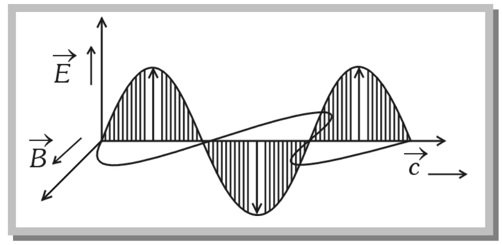
EM Waves.

(1) Definition

A changing electric field produces a changing magnetic field and vice versa which gives rise to a transverse wave known as electromagnetic wave. The time varying electric and magnetic field are mutually perpendicular to each other and also perpendicular to the direction of propagation of this wave.

The electric vector is responsible for the optical effects of an EM wave and is called the *light vector*.



(2) History of EM waves:

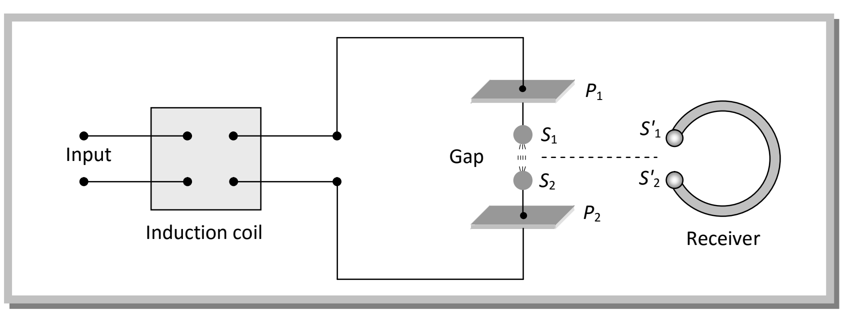
(i) Maxwell: Was the first to predict the EM wave.

(ii) Hertz: Produced and detected electromagnetic waves experimentally at wavelengths of 6 m.

Experimental setup

Hertz experiment based on the fact that an oscillating charge is accelerating continuously, it will radiate electromagnetic waves continuously. In the following figure

- The metallic plates (P1 and P2) acts as a capacitor.
- The wires connecting spheres S1 and S2 to the plates provide a low inductance.



When a high voltage is applied across metallic plates these plates get discharged by sparking across the narrow gap. The spark will give rise to oscillations which in turn send out electromagnetic waves. Frequency of these wave is given by $\nu = \dfrac{1}{2\pi\sqrt{LC}}$

The succession of sparks send out a train of such waves which are received by the receiver.

(iii) J.C. Bose: Produced EM waves of wavelength ranging from 5mm to 25 mm.

(iv) Marconi:Successfully transmitted the EM waves up to a few kilometer. Marconi discovered that if one of the spark gap terminals is connected to an antenna and the other terminal is Earthed, the electromagnetic waves radiated could go up to several kilometers.

(3) Source of EM waves

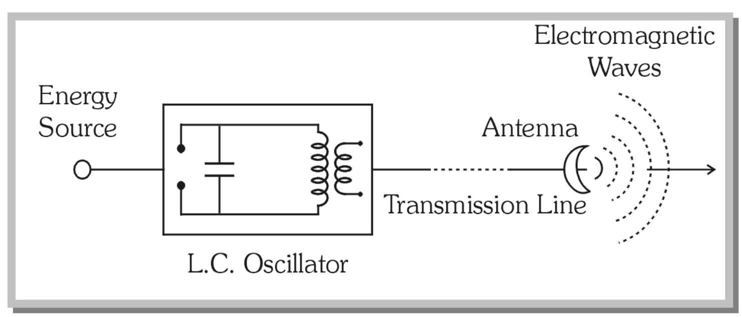
A charge oscillating harmonically is a source of EM waves of same frequency.

(4) Production of EM waves

A simple LC oscillator and energy source can produce waves of desired frequency.

Frequency of oscillating discharge in *LC* circuit =

Frequency of EM waves $= \dfrac{1}{2\pi\sqrt{LC}}$



Note: In an atom an electron circulating around the nucleus in a stable orbit, although accelerating does not emit electromagnetic waves; it does so only when it jumps from a higher energy orbit to a lower energy orbit.

Electromagnetic waves (X-rays) are also produced when fast moving electrons are suddenly stopped by a metal target of high atomic number.

Most efficient antennas are those which have a size comparable to the wavelength of the electromagnetic wave they emit or receive.

(5) Nature of EM waves

The EM Waves are transverse in nature. They do not require any material medium for their propagation.

(6) Properties of EM waves

(i) Speed: In free space it's speed $c=\frac{1}{\sqrt{\mu_0\varepsilon_0}}=\frac{E_0}{B_0}=3\times10^8\,m/s.$

In medium $v=\frac{1}{\sqrt{\mu\varepsilon}}$; where $\mu_0 =$ Absolute permeability, $\varepsilon_0 =$ Absolute permittivity

E_0 and $B_0 =$ Amplitudes of electric field and magnetic field vectors.

(ii) Energy: The energy in an EM waves is divided equally between the electric and magnetic fields.

Energy density of electric field $u_e=\frac{1}{2}\varepsilon_0E^2$, Energy density of magnetic field $u_B=\frac{1}{2}\frac{B^2}{\mu_0}$

It is found that $u_e=u_B$. Also $u_{av}=u_e+u_B=2u_e=2u_B=\varepsilon_0E^2=\frac{B^2}{\mu_0}$

(iii) Intensity (I): The energy crossing per unit area per unit time, perpendicular to the direction of propagation of EM wave is called intensity. $I=u_{av}\times c=\frac{1}{2}\varepsilon_0E^2c=\frac{1}{2}\frac{B^2}{\mu_0}.c$

(iv) Momentum: EM waves also carries momentum, if a portion of EM wave of energy u propagating with speed c, then linear momentum $=\frac{\text{Energy }(u)}{\text{Speed }(c)}$

Note: When the incident EM wave is completely absorbed by a surface, it delivers energy u and momentum u / c to the surface.

When a wave of energy u is totally reflected from the surface, the momentum delivered to surface is $2u/c$.

(v) Pointing vector $(\vec{S})$. : In EM waves, the rate of flow of energy crossing a unit area is described by the pointing vector. Its unit is $watt/m^2$ and $\vec{S} = \frac{1}{\mu_o}(\vec{E} \times \vec{B}) = c^2 \varepsilon_0 (\vec{E} \times \vec{B})$. Because in EM waves $\vec{E}$ and $\vec{B}$ are perpendicular to each other, the magnitude of $\vec{S}$ is

$$|\vec{S}| = \frac{1}{\mu_0} E\,B \sin 90^o = \frac{EB}{\mu_0} = \frac{E^2}{\mu C}.$$

Note: The direction of the pointing vector $\vec{S}$ at any point gives the wave's direction of travel and direction of energy transport the point.

(vi) Radiationpressure: Is the momentum imparted per second pre unit area. On which the light falls.

For a perfectly reflecting surface $P_r = \frac{2S}{c}$; S = Pointing vector; c = Speed of light for a perfectly absorbing surface $P_a = \frac{S}{c}$.

Note: The radiation pressure is real that's why tails of comet point away from the sun.