CHAPTER 8

ELECTROMAGNETIC WAVES

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INTRODUCTION

- Electromagnetic waves are one of the predictions of Maxwell's equations.
- Electromagnetic waves are time varying electric and magnetic fields that propagate in space.
- **Hertz** experimentally confirmed the existence of electromagnetic waves with the help of **spark gap oscillator**.
- **J C Bose** produced electromagnetic waves of smaller wavelength (5mm-25mm).
- **Marconi** discovered that electromagnetic wave can radiate up to several kilometers.

DISPLACEMENT CURRENT

- From Maxwell's correction to Ampere's circuital law , the total current *i is the sum of the conduction current* denoted by i_c, *and the displacement current denoted by* i_d.

$$i = i_e + i_d = i_c + \varepsilon_0 \frac{d\Phi_E}{dt}$$

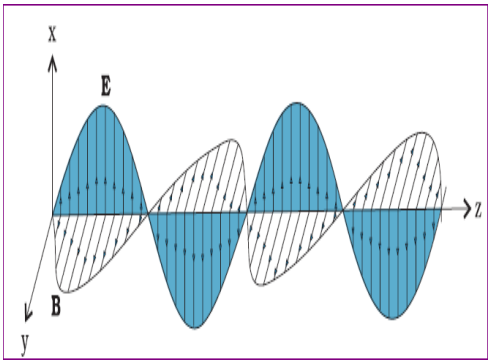
$$I_d = \varepsilon_0 \frac{d\phi_E}{dt}$$

- The current due to changing electric field (or electric *displacement*) is called ***displacement current or Maxwell's displacement current.***
- The current carried by conductors due to flow of charges is called ***conduction current.***
- Thus the generalized Ampere's circuital law (Ampere-Maxwell law) is given by

$$\oint \mathbf{B}\cdot d\mathbf{l} = \mu_0 i_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$$

Nature of electromagnetic waves

- An electric charge oscillating with a frequency produces em waves of the same frequency.
- The electric and magnetic fields in an electromagnetic wave are perpendicular to each other, *and to the direction of* propagation.



- The electric and magnetic fields are represented by

$$E_x = E_0 \sin(kz - \omega t)$$
$$B_y = B_0 \sin(kz - \omega t)$$

- Here *k is related to the wave length λ of the wave by the* equation,

$$k = \frac{2\pi}{\lambda}$$

- The speed of propagation of the wave is ***(ω/k).***
- The magnitude of the electric and the magnetic fields in an electromagnetic wave are related as

$$B_0 = (E_0/c)$$

- Pressure exerted by em wave is called **radiation pressure**

Properties of EM waves

- They are self-sustaining oscillations of electric and magnetic fields in free space, or vacuum.
- Shows transverse wave nature.
- No material medium is needed for its propagation.
- EM waves are not deflected in electric field and magnetic field.
- The velocity of em waves in any media is given by

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

- EM waves are polarised.

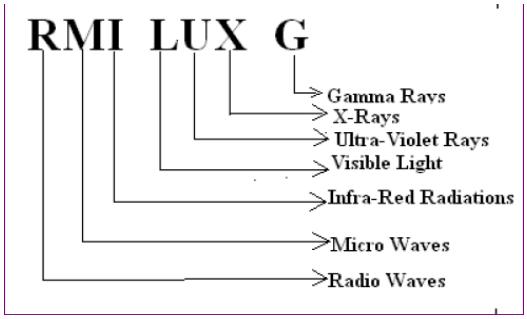
- Electromagnetic waves carry energy and momentum like other waves.
- If the total energy transferred to a surface in time *t is U,* the magnitude of the total momentum delivered to this surface (*for complete absorption) is,*

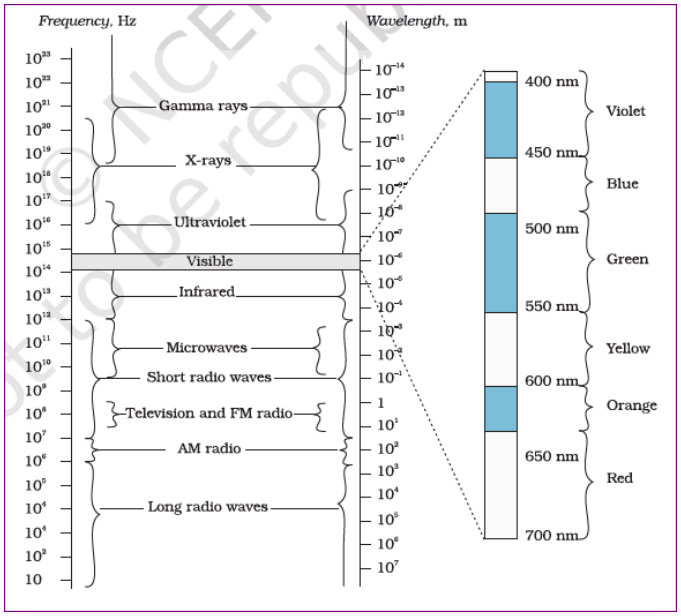
$$p = \frac{U}{c}$$

ELECTROMAGNETIC SPECTRUM

- An arrangement of electromagnetic radiations according to their wavelength or frequency**.**
- Some of the waves in the **increasing order of frequency (decreasing order of wavelength) are :**

Radio waves, microwaves, infra-red, visible light, ultra violet, x-rays, Gamma rays





Radio waves

- Radio waves are produced by the accelerated motion of charges in conducting wires.
- They are used in radio and television communication systems.
- They are generally in the frequency range from 500 kHz to about 1000 MHz.
- The AM (amplitude modulated) band is from 530 kHz to 1710 kHz.
- Higher frequencies up to 54 MHz are used for *short wave bands. TV waves range* from 54 MHz to 890 MHz.
- The FM (frequency modulated) radio band extends from 88 MHz to 108 MHz.
- Cellular phones use radio waves to transmit voice communication in the ultrahigh frequency (UHF) band.

Microwaves

- Microwaves are produced by special vacuum tubes such as klystrons, magnetrons and Gunn diodes.
- Microwaves are used for the radar systems used in aircraft navigation. Radar also provides the basis for the speed guns used to time fast balls, tennis serves, and automobiles.
- Used in Microwave ovens.
- In such ovens, the frequency of the microwaves is selected to match the resonant frequency of water molecules so that energy from the waves is transferred efficiently to the kinetic energy of the molecules. This raises the temperature of any food containing water.
- Also used in satellite communication.

Infrared waves

- Infrared waves are produced by hot bodies and molecules.
- Infrared waves are referred to as *heat waves. This i*s because water molecules present in most materials readily absorb infrared waves (many other molecules, for example, CO_2, NH_3, also absorb infrared waves). After absorption, their thermal motion increases, that is, they heat up and heat their surroundings.

- Infrared radiation plays an role in maintaining the earth's warmth or average temperature through the **greenhouse effect**.
- Incoming visible light is absorbed by the earth's surface and reradiated as infrared radiations. This radiation is trapped by greenhouse gases such as carbon dioxide and water vapour.
- Infrared detectors are used in Earth satellites, both for military purposes and to observe growth of crops.
- Electronic devices (for example semiconductor light emitting diodes) also emit infrared and are widely used in the remote switches of household electronic systems such as TV sets, video recorders and hi-fi systems.
- Used in secret signaling and burglar alarms.
- Used in the treatment of dislocations, paralysis etc.
- Used to take the photographs of distant objects.
- Used in physiotherapy
- Used for determination of molecular structure.

Visible rays

- It is the part of the spectrum that is detected by the human eye.
- It runs from about a wavelength range of about 700 – 400 nm.
- Visible light emitted or reflected from objects around us provides us information about the world. Our eyes are sensitive to this range of wavelengths.
- Different animals are sensitive to different range of wavelengths. For example, snakes can detect infrared waves, and the 'visible' range of many insects extends well into the ultraviolet.

Ultraviolet rays

- Ultraviolet (UV) radiation is produced by special lamps and very hot bodies
- The sun is an important source of ultraviolet light. But most of it is absorbed in the ozone layer in the atmosphere at an altitude of about 40 – 50 km.
- UV light in large quantities has harmful effects on humans. Exposure to UV radiation induces the production of more melanin, causing tanning of the skin.
- UV radiation is absorbed by ordinary glass. Hence, one cannot get tanned or sunburn through glass windows.
- Welders wear special glass goggles or face masks with glass windows to protect their eyes from large amount of UV produced by welding arcs.
- Due to its shorter wavelengths, UV radiations can be focused into very narrow beams for high precision applications such as **LASIK** (*Laser assisted in situ keratomileusis) eye surgery.*
- *UV lamps are used to kill* germs in water purifiers.
- Ozone layer in the atmosphere plays a protective role.
- Used in the manufacture of fluorescent tubes
- Used in the determination of age of written documents
- Used in the detection of finger prints.
- Helps to produce vitamin D in our skin.

X-rays

- Beyond the UV region of the electromagnetic spectrum lies the X-ray region.
- W Roentgen discovered x-rays
- One common way to generate X-rays is to bombard a metal target by high energy electrons.
- X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.
- Because X-rays damage or destroy living tissues and organisms, care must be taken to avoid unnecessary or over exposure**.**

- Used to study structure of atoms molecules and crystals
- Used to detect cracks and holes inside a sheet of metal.
- Used to detect hidden materials.

Gamma rays

- They lie in the upper frequency range of the electromagnetic spectrum.
- This high frequency radiation is produced in nuclear reactions and also emitted by radioactive nuclei.
- They are used in medicine to destroy cancer cells.
- Used to study structure of nuclei of atom.
- Used to sterilize surgical Instruments,
- Used to detect cracks in underground metal pipes etc

Production and detection of em waves

Type	Wavelength range	Production	Detection
Radio	> 0.1 m	Rapid acceleration and decelerations of electrons in aerials	Receiver's aerials
Microwave	0.1m to 1 mm	Klystron valve or magnetron valve	Point contact diodes
Infra-red	1mm to 700 nm	Vibration of atoms and molecules	Thermopiles Bolometer, Infrared photographic film
Light	700 nm to 400 nm	Electrons in atoms emit light when they move from one energy level to a lower energy level	The eye Photocells Photographic film
Ultraviolet	400 nm to 1nm	Inner shell electrons in atoms moving from one energy level to a lower level	Photocells Photographic film
X-rays	1nm to 10^{-3} nm	X-ray tubes or inner shell electrons	Photographic film Geiger tubes Ionisation chamber
Gamma rays	$<10^{-3}$ nm	Radioactive decay of the nucleus	-do-

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