Diyala University-College of Science

Physics Department

Medical Physics Branch

CHAPTER TWO

ELECTROMAGNETIC WAVES

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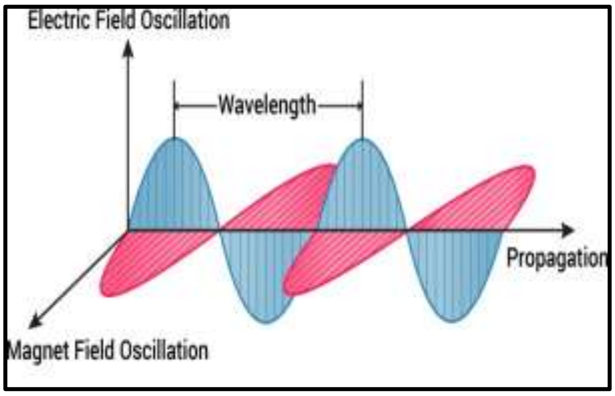
1- INTRODUCTION:

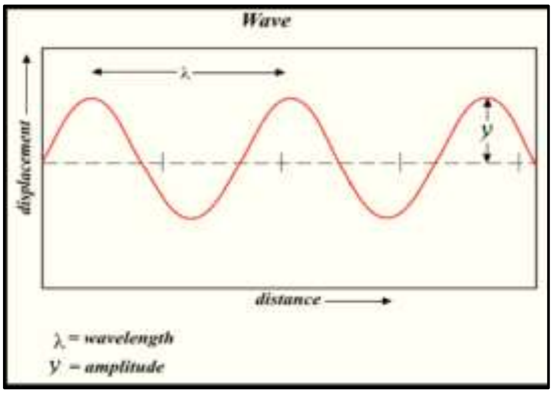
The phenomenon of Faraday's electromagnetic induction concludes that a **changing magnetic field** at a point with time **produces an electric field** at that point. Maxwell, pointed out that there is symmetry in nature (i.e) **changing electric field** with time at a point **produces a magnetic field** at that point. It means that a **change in one field with time** (either electric or magnetic) **produces another field**. This idea led Maxwell to conclude that the variation in electric and magnetic fields perpendicular to each other, produces electromagnetic disturbances in space. These disturbances have the properties of a wave and propagate through space without any material medium. These waves are called **electromagnetic waves**. They travel in vacuum or free space with a velocity $\mathbf{3 \times 10^8\ m\ s^{-1}}$.

Wavelength can be defined as the distance between two successive crests or troughs of a wave. It is measured in the direction of the wave.

Amplitude can be defined as the maximum displacement or distance moved by a point on a vibrating body or wave measured from its equilibrium position.

Frequency can be defined as the number of waves that pass a fixed point in unit time; also, the number of cycles or vibrations undergone during one unit of time by a body in periodic motion





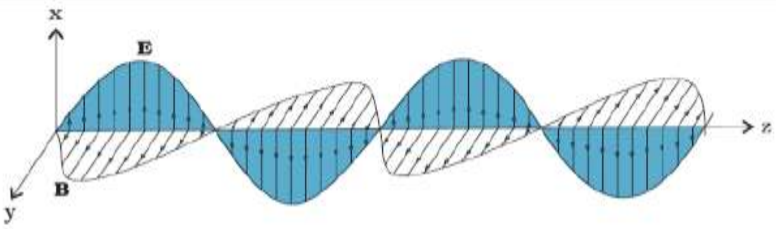
Many people confuse sound waves with radio waves, one type of electromagnetic (EM) wave. However, sound and radio waves are completely different phenomena. Sound creates pressure variations (waves) in matter, such as air or water, or your eardrum. Conversely, radio waves are electromagnetic waves, like visible light, infrared, ultraviolet, X-rays, and gamma rays. EM waves don't need a medium in which to propagate; they can travel through a vacuum, such as outer space.

2- SOURCES OF ELECTROMAGNETIC WAVES:

Consider a charge oscillating with some frequency (**accelerating charge**).This produces an **oscillating electric field** in space, which produces an **oscillating magnetic field**, which in turn, is a source of oscillating electric field, and so on. The oscillating electric and magnetic fields thus regenerate each other, as the wave propagates through the space . The frequency of the electromagnetic wave naturally equals the frequency of oscillation of the charge. The energy associated with the propagating wave comes at the expense of the energy of the source – the accelerated charge.

3- NATURE OF ELECTROMAGNETIC WAVES:

From Maxwell's equations, it is found that electric and magnetic fields in an electromagnetic wave are perpendicular to each other, and to the direction of propagation. A typical example of a plane electromagnetic wave propagating along the z direction(the fields are shown as a function of the z coordinate, at a given time t). The electric field $\boldsymbol{E_x}$ is along the x-axis, and varies sinusoidally with z, at a given time. The magnetic field $\boldsymbol{B_y}$ is along the y-axis, and again varies sinusoidally with z. The electric and magnetic fields $\boldsymbol{E_x}$ and $\boldsymbol{B_y}$ are perpendicular to each other, and to the direction z of propagation.



E → Electric Field (along X-axis)

B → Magnetic Field (along Y- axis)

Electromagnetic Waves along Z-axis

We can write $\boldsymbol{E_x}$ and $\boldsymbol{B_y}$ as follows:

$$E_x = E_0 \sin (k z - \omega t) \longrightarrow \quad (1)$$

$$B_y = B_0 \sin (k z - \omega t) \longrightarrow \quad (2)$$

where, $k = \frac{2\pi}{\lambda}$ → magnitude of the wave vector (or) propagation vector. Its direction describes the direction of propagation of the wave.

and ω → angular frequency

The speed of propagation of EM waves is $c = \frac{\omega}{k} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \longrightarrow \quad (3)$

where, μ_0 → permeability of free space

and, ε_0 → permittivity of free space

Since $\omega = 2\pi\upsilon$ and $k = \dfrac{2\pi}{\lambda}$, $\quad c = \dfrac{\omega}{k} = 2\pi\upsilon \times \dfrac{\lambda}{2\pi}$

(or) $$\boxed{c = \upsilon\ \lambda} \longrightarrow (4)$$

Also, it can be shown that

$$\boxed{B_0 = \frac{E_0}{c}} \longrightarrow (5)$$

where, $B_0 \rightarrow$ amplitude of magnetic field and

$E_0 \rightarrow$ amplitude of electric field

4- PROPERTIES OF ELECTROMAGNETIC WAVES:

(1) Electromagnetic waves are produced by accelerated charges.

(2) They do not require any material medium for propagation.

(3) In an electromagnetic wave, the electric (E) and magnetic (B) field vectors are at right angles to each other and to the direction of propagation. Hence electromagnetic waves are transverse in nature.

(4) Variation of maxima and minima in both E and B occur simultaneously.

(5) EM waves can be diffracted, refracted and polarized.

(6) They travel in vacuum or free space with a velocity 3×10^8 m s^{-1}. It is given by the above relation (3).

(7) Electromagnetic waves possess energy and momentum. Hence EM waves exert pressure called ‘radiation pressure.

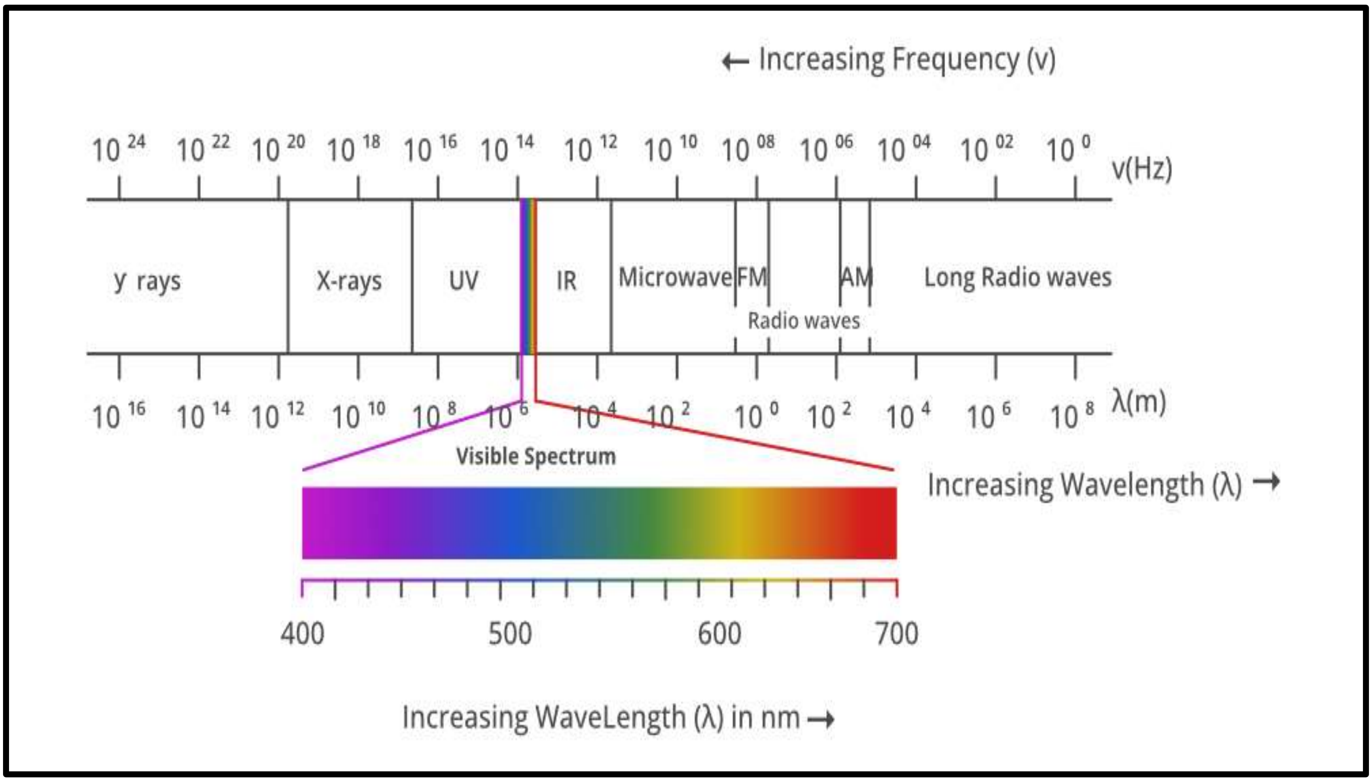
(8) Electromagnetic waves are not deflected by electric and magnetic fields.

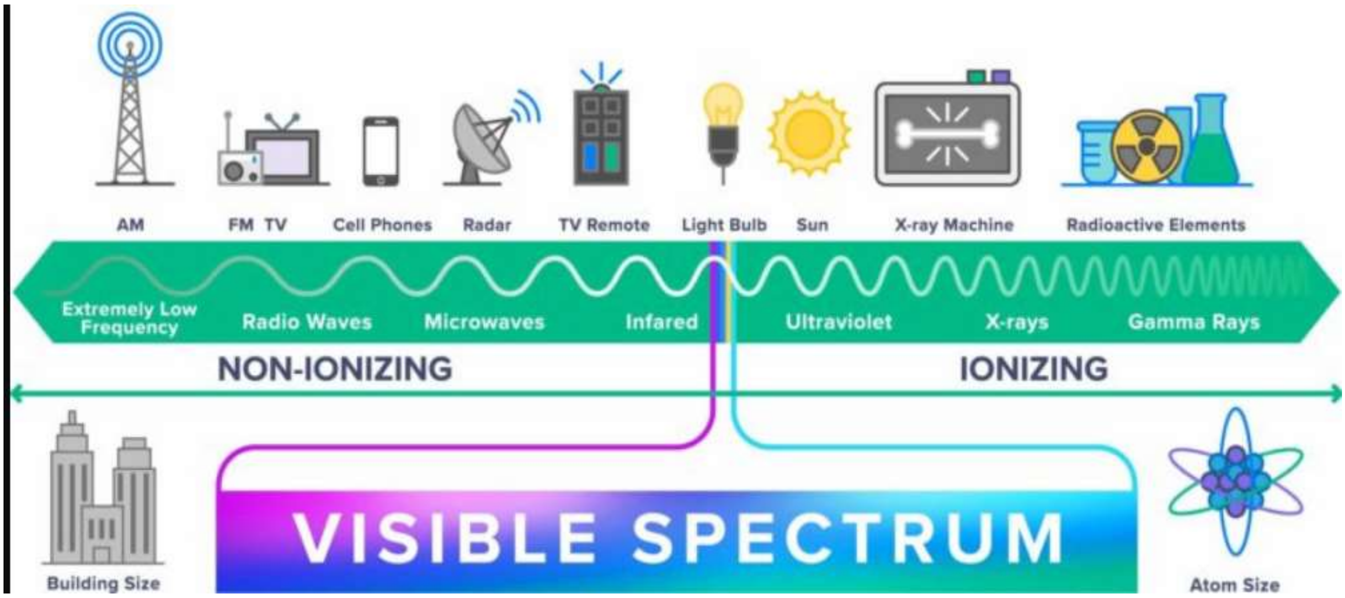
5- ELECTROMAGNETIC SPECTRUM:

Electromagnetic spectrum is an orderly distribution of electromagnetic waves in terms of wavelength or frequency.

Electromagnetic spectrum covers a wide range of wavelengths (or) frequencies. There is no sharp division between one kind of wave and the next. The overlapping in certain parts of the spectrum shows that the particular wave can be produced by different methods. We briefly describe these different types of electromagnetic waves, in order of decreasing wavelengths or increasing frequencies as in figures below.

1- Radio waves
2- Micro waves
3- Infra red waves
4- Visible rays
5- Ultra violet rays
6- X-rays
7- Gamma rays





A- RADIO WAVES :

(1) Radio waves are produced by the accelerated motion of charges in conducting wires.

(2) They are used in radio and television communication systems.

(3) They are generally in the frequency range from 500 kHz to about 1000 MHz.

(4) The AM (amplitude modulated) band is from 530 kHz to 1710 kHz.

(5) Higher frequencies upto 54 MHz are used for short wave bands.

(6) TV waves range from 54 MHz to 890 MHz.

(7) The FM (frequency modulated) radio band extends from 88 MHz to 108 MHz.

(8) Cellular phones use radio waves to transmit voice communication in the ultrahigh frequency (UHF) band.

B- MICRO WAVES:

(1) Microwaves are short-wavelength radio waves, with frequencies in the gigahertz (GHz) range.
(2) They are produced by special vacuum tubes (called klystrons, magnetrons and Gunn diodes.
(3) Due to their short wavelengths, they are suitable for the radar systems used in aircraft navigation.
(4) Radar also provides the basis for the speed guns used to time fast balls, tennis serves, and automobiles.
(5) Micro waves are used in very long distance wireless communication through satellites.
(6) Micro waves are used in micro wave oven to cook food.

Working: It is used to cook the food in a short time. When the oven is operated, the microwaves are generated, which in turn produce a non–uniform oscillating electric field. The water molecules in the food which are the electric dipoles are excited by an oscillating torque. Hence few bonds in the water molecules are broken, and heat energy is produced. This is used to cook food.

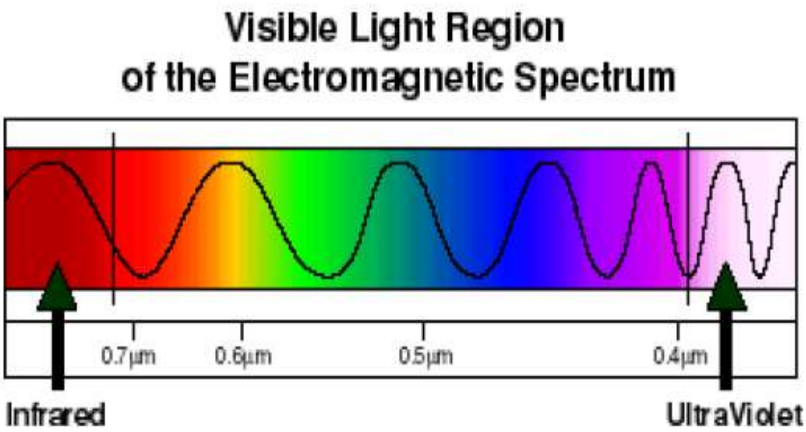
C- INFRA RED WAVES:

(1) Infrared waves are produced by hot bodies and molecules.
(2) This band lies adjacent to the low-frequency or long-wave length end of the visible spectrum.
(3) Infrared waves are sometimes referred to as '***heat waves'***.
(4) Infrared lamps are used in physical therapy.
(5) Infrared radiation also plays an important role in maintaining the earth's warmth or average temperature through the greenhouse effect.
(6) Infrared detectors are used in Earth satellites, both for military purposes and to observe growth of crops.

Working: Electronic devices (for example semiconductor light emitting diodes) also emit infrared and are widely used in theremote switches of household electronic systems such as TV sets, video recorders and hi-fi systems.

D- VISIBLE RAYS:

(1) It is the part of the spectrum that is detected by the human eye.
(2) Its frequency ranges from about 4×10^{14} Hz to about 7×10^{14} Hz or a wavelength range of about 700 nm to 400 nm.
(3) Visible light emitted or reflected from objects around us provides us information about the world.
(4) It is produced by incandescent bodies.



E- ULTRA VIOLET RAYS:

(1) It covers wavelengths ranging from about 4×10^{-7} m (400 nm) down to 6×10^{-10} m (0.6 nm).
(2) Ultraviolet (UV) radiation is produced by special lamps and very hot bodies.
(3) The Sun is an important source of ultraviolet light.
(4) UV light in large quantities has harmful effects on humans.
(5) UV radiation is absorbed by ordinary glass. (Application: Welders wear special glass goggles or face masks with glass windows to protect their eyes from large amount of UV produced by welding arcs
(6) UV lamps are used to kill germs in water purifiers.

F- X-RAYS:

(1) X-rays lie beyond the UV region of the electromagnetic spectrum.
(2) It covers wavelengths from about 10^{-8} m (10 nm) down to 10^{-13} m (10^{-4} nm).
(3) X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.
(4) X-rays damage or destroy living tissues and organisms.
(5) One common way to generate X-rays is to bombard a metal target by high energy electrons.

G- GAMMA RAYS:

(1) They lie in the upper frequency range of the electromagnetic spectrum and have wavelengths from about 10−10 m to less than 10−14 m.
(2) They are the high frequency radiation produced in nuclear reactions and also emitted by radioactive nuclei..
(3) They are used in medicine to destroy cancer cells.