$E_x = E_0 \sin(kz - \omega t)$

$B_y = B_0 \sin(kz - \omega t)$

- In electromagnetic wave, the electric and magnetic fields vary with space and time and have the same frequency and are in the same phase.
- The amplitudes of electric and magnetic fields in free space, in electromagnetic waves are related by

$$E_0 = cB_0 \quad \text{or} \quad B_0 = \frac{E_0}{c}$$

- The speed of electromagnetic wave in free space is

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

- where μ_0 and ε_0 are the permeability and permittivity of free space.
- The speed of electromagnetic wave in a medium is

$$v = \frac{1}{\sqrt{\mu \varepsilon}}$$

- where μ and ε are permeability and permittivity of the medium.

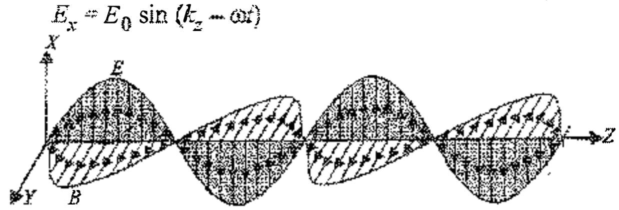
$$v = \frac{1}{\sqrt{\mu_0 \mu_r \varepsilon_0 \varepsilon_r}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}}$$

Characteristics of Electromagnetic Waves

- These waves do not carry any charge.
- These waves are not deflected by electric and magnetic fields.
- They travel with the speed of light c ($= 3 \times 10^8$ m s^{-1}) in vacuum.
- The frequency of electromagnetic wave does not change when it goes from one medium to another but its wavelength changes.
- These waves are transverse in nature, hence they can be polarized.

NATURE OF ELECTROMAGNETIC WAVES

- The equation of an electric field along x-axis is given as $E_x = E_0 \sin(k_z - \omega t)$



The equation of a magnetic field along y-axis is given as $B_y = B_0 \sin(kz - \omega t)$

here k is propagation constant and is equal to $\frac{2\pi}{\lambda}$

ω is the angular frequency $= \frac{2\pi}{T}$

- Electromagnetic wave is transverse in nature as the electric and magnetic field are perpendicular to each other and to the direction of propagation of em wave.
- If the $\vec{E}$ electric field vector is along Y-axis and magnetic field vector $\vec{B}$ is along Z-axis, the direction of propagation is along $\vec{E} \times \vec{B}$. *i.e.* along the X-axis.

So, electric field vector

$$\vec{E} = E_y \hat{j}$$

$$\vec{E} = E_0 \sin(kx - \omega t)\hat{j}$$

$$\vec{E} = E_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]\hat{j}$$

$$\vec{E} = E_0 \sin\left[\frac{2\pi}{\lambda}(x - ct)\right]\hat{j}$$

here $E_x = E_z = 0$ and magnetic field vector

$$\vec{B} = B_z \hat{k}$$

$$\vec{B} = B_0 \sin(kx - \omega t)\hat{k}$$

$$\vec{B} = B_0 \sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]\hat{k}$$

$$\vec{B} = B_0 \sin\left[\frac{2\pi}{\lambda}(x - ct)\right]\hat{k}$$

here $\vec{B}_x = \vec{B}_y = 0$

- In case the EM wave is propagating in Z direction the equation may be.

$$\vec{E} = E_0 \sin\frac{2\pi}{\lambda}[z - ct]\hat{i}$$

$$\vec{B} = B_0 \sin\frac{2\pi}{\lambda}[z - ct]\hat{j}$$

Illustration 2

An electromagnetic wave going through vacuum is described by $E = E_0 \sin(kx - \omega t)$ and $B_0 = B_0 \sin(kx - \omega t)$. Then show that $E_0 k = B_0 \omega$

Soln. : For electromagnetic waves, $c = \frac{E_0}{B_0}$ but $\frac{\omega}{k} = c$,

Hence $\frac{E_0}{B_0} = \frac{\omega}{k}$.

ELECTROMAGNETIC SPECTRUM

- Electromagnetic waves include radio waves, microwaves, visible light waves Infrared rays, U.V. rays, X-rays and gamma rays.
- The classification of e.m. waves done according to the frequency is called electromagnetic spectrum.
- The basic difference between various type of electromagnetic waves lies in their wavelength or frequency since all of them travel through vacuum with the same speed. Also, the waves differ in their mode of interaction with matter.
- **Radio waves**
  - They are generally in the frequency range 500 kHz to 1000 MHz.
  - The AM (amplitude modulated) band used for short distance radio transmission is from 530 kHz to 1710 kHz. The SW (short wave) band involve frequencies between 1500 kHz to 50 MHz and is used for long range radio broadcast.

- TV transmission uses VHF (Very high Frequency) band and frequency modulation is done. The VHF band extend from 50 MHz to 900 MHz.
- Cellular phones uses radio waves to transmit voice communication in the UHF (Ultra high Frequency) Band. The UHF band extend from 900 MHz to 5000 MHz.
- Radio waves are produced by oscillating electric circuits having inductor and capacitor.

Microwaves

- Microwaves are high frequency radio waves of frequency range 1 GHz to 300 GHz.
- Microwaves are produced by special vacuum tubes *e.g.* klystrons, magnetrons.
- Microwaves are used in
  - (a) Radar system used in aircraft navigation.
  - (b) Speed guns to determine speed of moving automobiles, cricket ball, Tennis ball etc.
  - (c) In the study of atomic and molecular structure.
  - (d) In communication via satellite.
  - (e) In Microwave ovens for cooking. (In Microwave Ovens, the frequency of microwave produced is matched with natural frequency of water molecules so that resonance occurs and water molecules in the material vibrates at higher amplitude and transfer energy to nearby food molecules, results in heating up the food.)

Infrared waves

- Infrared waves are heat radiations also known as heat waves, and are of frequency range 3×10^{11} to 4×10^{14} Hz and of wavelength 8×10^{-7} m to 3×10^{-4} m.
- Infrared waves are produced by hot bodies and molecules.
- Infrared waves does heating because water molecules present in most of the materials readily absorb infrared waves and their thermal motion increases, so they heat up themselves and also heat up the surroundings.
- Infrared waves are used in
  - (a) Physical therapy to treat muscular strain
  - (b) Taking photographs during conditions of fog, smoke etc as these waves are scattered less than visible rays and hence can travel longer distances through atmosphere.
  - (c) Keeping earth's surface warm by green house effect. (Incoming visible light is absorbed by earth surface and earth radiates infrared radiations. The radiations are trapped by green house gases such as CO_2 and water vapours which results in rise of temperature of earth atmosphere).
  - (d) To provide electrical energy by using solar cells.
  - (e) Used in remote switches of household electronic systems.

Ultraviolet rays

- Ultraviolet rays are of frequency range 8×10^{14} to 5×10^{16} Hzof wavelength 3×10^{-8} to 4×10^{-7} m.
- Ultraviolet rays are produced by special lamps like mercury and from arc lamps and by very hot bodies like sun.
- Ultraviolet rays in solar radiations on reaching earth are absorbed by the ozone layer in atmosphere. Ultraviolet radiations in large quantities have harmful effects on humans.
- Ultraviolet rays are used in
  - (a) Study of molecular structure
  - (b) In sterilization to destroy bacteria
  - (c) In burglar alarms etc as they can cause photoelectric effect.
- U.V radiation is absorbed by ordinary glass. Hence glass window can protect us from UV rays.

***X*-rays**

- X-rays are of frequency range 8×10^{16} to 3×10^{21} Hz.
- X-rays are produced by Coolidge X-rays tube by bombarding a metal target by high energy electrons.
- X-rays are used in
  - (a) medical applications like detections of fractures, formation of stones etc, in human bodies.
  - (b) radio-therapy to cure skin disease and certain form of cancers.
  - (c) to scan luggage for explosives, guns etc.
  - (d) engineering for detection of faults, cracks etc in finished metal products.
  - (e) to study crystal structure of solids.
  - (f) over exposure of X-rays damages living tissues and organisms.

Gamma rays

- Gamma rays are of frequency range 3×10^{18} to 5×10^{22} Hzand of wavelength 6×10^{-13} to 10^{-10} m.
- Gamma rays are produced in nuclear reactions and are also emitted by radioactive nuclei.
- Gamma rays are used in
  - (a) radiotherapy to treat certain cancers and tumors.
  - (b) to produce nuclear reactions.

Illustration 3

A radio can tune to any station in the frequency range from 7.5 MHz to 12 MHz band. What is the corresponding wavelength band?

Soln.: Maximum wavelength in the band is for lowest frequency.

$$c = f_{min}\lambda_{max}$$

$$\lambda_{max} = \frac{c}{f_{min}} = \frac{3 \times 10^8}{7.5 \times 10^6}$$

$$\lambda_{max} = 40 \text{ m}$$

Minimum wavelength in the band is for highest frequency.

$$c = f_{max}\lambda_{min}$$

$$\lambda_{min} = \frac{c}{f_{max}} = \frac{3 \times 10^8}{12 \times 10^6} = 25 \text{ m}$$

So, the wavelength band for tuning is between 25 m to 40 m.