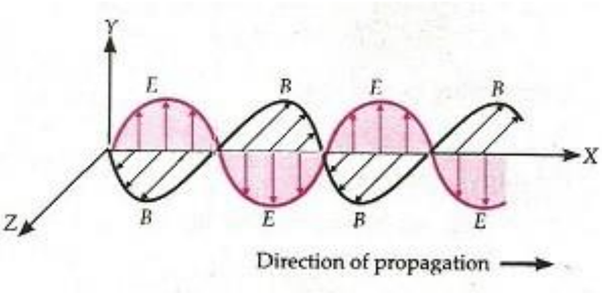
Electromagnetic Waves

- **Displacement Current:** It is due to time-varying electric field - $i_d = \varepsilon_0 \frac{d\phi_E}{dt}$
  Displacement current acts as a source of magnetic field in exactly the same way as conduction current.
- **Maxwell's equations:**

1. Gauss law of electrostatics- $\oint_s \vec{E}.d\vec{s} = \frac{q}{\varepsilon_o}$
2. Gauss law of magnetism- $\oint_s \vec{B}.d\vec{s} = 0$
3. Faraday's law of eletromagnetic induction- $\oint_c \vec{E}.d\vec{l} = -\frac{d\phi_B}{dt}$
4. Modified form of Ampere's circuital law- $\oint_c \vec{B}.d\vec{l} = \mu_o \left[I_c + \varepsilon_o \frac{d\phi_E}{dt}\right]$

- **Electromagnetic Waves:** These waves propagates through spaceas coupled electric and magnetic fields, oscillating perpendicular to each other and to the direction of propagation of the wave.



1. Electromagnetic waves are produced only by charges that are accelerating, since acceleration is absolute, and not a relative phenomenon.
2. An electric charge oscillating harmonically with frequency υ, produces electromagnetic waves of the same frequency υ.
3. An electric dipole is a basic source of electromagnetic waves.
4. Electromagnetic waves with wavelength of the order of a few metres were first produced and detected in the laboratory by Hertz in 1887. He thus verified a basic prediction of

Maxwell's equations.

5. Electromagnetic waves are transverse in nature.
6. They do not require any material medium for their propagation.

- **Oscillation of Electric and Magnetic Fields:** These oscillate sinusoidally in space and time in an electromagnetic wave. The oscillating electric and magnetic fields, E and B are perpendicular to each other and to the direction of propagation of the electromagnetic wave.
- For a wave of frequency v, wavelength λ, propagating along z-direction

$$E = E_X(t) = E_0 \sin(kz - \omega t) = E_0 \sin\left[2\pi\left(\frac{z}{\lambda} - vt\right)\right] = E_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \frac{t}{T}\right)\right]$$

$$B = B_Y(t) = B_0 \sin(kz - \omega t) = B_0 \sin\left[2\pi\left(\frac{z}{\lambda} - vt\right)\right] = B_0 \sin\left[2\pi\left(\frac{z}{\lambda} - \frac{t}{T}\right)\right]$$

$$\frac{E_o}{B_o} = c$$

- **Relation between μ_0 and ε_0** : The speed c of electromagnetic wave in vacuum is related to μ_0 and ε_0 (the free space permeability and permittivity constants) as $C = 1/\sqrt{\mu_0 \varepsilon_0}$
- The value of c equals the speed of light obtained from optical measurements. Light is an electromagnetic wave; c is, therefore, also the speed of light. Electromagnetic waves other than light also have the same velocity c in free space.
- **Speed of Light:** The speed of light, or of electromagnetic waves in a material medium is

$v = 1/\sqrt{\mu\varepsilon}$ Where μ is the permeability of the medium and ε its permittivity.

- Electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields.
- **Energy Per Unit Volume:** If in a region of space in which there exist electric and magnetic fields $\vec{E}$ and $\vec{B}$, there exists Energy Density (Energy per unit volume) associated with these fields is,
  $U = \frac{\varepsilon_0}{2}\vec{E}^2 + \frac{1}{2\mu_0}\vec{B}^2$ where we are assuming that the concerned space consists of vacuum only.

- Electromagnetic waves transport momentum as well. When these waves strike a surface, a pressure is exerted on the surface.
- If total energy transferred to a surface in time t is U, total momentum delivered to this surface is $p = U/c$.
- **Electromagnetic Spectrum:** The orderly distribution of the electromagnetic waves in accordance with their wavelength or frequency into distinct groups having widely differing properties is called electromagnetic spectrum.
- The classification has more to do with the way these waves are produced and detected.
- **Different Regions of Spectrum:** Different regions are known by different names; γ - rays, X-rays, ultraviolet rays, visible rays, infrared rays, microwaves and radio waves in order of increasing wavelength from $10^{-2}\overset{0}{A}$ or $10^{-12}m$ to $10^{6}m$

(a) Radio Waves:

- These are produced by accelerated motion of charges in wires.
- These are used in radio and television communication systems.
- These are generally in the frequency range from 500 kHz to about 1000 MHz or wavelength range 600 m to 0.1 m.

(b) Microwaves:

- These are short wavelength radio waves with frequency range 10^{9} Hz to 10^{12} Hz or wavelength range 0.3 m to 10^{-3} m.
- Due to their short wavelengths, they are suitable for radar systems used in aircraft navigation.
- Microwave ovens use them for cooking.

(c) Infrared Waves:

- Frequency range $10^{11}\,Hz\ to\ 5\times10^{14}\ Hz$ or wavelength range $5\times10^{-3}m\ to\ 10^{-6}m$
- These are produced by hot bodies and molecules.
- They lie in the low frequency or long wavelength end of the visible spectrum.

(d) Visible Light:

- The spectrum frequency runs from about 4 x $10^{14}Hz$ to about 7 x $10^{14}Hz$ or wavelength range $8 \times 10^{-7}m\ to\ 4 \times 10^{-7}m$.
- Our eyes are sensitive to this range of wavelengths.

(e) Ultraviolet light:

- It covers frequency range from $10^{16}Hz\ to\ 10^{17}Hz$ or wavelengths range from $3.5 \times 10^{-7}m\ to\ 1.5 \times 10^{-7}m$.
- The sun is an important source of UV rays.

(f) X-rays:

- It covers frequency range from $10^{18}Hz\ to\ 10^{20}Hz$ or wavelengths range from $100\ \overset{o}{\mathrm{A}}\ to\ 0.1\ \overset{o}{\mathrm{A}}$.
- It is used in medical diagnosis.

(g) Gamma Rays:

- These lie in the upper frequency range $\left(10^{18}Hz\ to\ 10^{22}Hz\right)$ of the spectrum, and have wavelengths in the range $10^{-14}m$ to $10^{-10}m$.
- It is used in manufacture of polyethylene from ethylene.

Various layers of earth's atmosphere: