Physics of Medical Devices

Eight lecture

Electromagnetic Radiations

Dr. Nasma Adnan

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Department of medical physics

Al-Mustaqbal University-College

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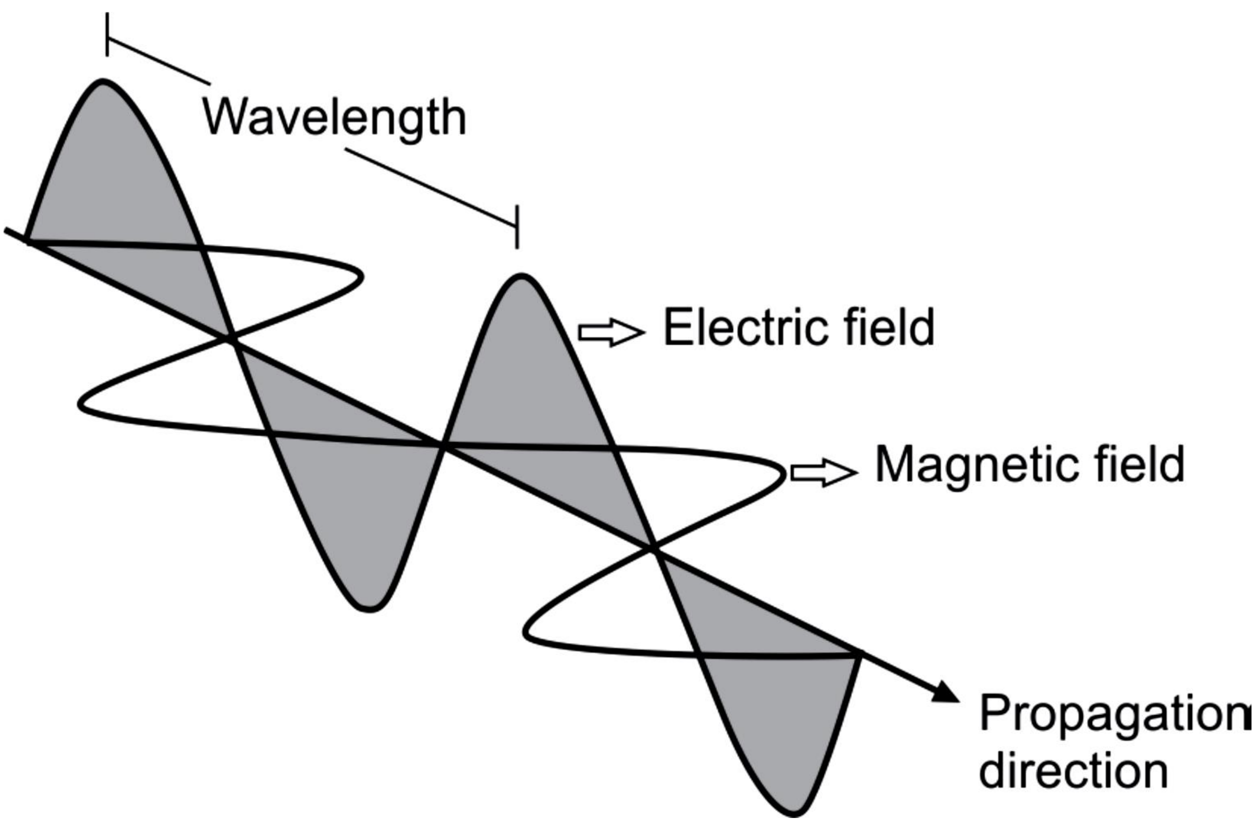
1. Introduction

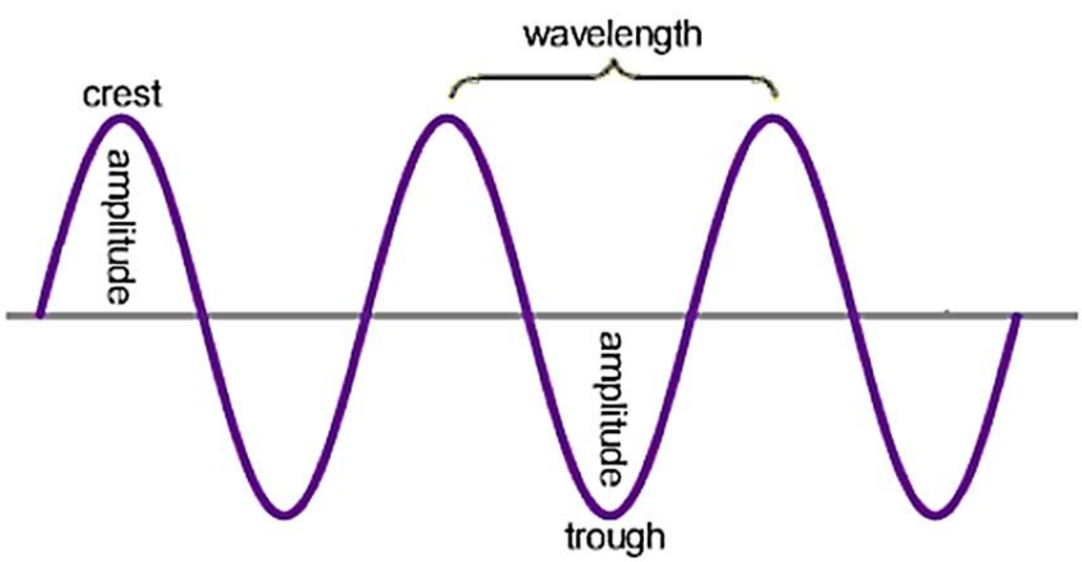
- An electric charge is surrounded by an electric field and if the charge moves, a magnetic field is produced.
- When the charge undergoes an acceleration or deceleration, the magnetic and the electric fields of the charge will vary.
- The combined variation of the electric and magnetic fields results in loss of energy.
- The charge radiates this energy in a form known as electromagnetic radiation.
- The electromagnetic radiation moves in the form of sinusoidal waves.
- The nature of the electromagnetic radiation (X-rays, ultraviolet, etc.) depends on the way in which the electric charges are disturbed.



- Electromagnetic radiations are transverse waves that transfer energy away from the electric charge.
- Electromagnetic radiations may be absorbed or scattered in a medium, resulting in loss of energy

2.Features of wave length

- Electromagnetic waves can be characterized by their amplitude, wavelength (λ), frequency (v) and speed.
- The amplitude is the intensity of the wave.
- The wavelength is the distance between two consecutive positive peaks.
- The frequency is the number of complete wave oscillations per unit time.
- The speed of the wave is equal to the product of the frequency and the wavelength, and its magnitude depends upon the nature of the material through which the wave travels and the frequency of the radiation.



- Wavelength is a measure of the distance from the crest on one wave to the crest on the very next wave.
- Shorter wavelengths are influenced by the frequency.

- A higher frequency causes a shorter wavelength and greater energy.
- In a vacuum, however, the speed for all electromagnetic waves is a constant, usually denoted by *c*.
- The relation between wavelength, frequency, and velocity of the electromagnetic wave.

$$c = \lambda v$$

- All electromagnetic waves, travel at the same velocity in a given medium and its velocity in vacuum is about 2.998×10^8 ms–1.
- For X rays, wavelength is usually expressed in nanometers (nm) (1 nm = 10^{-9} m) and frequency is expressed in Hertz (Hz) (1 Hz = 1 cycle/s = 1 s^{-1}).
- When interactions with matter are considered, electromagnetic radiation is generally treated as series of individual particles, known as photons. The energy of each photon is given by:

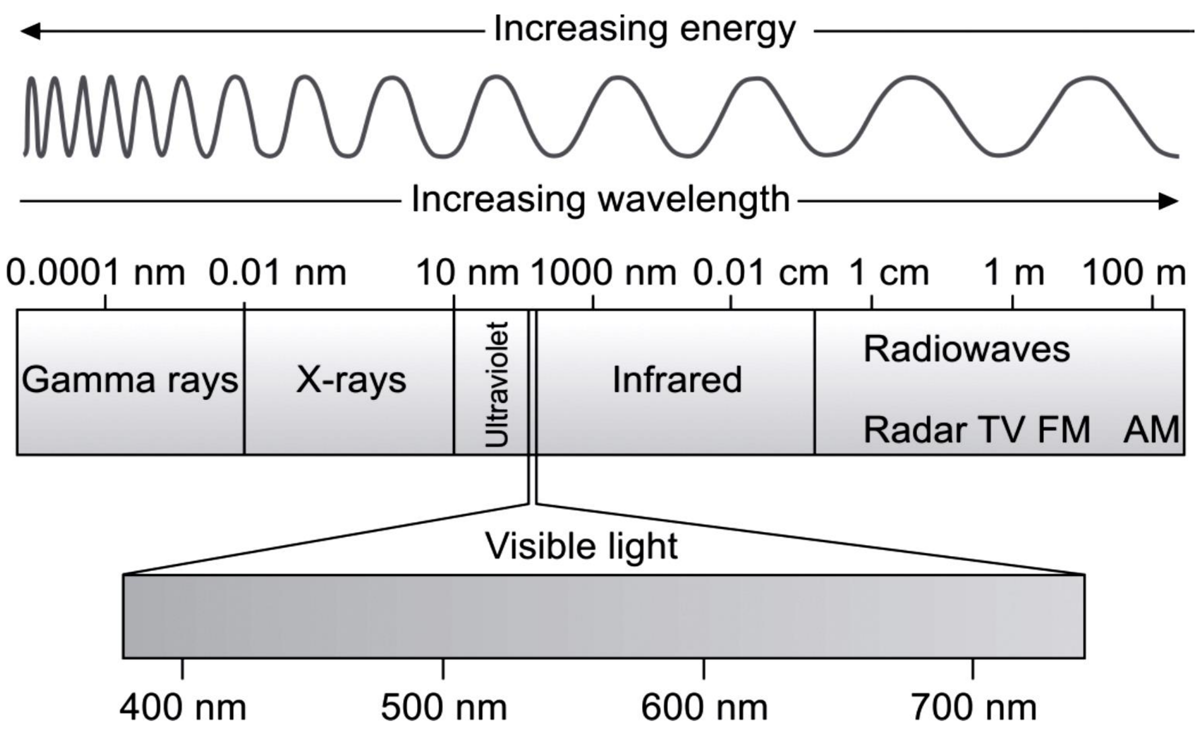
$$E = hv$$

where the constant *h* is known as Planck's constant.

- In diagnostic radiology, the photon energy is usually expressed in units of keV.
- where 1 electron-volt (eV) is the energy received by an electron when it is accelerated across of a potential difference of 1 V.

3. Electromagnetic radiation properties

- Radiation may be classified as electromagnetic or particulate.
- Electromagnetic spectrum includes radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays and cosmic rays.



- All of them travel at a velocity ‘c’ in a vacuum. The wavelength and photon energy of the whole range of electromagnetic radiation are summarized in Table.

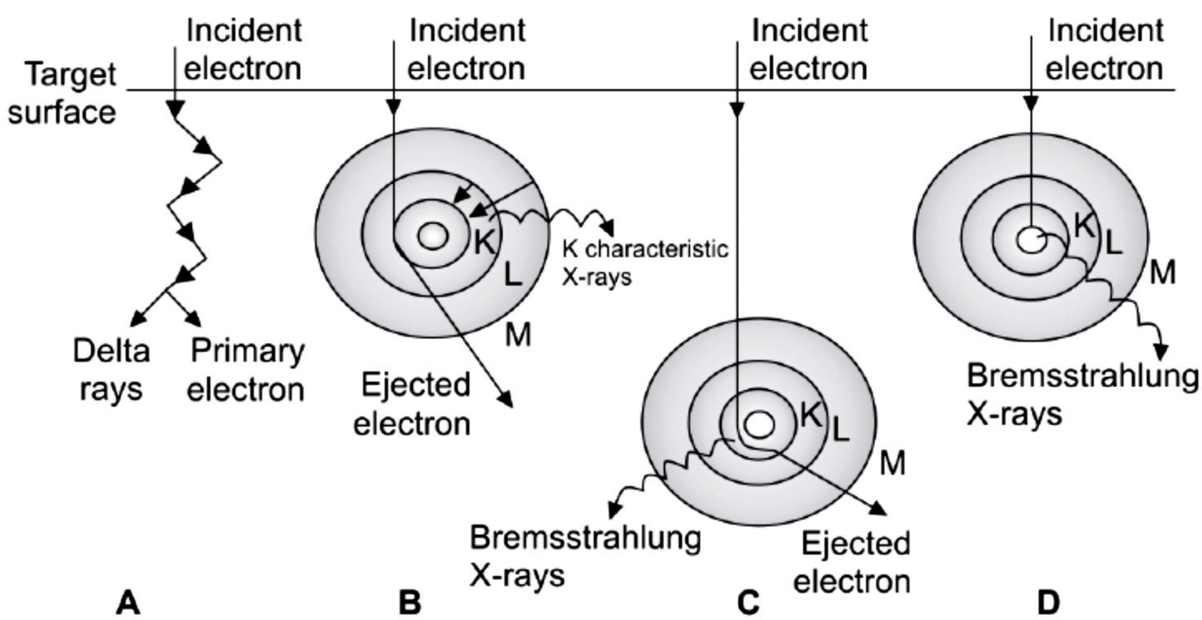
Radiation	**Wavelength**	**Frequency**	**Energy**
Radiowaves	1000 – 0.1 m	0.3 – 3000 MHz	0.001 – 10 μeV
Microwaves	100 – 1 mm	3 – 300 GHz	10 – 1000 μeV
Infrared	100 – 1 μm	3 – 300 THz	10 – 1000 meV
Visible light	700 – 400 nm	430 – 750 THz	1.8 – 3 eV
Ultraviolet	400 – 10 nm	750 – 30000 THz	1.8 – 100 eV
X- and gamma rays	1 nm – 0.1 pm	3×10^5 – 3×10^9 THz	1 keV – 10 MeV

- Radiation is classified as ionizing or non-ionizing, depending on its ability to ionize matte.
- Ionization is a process of removal of electron from neutral atom.

- The radiation which does ionization in a medium, by removal of electron is called ionizing radiation, e.g. UV, X-rays, and gamma rays have sufficient energy to do ionization.
- As a result, ionized atoms and molecules or ion-pairs are produced. This forms the basis for biological effects of radiation.
- Radiation that do not have sufficient energy to produce ionization are called non-ionizing radiation, e.g. visible light, infrared, radio waves, and TV broadcasts.

4. Production of the X-Ray Beams

- X-rays are produced when fast moving electrons are stopped by means of a target material.
- The moving electrons possess kinetic energy. When the electron is suddenly stopped, its kinetic energy is converted into heat and X-rays.
- This conversion is taking place in the target material. Therefore, the interaction of electron with the target is the basis for X-ray production.
- When the electron arrives at the target, it interacts in four ways as follows



- The electron interaction involves ionizational collisions and radiative collisions.

(A) Ionization of target atoms: The fast moving electron enters the surface layer of the target and undergoes collisions. In this process, the incident electron transfers sufficient energy and removes an electron from the atom. This involves small energy transfer, resulting in ionization of target atoms. The displaced electron, known as a secondary electron, may have sufficient energy and produce further ionization of target atoms. They are few in number and produce their own track, known as delta rays.

(B) Characteristic X-rays: This is an interaction between the incident electron and the electron in the K shell, transfers energy and removes the K shell electron. The vacancy in the K shell is filled by an electron moving inwards from the outer shell. During this transition, the difference in binding energies of the two shells is given out as X-ray photon. This photon is known as the characteristic X-ray.

(C) Interaction with nuclear field: The incident electron occasionally reaches nearer to nucleus of an atom in the target. Since the electron is a negative particle, it is attracted by the positive nucleus. It is made to orbit partially around the nucleus, decelerates and goes out with reduced energy. The loss of energy appears in the form of X-ray photons, known as Bremsstrahlung. The energy of the X-ray photon depends on the degree to which the electron is decelerated by the nuclear attraction.

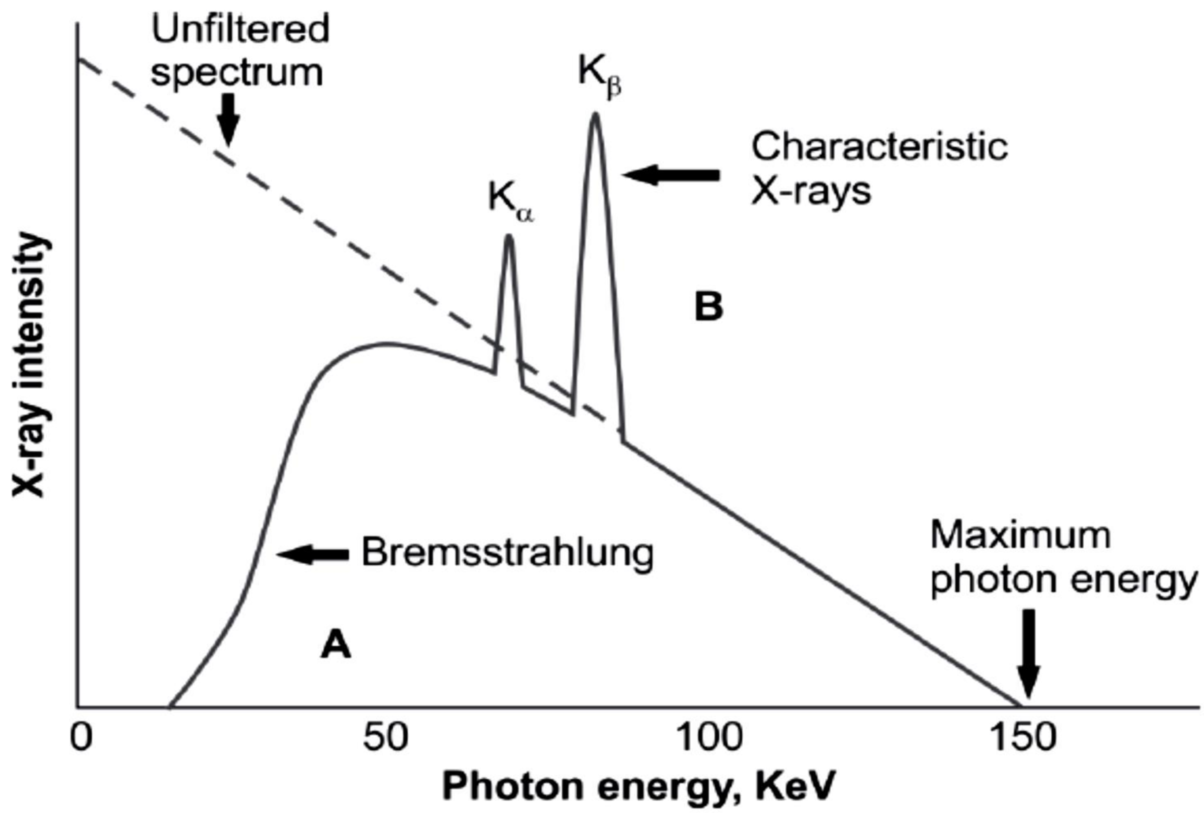
(D)The electron may hit the nucleus directly and is stopped completely in a single collision. The entire electron energy appears as bremsstrahlung radiation. This type of interaction is very rare, but capable of giving high energy X-rays.

- There are two types of X-ray spectrum, namely,

  (a) Bremsstrahlung or continuous spectrum

  (b) characteristic spectrum.

- A bremssrahlung spectrum consists of X-ray photons of all energies up to maximum in a continuous fashion, which is also known as white radiation, because of its similarity to white light.
- A characteristic spectrum consists of X-ray photons of few energy, which is also called as line spectrum. The position of the characteristic radiation depends upon the atomic number of the target.



5.Factors Affecting X-Ray Production

1- Anode material

2- Voltage applied

3- Tube Current

4- Filters used