ELECTRO MAGNETIC WAVES

KEY POINTS

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Displacement Current

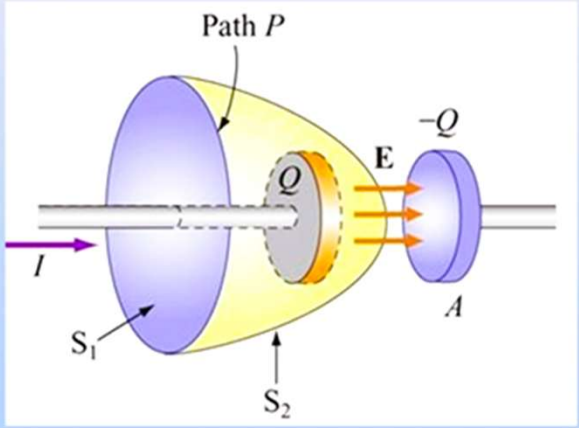
It is a current which produces in the region in which the electric field and hence the electric flux changes with time.

Displacement current, $I_D = \varepsilon_0 \cdot \dfrac{d\phi_E}{dt}$

where, ϕ_E is the electric flux.

Displacement Current

We don't have current between the capacitor plates but we do have a changing E field. Can we "make" a current out of that?



$$E = \frac{Q}{\varepsilon_0 A} \qquad Q = \varepsilon_0 EA = \varepsilon_0 \Phi_E$$

$$\frac{dQ}{dt} = \varepsilon_0 \frac{d\Phi_E}{dt} = I_{dis}$$

This is called the "displacement current".

It is not a flow of charge but proportional to changing electric flux

Maxwell's Equations

(i) $\oint_S \mathbf{E} \cdot d\mathbf{S} = \frac{q}{\varepsilon_0}$

This equation is Gauss's law in electrostatics.

(ii) $\oint_S \mathbf{B} \cdot d\mathbf{S} = 0$

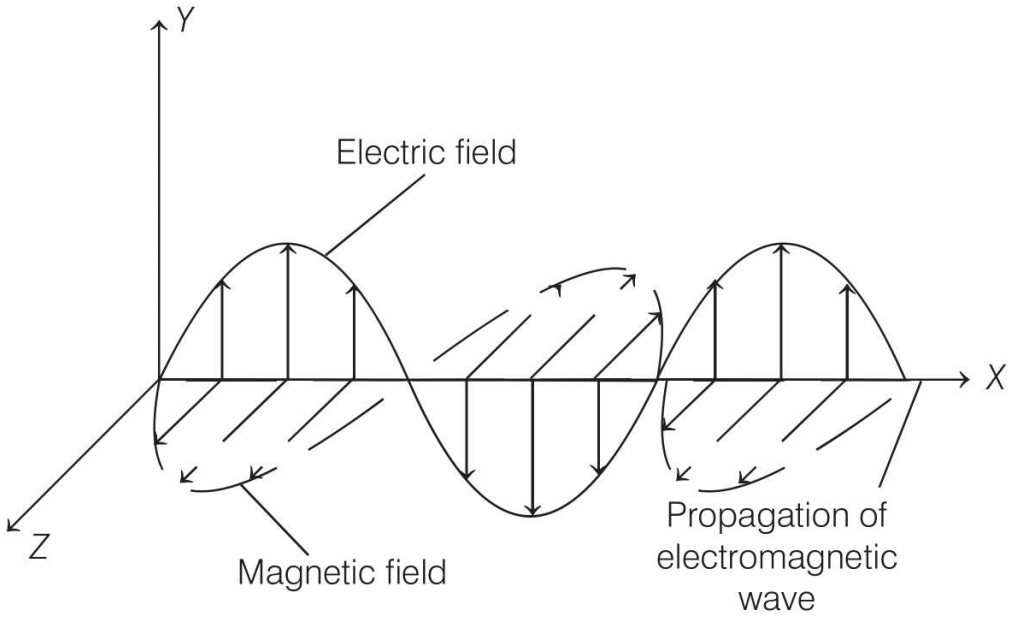
This equation is Gauss's law in magnetostatics.

(iii) $\oint_S \mathbf{E} \cdot d\mathbf{l} = -\frac{d\phi_\mathbf{B}}{dt}$

This equation is Faraday's law of electromagnetic induction.

(iv) $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 (I_C + I_D) = \mu_0 \left(I_C + \varepsilon_0 \frac{d\phi_E}{dt} \right)$

This equation is Ampere-Maxwell law.



The equation of plane progressive electromagnetic wave can be written as

$$E = E_0 \sin \omega \left(t - \frac{x}{c} \right)$$

and

$$B = B_0 \sin \omega \left(t - \frac{x}{c} \right) \text{a},$$

Properties of EM Waves

(i) These waves are transverse in nature.

(ii) The speed of electromagnetic wave, $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

where, μ_0 is permeability of free space and ε_0 is permittivity of free space,

$$c = \frac{E_0}{B_0}$$

where, E_0 and B_0 are maximum values of electric and magnetic field vectors.

The rate of flow of energy in an electromagnetic wave is described by the vector **S** called the poynting vector, which is defined by the expression,

$$\mathbf{S} = \frac{1}{\mu_0}(\mathbf{E} \times \mathbf{B})$$

SI unit of **S** is watt/m^2 or joules/second.

The energy in electromagnetic waves is divided equally between electric field and magnetic field vectors.

The average electric energy density.

$$U_E = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{4}\varepsilon_0 E_0^2$$

The average magnetic energy density,

$$U_B = \frac{1}{2}\frac{B^2}{\mu_0} = \frac{1}{4}\frac{B_0^2}{\mu_0}$$

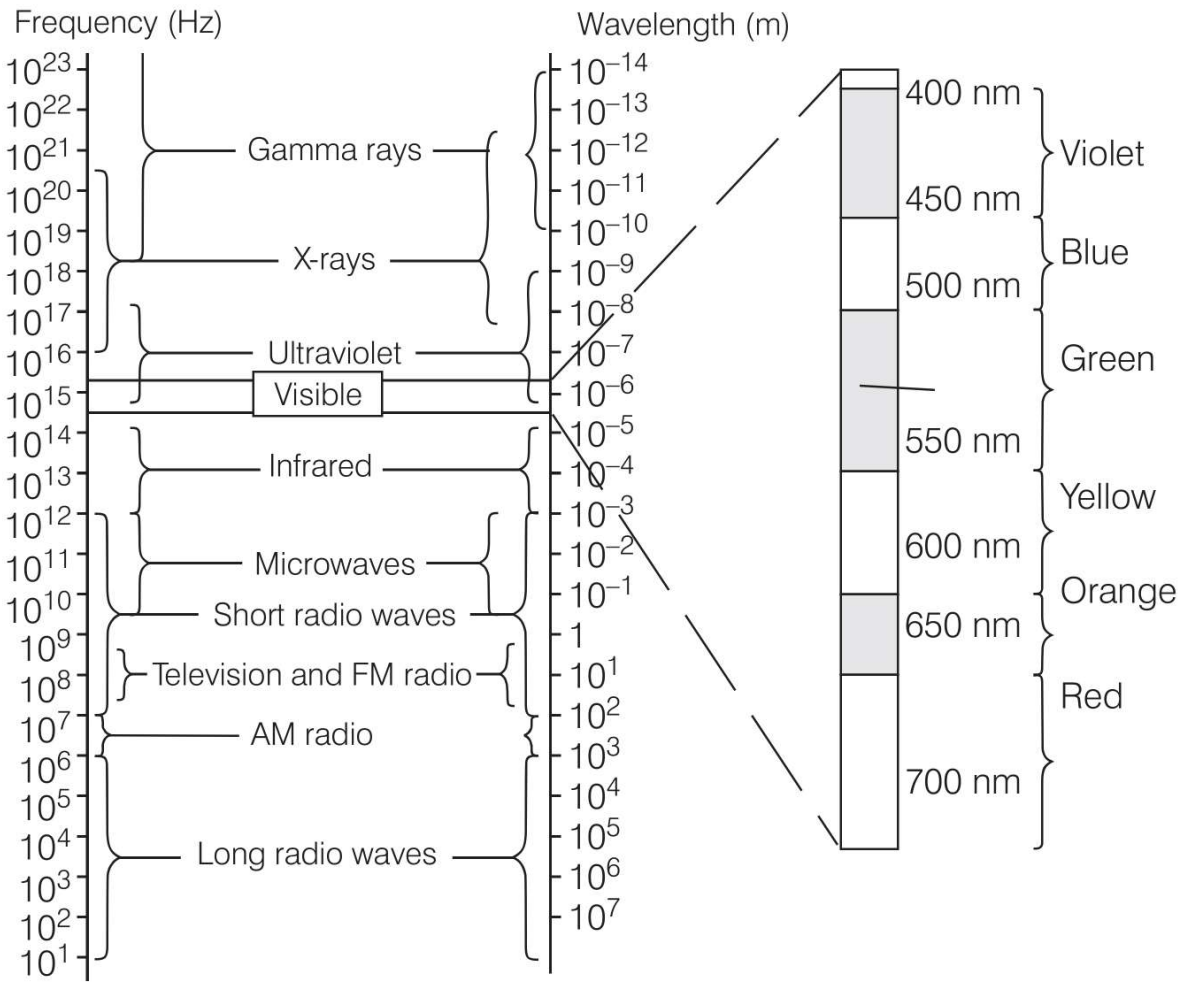
The intensity I is given by the relation, $I = < u > c = \frac{1}{2} \varepsilon_0 E_0^2 c$

Linear momentum of an EM wave is, $p = \frac{U}{c}$

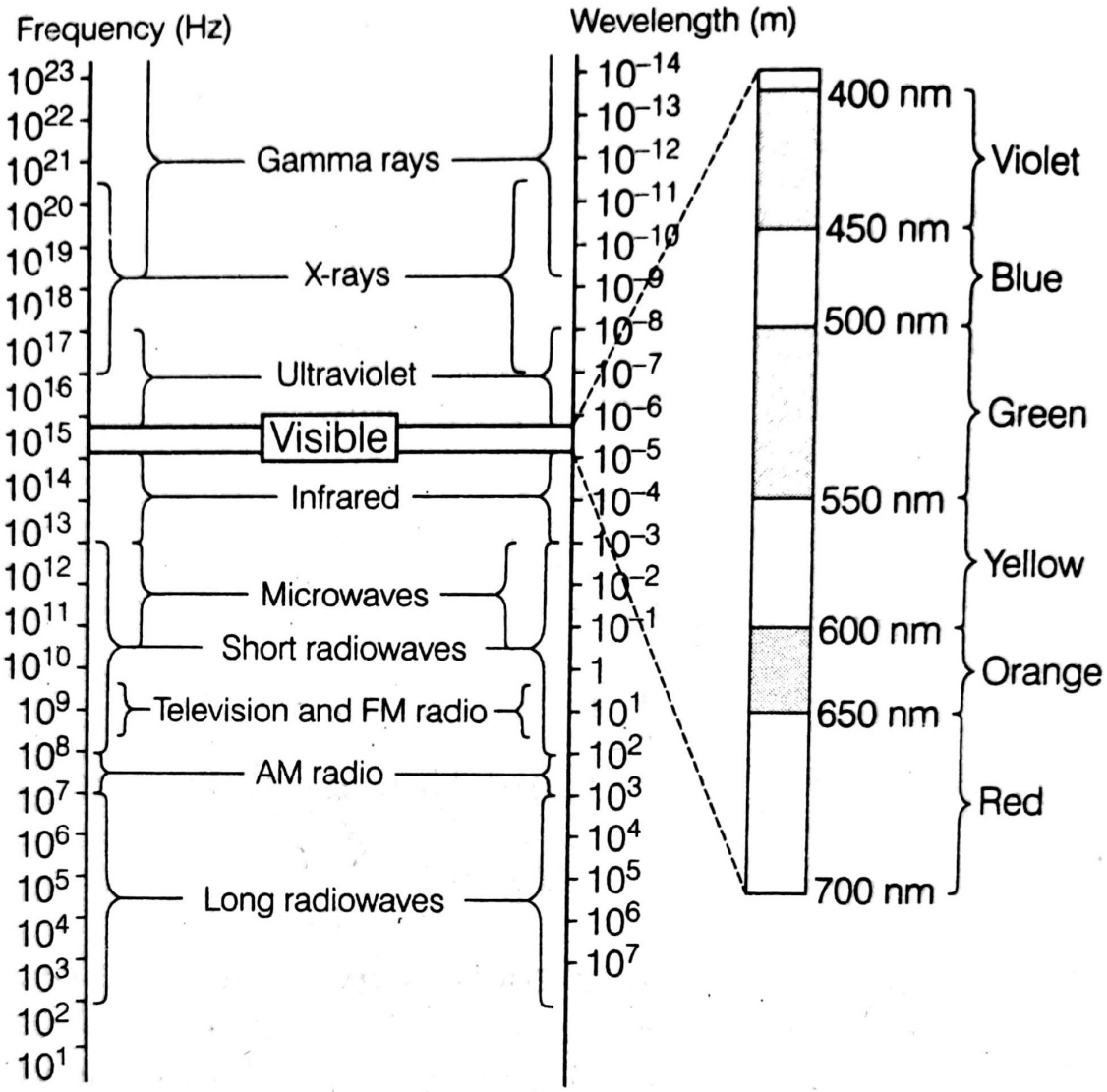
If wave is incident on a completely absorbing surface, then

$$p = \frac{U}{c}$$

If wave is incident on a totally reflecting surface, then $p = \frac{2U}{c}$



Electromagnetic spectrum with common names for various parts of it


Frequency (Hz)
Wevelength (m)
Gamma rays
X-rays
Ultraviolet
Visible
Infrared
Microwaves
Short radiowaves
Television and FM radio
AM radio
Long radiowaves
400 nm
450 nm
500 nm
550 nm
600 nm
650 nm
700 nm
Violet
Blue
Green
Yellow
Orange
Red

Radio waves

These are produced due to oscillating charge particles. The frequency varies from 500 kHz to 1000 MHz.

Uses of radio waves are given below

(i) These are used in AM (Amplitude Modulation) from 530 kHz to 1710 kHz. These are also used in ground wave propagation.

(ii) These are used in TV waves ranging from 54 MHz to 890 MHz.

(iii) These are used in FM (Frequency Modulation) ranging from 88 MHz to 108 MHz.

(iv) UHF (Ultra High Frequency) waves are used in cellular phones.

Microwaves

These waves are called **short wavelength radio waves** which are produced by vacuum tubes. Their frequency lies in the range of 1 GHz to 300 GHz (gigahertz).

Uses of microwaves are given below

(i) These are used in RADAR systems for aircraft navigation.

(ii) These are used in microwave oven for cooking purpose.

(iii) These are used in study of atomic and molecular structures.

(iv) These are used to measure the speed of vehicle, speed of cricket ball, etc.

Infrared Waves

These waves were discovered by Herschell. These waves are also called **heat waves.** These waves are produced from the heat radiating bodies and molecules.

They have high penetration power. Its frequency range is from 3×10^{11} Hz to 4×10^{14} Hz.

Uses of infrared waves are given below

(i) These are used in physical therapy.

(ii) These are used in satellite for army purpose.

(iii) These are used in weather forecasting.

(iv) These are used for producing dehydrated fruits.

(v) These are used in solar water heater, solar cells and cooker.

Visible Rays

It is that part of spectrum which is visible by human eye and its frequency range is from 4×10^{14} Hz to 7×10^{14} Hz.

Uses of visible rays are given below

Visible rays are used by the optical organs of humans and animals for three primary purposes given below:

(i) To see things, avoid bumping from them and escape danger.

(ii) To find stuff to eat.

(iii) To find other living things with which to consort so as to prolong the species.

Ultraviolet Rays

These rays were discovered by Ritter in 1801. These rays are produced by special lamps and very hot bodies. The sun is an important source of UV-rays but fortunately absorbed by ozone layer at an altitude of about 40-50km. Its frequency range is from 10^{14} Hz to 10^{16} Hz.

Uses of ultraviolet rays are given below

(i) These are used in burglar alarm.

(ii) These are used in checking mineral sample.

(iii) These are used to study molecular structure.

(iv) To kill germs in minerals.

(v) To sterilise surgical instruments.

(vi) These rays can be focussed into very narrow beams for high precision applications such as LASIK eye surgery.

X-Rays

These rays were discovered by German professor Roentgen. Its frequency range is from 3×10^{16} Hz to 3×10^{21} Hz.

Uses of X-rays are given below

(i) These are used in surgery to detect the fracture, diseased organs, stones in the body, etc.

(ii) These are used in engineering to detect fault, crack on bridges, testing of welds.

(iii) These are used at metro station to detect metal or explosive material.

(iv) These are used in scientific research.

Gamma (γ) Rays

These rays were discovered by Rutherford. They travel with the speed of light and having high penetration power. The frequency ranges from 3×10^{18} Hz to 5×10^{22} Hz.

Uses of gamma (γ) rays are given below

(i) These are used to produce nuclear reaction.

(ii) These are used in radio therapy for the treatment of tumour and cancer.

(iii) These are used in food industry to kill pathogenic microorganism.

(iv) These are used to provide valuable information about the structure of atomic nucleus.

THANK YOU

JAI HIND

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