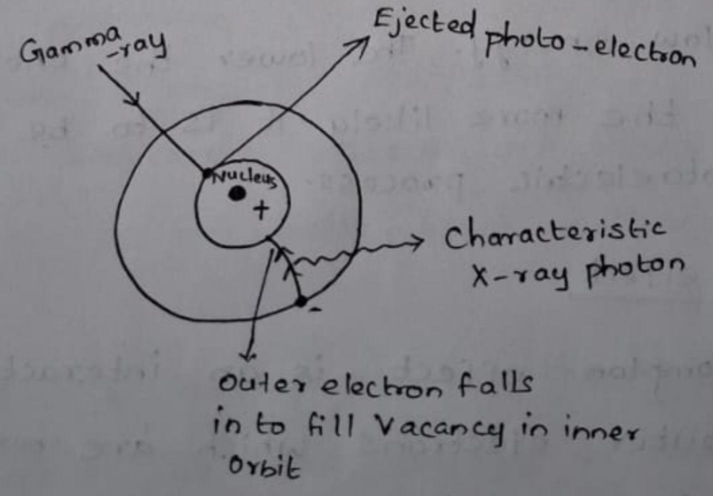
Exposure to UV can be assessed by measuring the erythemal response of skin or by noting the effect on micro-organisms. There are various chemical techniques for measuring UV but it is most common to use physics-based techniques. These include the use of photodiodes, photovoltaic cells, fluorescence detectors and thermoluminescent detectors such as lithium fluoride.

Applications:

- UV radiation is used in medicine to treat skin diseases and to relieve certain form of itching.
- It is applied directly to the skin or taken systematically in conjunction with photoactive drugs.
- Most common application of UV in treatment is psolaren ultraviolet A (PUVA).
- The photoactive drug psoralen in combination with long-wave ultraviolet Radiation provides beneficial effect in the treatment of psoriasis and other skin disorders.

- psoralen photochemotheraphy has been used to treat many skin diseases. The mechanism of the treatment is such that: psolarens bind to DNA in the presence of UV-A resulting in a transient inhibition of DNA synthesis and cell division.
- 8-methoxypsolaren and UV-A are used to stop epithelial cell proliferation.
- The dosage of UV-A has to be controlled inorder to avoid side-effects
- The UV-A dose per treatment session is generally in the range 1-10 J cm^{-2}.

Q5: Photoelectric effect:



An γ-ray can be absorbed by transferring all of its energy to an inner orbital electron in an atom of the absorber. The electron is ejected from the atom and the γ-ray disappears as it has lost all of its energy and it never had any mass. The atom is now left with a vacant inner electron orbit, which it will fill with one of the outer electrons. When this happens, it release a small amount of energy in the form of a characteristic x-ray photon. The x-ray is called a characteristic photon because its energy is characteristic of the absorbing material. The x-ray photon has a fixed energy because orbital electrons have fixed energies which correspond to the orbit which they occupy. Photo electric absorption occurs when the incident γ-ray has a fairly low energy. The lower the energy of the photon, the more likely it is to be absorbed by the photoelectric process.

Q6: Compton effect:

Compton effect is an interaction with the outer electrons which are not tightly bound to an atom.

Q 7: Coherent Scattering

Coherent scattering is an interaction between electromagnetic radiation and matter in which the incident radiation is scattered by atoms without any change in its wavelength, frequency, or energy. It occurs when low-energy photons interact with tightly bound electrons of an atom. The electric field associated with the incident electromagnetic wave forces the bound electrons to oscillate about their equilibrium positions. These oscillating electrons then act as secondary sources and re-radiate electromagnetic waves of the same frequency and wavelength as the incident radiation. Since there is no transfer of energy between the photon and the atom, the scattering process is elastic in nature. The scattered waves maintain a constant phase relationship with the incident wave, and hence the process is called coherent scattering. Only the direction of propagation of the radiation changes, while its energy remains conserved. Coherent scattering is more probable for long-wavelength or low-energy radiation and occurs predominantly at small scattering angles. In the case of X-rays, coherent scattering is also known as Rayleigh scattering, where the entire electron cloud of the atom participates in the interaction.

Applications of Coherent Scattering

1. X-ray Crystallography
    - Used to study crystal structure
    - Basis for Bragg's diffraction
    - Determines lattice spacing
2. Medical Imaging
    - Contributes to image formation in: X-ray radiography
    - Affects image contrast

3. Material Science

- Analysis of atomic arrangement
- Used in solid-state physics research

4. Optical Phenomena

Explains:

- Blue colour of sky
- Rayleigh scattering of light

Advantages

- Provides information about atomic structure
- Useful in structural analysis
- Non-destructive technique

Limitations

- Low intensity at high angles
- Significant only for low-energy radiation

Q 8: Infrared Radiation and its Biological Applications

Infrared Radiation

Infrared radiation (IR) is an electromagnetic radiation lying between visible light and microwaves in the electromagnetic spectrum. It was discovered by William Herschel in 1800.

Characteristics of Infrared Radiation

1. Wavelength range: 700 nm to 1 mm
2. Frequency range: 3×10^{11} Hz to 4×10^{14} Hz
3. Invisible to the human eye
4. Emitted by hot bodies
5. Produces strong heating effect

6. Travels with the velocity of light
7. Obeys laws of reflection and refraction
8. Non-ionizing radiation

Sources of Infrared Radiation

i. Natural Sources: Sun, Fire
ii. Living organisms
iii. Hot objects
iv. Artificial Sources
v. Tungsten filament lamps
vi. Infrared lamps
vii. Electric heaters
viii. Infrared LEDs and lasers

Interaction of Infrared Radiation with Biological Tissue

i. Infrared radiation is mainly absorbed by skin and tissues
ii. Causes increase in temperature
iii. Results in vasodilation and improved blood flow
iv. Excess exposure may lead to burns and tissue damage

Biological Applications of Infrared Radiation

1. Infrared Therapy (Physiotherapy)

- Used for relief from: Muscle pain, Joint stiffness, Arthritis
- Improves blood circulation
- Promotes healing of tissues

2. Medical Diagnosis

Infrared thermography is used to:

- Detect tumors

- Identify inflammation
- Study abnormal blood circulation

3. Neonatal Care

Infrared warmers are used to:

- Maintain body temperature of newborn babies
- Prevent hypothermia in premature infants

4. Treatment of Skin Diseases

Used in treatment of:

- Rheumatism
- Muscular injuries
- Chronic pain conditions
- Reduces inflammation and pain

5. Surgical Applications

- Used in infrared and laser surgery
- Controls bleeding by coagulation
- Minimizes damage to surrounding tissues

6. Sterilization

- Used to sterilize:
- Medical instruments
- Laboratory equipment
- Microorganisms are destroyed by heating effect

7. Biological Research

Used to study:

- Metabolic activity
- Blood flow patterns

- Heat distribution in living organisms

Advantages of Infrared Radiation in Biology

- Non-invasive method
- Painless and safe under controlled exposure
- Quick treatment
- Wide medical applicability

Q 10: Damaging Effects of Ultraviolet (UV) Light

1. Sunburn (Erythema)

Excess exposure to UVB radiation causes redness, pain, and inflammation of the skin due to damage of skin cells.

2. Premature Ageing of Skin

UVA radiation penetrates deep into the skin causing wrinkles, dryness, loss of elasticity, and early ageing.

3. Skin Cancer

Prolonged UV exposure damages DNA in skin cells leading to cancers such as melanoma, basal cell carcinoma, and squamous cell carcinoma.

4. DNA Damage and Genetic Mutations

UV radiation breaks DNA strands and causes mutations, leading to abnormal cell division.

5. Eye Damage (Photokeratitis)

Short-term exposure causes inflammation of the cornea resulting in pain, redness, and temporary vision loss.

6. Cataract Formation

Long-term exposure to UV light leads to clouding of the eye lens, causing cataracts and impaired vision.

7. Conjunctivitis

UV radiation causes inflammation of the conjunctiva, resulting in irritation and watering of eyes.

8. Suppression of Immune System

UV light weakens the immune response, reducing the body’s ability to fight infections.

9. Skin Pigmentation Disorders

Causes tanning, dark spots, uneven pigmentation, and discoloration of skin.

10. Damage to Proteins and Enzymes

UV radiation alters protein structure, affecting normal cellular functions.

11. Cell Death (Apoptosis)

High-energy UV radiation can destroy skin cells, leading to peeling and tissue damage.

12. Damage to Cornea and Retina

Intense UV exposure can injure eye tissues and may cause long-term vision problems.

13. Damage to Plant Life

UV radiation affects photosynthesis and reduces plant growth and crop yield.

14. Destruction of Beneficial Microorganisms

Excess UV exposure kills useful bacteria and microorganisms, disturbing ecological balance.

15. Dehydration of Skin Tissues

Causes loss of moisture from skin leading to dryness and cracking.

16. Increased Risk of Occupational Hazards

Continuous exposure in welding, laboratory, and industrial environments increases health risks.

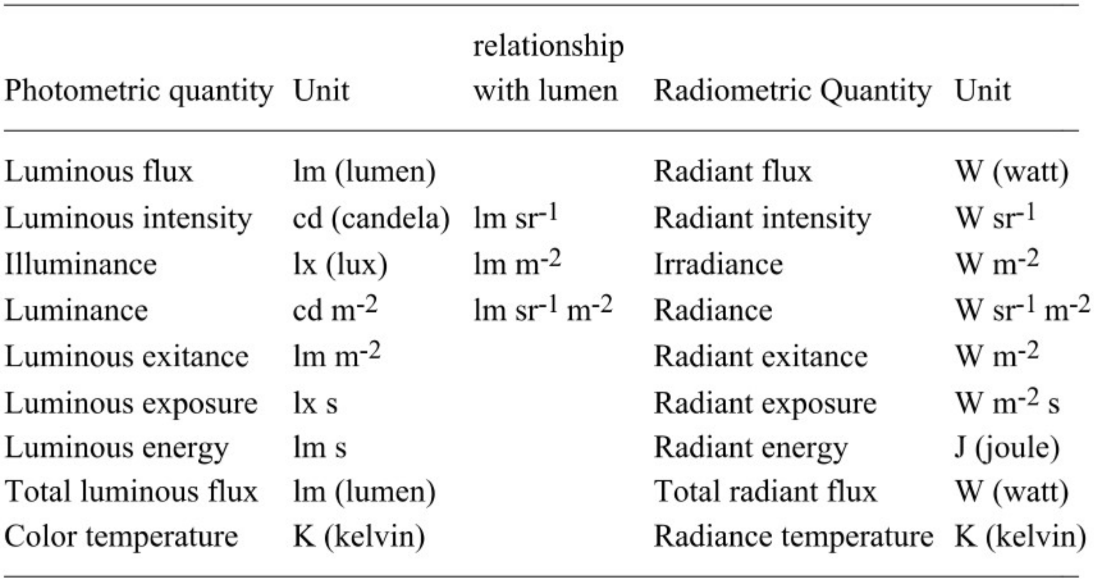
Q 11: Radiometry and Photometry

Radiometry is the measurement of optical radiation, which is electromagnetic radiation in the frequency range between 3×10^{11}Hz and 3×10^{16} Hz. This range corresponds to wavelengths between 10 nm and 1000 mm, and includes the regions commonly called the ultraviolet, the visible, and the infrared. Typical radiometric units include watt (radiant flux), watt per steradian (radiant intensity), watt per square meter (irradiance), and watt per square meter per steradian (radiance). Photometry is the measurement of light, which is defined as electromagnetic radiation detectable by the human eye. It is thus restricted to the visible region (wavelength range from 360 nm to 830 nm), and all the quantities are weighted by the spectral response of the eye. Photometry uses either optical radiation detectors constructed to mimic the spectral response of the eye, or spectroradiometer coupled with appropriate calculations for weighting by the spectral response of the eye. Typical photometric units include lumen (luminous flux), candela (luminous intensity), lux (illuminance), and candela per square meter (luminance). The difference between radiometry and photometry is that radiometry includes the entire optical radiation spectrum (and often involves spectrally resolved measurements), while photometry deals with the visible spectrum weighted by the response of the eye.

Quantities and Units in Photometry and Radiometry

In 1960, the SI (System International) was established, and the candela became one of the seven SI base units. Several quantities and units, defined in different geometries, are used in photometry and radiometry.

Table 1. Quantities and units used in photometry and radiometry.



Photometric quantity	Unit	relationship with lumen	Radiometric Quantity	Unit
Luminous flux	lm (lumen)		Radiant flux	W (watt)
Luminous intensity	cd (candela)	lm sr^{-1}	Radiant intensity	W sr^{-1}
Illuminance	lx (lux)	lm m^{-2}	Irradiance	W m^{-2}
Luminance	cd m^{-2}	lm sr^{-1} m^{-2}	Radiance	W sr^{-1} m^{-2}
Luminous exitance	lm m^{-2}		Radiant exitance	W m^{-2}
Luminous exposure	lx s		Radiant exposure	W m^{-2} s
Luminous energy	lm s		Radiant energy	J (joule)
Total luminous flux	lm (lumen)		Total radiant flux	W (watt)
Color temperature	K (kelvin)		Radiance temperature	K (kelvin)

While the candela is the SI base unit, the luminous flux (lumen) is perhaps the most fundamental photometric quantity, as the other photometric quantities are defined in terms of lumen with an appropriate geometric factor.

i) Radiant Flux and Luminous Flux

Radiant flux (also called optical power or radiant power) is the energy Q (in Joules) radiated by a source per unit of time.

Luminous flux (ϕ_v) is the time rate of flow of light as weighted by V(λ).

ii) Radiant Intensity and Luminous Intensity

Radiant intensity (I_e) or luminous intensity (I_v) is the radiant flux (luminous flux) from a point source emitted per unit solid angle in a given direction.

iii) Irradiance and Illuminance

Irradiance (E_e) or illuminance (E_v) is the density of incident radiant flux or luminous flux at a point on a surface, and is defined as radiant flux (luminous flux) per unit area.

iv) Radiance and Luminance

Radiance (L_e) or luminance (L_v) is the radiant flux (luminous flux) per unit solid angle emitted from a surface element in a given direction, per unit projected area of the surface element perpendicular to the direction.

v) Radiant Exitance and Luminous Exitance

Radiant exitance (M_e) or luminous exitance (M_v) is defined to be the density of radiant flux (luminous flux) leaving a surface at a point.

vi) Radiant Exposure and Luminous Exposure

Radiant exposure (H_e) or luminous exposure (H_v) is the time integral of irradiance E_e (t) or illuminance E_v (t) over a given duration Δt.

vii) Radiant Energy and Luminous Energy

Radiant energy (Q_e) or luminous energy (Q_v) is the time integral of the radiant flux or luminous flux (ϕ) over a given duration Δt.

viii) Total Radiant Flux and Total Luminous Flux

Total radiant flux or total luminous flux (ϕ_v) is the geometrically total radiant (luminous) flux of a light source.

ix) Radiance Temperature and Color Temperature

Radiance temperature (unit: kelvin) is the temperature of the Planckian radiator for which the radiance at the specified wavelength has the same spectral concentration as for the thermal radiator considered. Color temperature (unit: kelvin) is the temperature of a Planckian radiator with radiation of the same chromaticity as that of the light source in question.

Q12: Electrical Impedance and Biological Impedance

Electrical impedance and biological impedance are important concepts used to describe the opposition offered to the flow of alternating current, particularly in electrical circuits and biological systems.

Electrical impedance is defined as the total opposition offered by an electrical circuit to the flow of alternating current (AC). It is a complex quantity consisting of two components: resistance, which represents the opposition to current due to energy dissipation, and reactance, which represents the opposition due to energy storage in capacitors and inductors. Electrical impedance depends on the frequency of the applied AC signal and is expressed mathematically as $Z = R + iX$, where R is resistance and X is reactance. It is measured in ohms and plays a vital role in the analysis and design of AC circuits, power systems, filters, and electronic devices, as it determines current flow, phase difference between voltage and current, and power consumption.

Biological impedance, also known as bioimpedance, refers to the opposition offered by biological tissues and fluids to the flow of alternating current. In living systems, the impedance arises from the resistive nature of body fluids, which contain ions, and the capacitive nature of cell membranes, which behave like dielectric layers separating conducting intracellular and extracellular fluids. Biological impedance varies with factors such as tissue type, water content, cell structure, and frequency of the applied current. At low frequencies, current mainly flows through extracellular paths, while at higher frequencies it can penetrate cell membranes. Measurement of biological impedance is widely used in medical and biomedical applications such as body composition analysis, assessment of hydration levels, monitoring of blood flow, detection of tissue abnormalities, and bioelectrical impedance analysis (BIA). Thus, while electrical impedance is a fundamental concept in electrical engineering, biological impedance extends this concept to living tissues, providing valuable diagnostic and monitoring information in biomedical engineering.

Applications of Electrical Impedance

i) AC Circuit Analysis

Used to analyze RLC circuits

Helps in calculating current, voltage, and phase difference

ii) Impedance Matching

Used in communication systems and antennas

Ensures maximum power transfer and minimum signal reflection

iii) Electronic Circuit Design

Used in amplifiers, oscillators, and filters

Controls frequency response and stability

iv) Measurement Instruments

Used in LCR meters and impedance bridges

Measurement of resistance, capacitance, and inductance

v) Industrial Applications

Used in sensors for pressure, moisture, and level measurement

Used in industrial control systems

Applications of Biological Impedance

i) Body Composition Analysis

Determines body fat, muscle mass, and body water

Used in Bio-electrical Impedance Analysis (BIA)

ii) Medical Diagnosis

Used to detect tissue abnormalities

Helps in identifying tumors and edema

iii) Monitoring of Blood Flow

Used in impedance plethysmography

Measures changes in blood volume

iv) Cardiac Applications

Used in monitoring cardiac output

Helps in heart function assessment

v) Medical Instrumentation

Used in ECG, EEG, and other bio-signal measurement systems

Improves accuracy of physiological monitoring

Q 13: Artificial intelligence (AI) in radiotherapy

Artificial intelligence (AI) in radiotherapy has become an important and transformative tool in modern cancer treatment by improving the accuracy, efficiency, and safety of radiation therapy procedures. Radiotherapy uses high-energy radiation to destroy malignant cells while sparing the surrounding healthy tissues, and even small errors in planning or delivery can lead to serious complications. AI techniques such as machine learning and deep learning are widely used in the analysis of medical images including CT, MRI, and PET scans to accurately detect tumors and delineate organs at risk. Automated tumor segmentation using AI reduces inter-observer variation and significantly shortens the time required for manual contouring. AI also plays a major role in treatment planning by optimizing radiation dose distribution, selecting appropriate beam angles, and generating high-quality treatment plans within a short time. In adaptive radiotherapy, AI continuously evaluates anatomical changes such as tumor shrinkage and patient movement during the treatment course and modifies the treatment plan to ensure precise dose delivery. Furthermore, AI assists in patient positioning and motion management by tracking real-time movements and correcting errors during irradiation. It is also used in quality assurance to detect machine faults and planning errors, thereby improving patient safety. In addition, AI helps predict treatment outcomes and radiation-induced side effects, enabling personalized treatment strategies. Thus, artificial intelligence enhances precision, reduces workload, improves treatment outcomes, and represents a major advancement in the field of radiotherapy.

Applications of AI in Radiotherapy

a) Tumor Detection and Diagnosis:

AI-based image analysis can identify small tumors that may be missed by human radiologists, significantly improving the detection rate and reducing the risk of misdiagnosis.

b) Automated Tumor Contouring:

Tumor contouring refers to delineating the tumor and surrounding organs in medical images. It is a critical step in treatment planning to ensure that radiation is targeted precisely at the tumor while sparing healthy tissues. AI-based models, particularly deep learning techniques, have been developed to automate this process. By learning from large datasets, these models can contour tumors with high accuracy and consistency, reducing the time clinicians spend on this task and improving inter-observer agreement.

c) Treatment Planning and Optimization:

AI enhances treatment planning by analyzing historical data and patient-specific factors to suggest the best possible radiation dose distribution. AI algorithms can optimize the placement, angle, and intensity of radiation beams to minimize damage to healthy tissues and improve tumor targeting. AI can also automate dose calculation, thus reducing human error and saving time.

d) Predicting Treatment Outcomes:

AI systems, especially machine learning models, can predict patient outcomes based on historical data.

e) Adaptive Radiotherapy:

In adaptive radiotherapy, AI algorithms are used to adjust the treatment plan dynamically as the tumor or patient anatomy changes over time. This is particularly useful for patients who undergo treatment over several weeks, as tumors and surrounding tissues may change in shape or position.