ATOMIC ENERGY CENTRAL SCHOOL, MYSORE

DISTANT LEARNING PROGRAM 2020-21

CLASS:XII – PHYSICS (CHAPTER-8)

ELECTROMAGNETIC WAVES

PPT (1 of 1)

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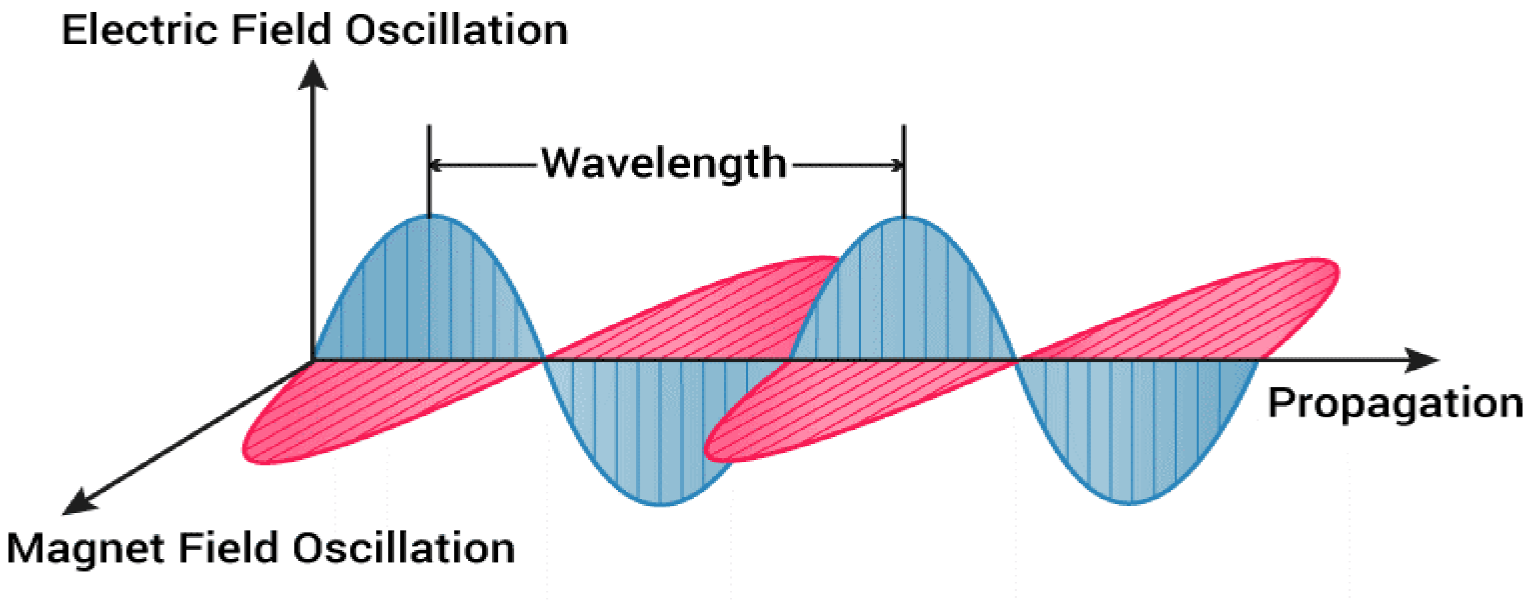
INTRODUCTION:

The phenomenon of Faraday's electromagnetic induction concludes that a **changing magnetic field** at a point with time **produces an electric field** at that point. Maxwell, pointed out that there is a symmetry in nature (i.e) **changing electric field** with time at a point **produces a magnetic field** at that point. It means that a **change in one field with time** (either electric or magnetic) **produces another field**. This idea led Maxwell to conclude that the variation in electric and magnetic fields perpendicular to each other, produces electromagnetic disturbances in space. These disturbances have the properties of a wave and propagate through space without any material medium. These waves are called **electromagnetic waves**.They travel in vacuum or free space with a velocity $\mathbf{3 \times 10^{8}\ m\ s^{-1}}$.



DISPLACEMENT CURRENT:

We know that an electric current produces a magnetic field around it. Maxwell showed that a changing electric field must also produce a magnetic field. To see how a changing electric field gives rise to a magnetic field, let us consider the process of charging of a capacitor .To find the magnetic field at a point outside the capacitor, let us apply Ampere's circuital law.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \, i \, (t) \longrightarrow (1)$$

Consider a parallel plate capacitor *C* which is a part of circuit through which a time-dependent current *i* (*t*) flows.

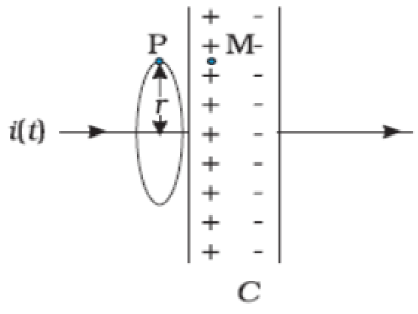


Figure (a)

To find the magnetic field at a point P, in a region outside the parallel plate capacitor, let us consider a plane circular loop of radius *r* whose plane is perpendicular to the direction of the current-carrying wire, and which is centred symmetrically with respect to the wire.

By symmetry, the magnetic field is directed along the circumference of the circular loop and is the same in magnitude at all points on the loop. If B is the magnitude of the field, then

$$B \oint dl = B\,(2\pi r)$$

$$\therefore \quad B\,(2\pi r) = \mu_0\, i\,(t) \quad \longrightarrow \quad (2)$$

Now, consider a different surface, which has the same boundary. This is a pot like surface as shown as in figure (b), which nowhere touches the current, but has its bottom between the capacitor plates, whose mouth is the circular loop mentioned above.

Consider another such surface which is shaped like a tiffin box (without the lid) as in figure (c)

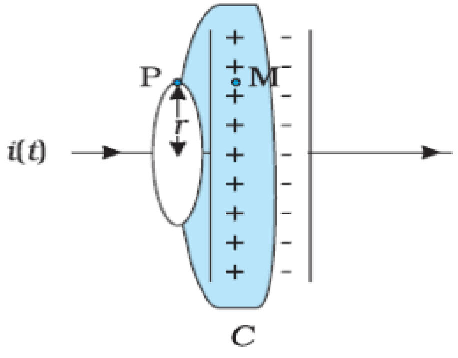


Figure (b)

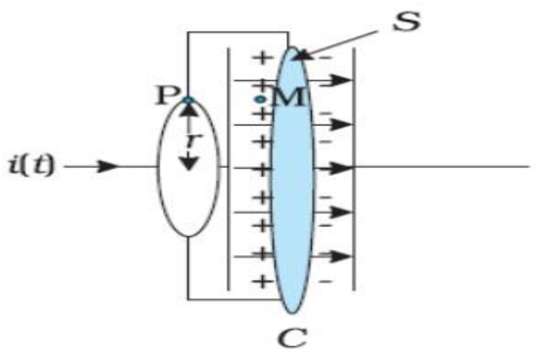


Figure (c)

On applying Ampere's circuital law to such surfaces with the **same perimeter**, we find that the LHS term in equn (2) is the same, but the RHS term is zero, since no current passes through the surfaces. Calculating by one way, there is a magnetic field at point P. Calculating by another way, the magnetic field at point P is zero. Hence, Ampere's circuital law must be missing something.

The missing term is due to the passage of electric field through the surface S between the plates of the capacitor.

If A → area of the plates of the capacitor and

Q → total charge on each plate of the capacitor,

The electric field E between the plates is given by

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0} \longrightarrow \quad (3)$$

This field is perpendicular to the surface S in figure (c). It has the same magnitude over the area A of the capacitor plates.

Using Gauss's law, the electric flux through the surface S is given by

$$\phi_E = E\,A = \frac{Q}{A\varepsilon_0} A$$

(or)

$$\phi_E = \frac{Q}{\varepsilon_0} \longrightarrow \quad (4)$$

Since the charge Q on the capacitor plates changes with time, there is a current *i* which is given by

$$i = \frac{dQ}{dt}$$

Differentiating equn (4) $\quad \frac{d\phi_E}{dt} = \frac{1}{\varepsilon_0}\frac{dQ}{dt} = \frac{1}{\varepsilon_0} i$

$$\text{(or)} \quad \varepsilon_0 \frac{d\phi_E}{dt} = i \longrightarrow (5)$$

This is the missing term in Ampere's circuital law.

The current given by equn (5) is due to changing electric field (or electric displacement). Hence, it is called '**Displacement Current'.**

The current carried by conductors due to flow of charges is called '**conduction current**'.

The source of a magnetic field is not just the conduction electric current due to flowing charges, but also the time rate of change of electric field. The total current *i* is the sum of the conduction current denoted by i_c , and the displacement current denoted by i_d ($\varepsilon_0 \frac{d\phi_E}{dt}$).

$$\therefore \quad i = i_c + i_d = i_c + \varepsilon_0 \frac{d\phi_E}{dt} \longrightarrow (6)$$

Outside the capacitor plates, we have only conduction current $i_c = i$, and **no displacement current**, i.e., $i_d = 0$. On the other hand, **inside the capacitor**, there is **no conduction current**, i.e., $i_c = 0$, and there is only displacement current, so that $i_d = i$. Hence, B at a point P outside the plates is the same at a point M between the plates.

The generalised Ampere's circuital law is given by

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \, i_c + \mu_0 \, i_d$$

(or) $$\oint \vec{B} \cdot \vec{dl} = \mu_0 \, (i_c + i_d)$$

(or) $$\oint \vec{B} \cdot \vec{dl} = \mu_0 \left[i_c + \varepsilon_0 \frac{d\phi_E}{dt} \right] \longrightarrow (7)$$

This equn (7) is called Ampere-Maxwell law.

MAXWELL'S EQUATIONS:

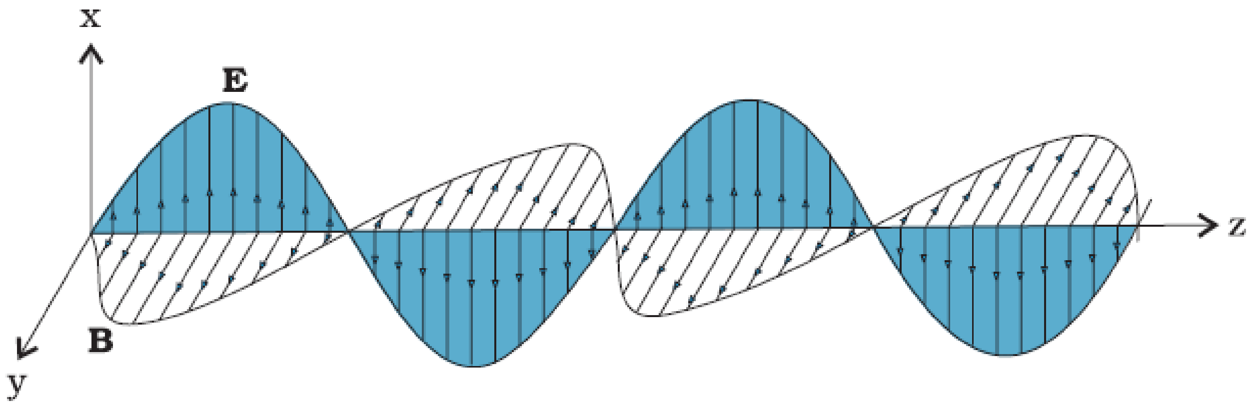
1. $\oint \vec{E} \cdot \vec{dA} = \frac{Q}{\varepsilon_0}$ — Gauss's law for electricity
2. $\oint \vec{B} \cdot \vec{dA} = 0$ — Gauss's law for magnetism
3. $\oint \vec{E} \cdot \vec{dl} = -\frac{d\phi_B}{dt}$ — Faraday's law
4. $\oint \vec{B} \cdot \vec{dl} = \mu_0 \left[i_c + \varepsilon_0 \frac{d\phi_E}{dt} \right]$ — Ampere-Maxwell law

SOURCES OF ELECTROMAGNETIC WAVES:

Consider a charge oscillating with some frequency (**accelerating charge**).This produces an **oscillating electric field** in space, which produces an **oscillating magnetic field**, which in turn, is a source of oscillating electric field, and so on. The oscillating electric and magnetic fields thus regenerate each other, as the wave propagates through the space . The frequency of the electromagnetic wave naturally equals the frequency of oscillation of the charge. The energy associated with the propagating wave comes at the expense of the energy of thesource – the accelerated charge.

NATURE OF ELECTROMAGNETIC WAVES:

From Maxwell's equations, it is found that electric and magnetic fields in an electromagnetic wave are perpendicular to each other, and to the direction of propagation. A typical example of a plane electromagnetic wave propagating along the *z* direction(the fields are shown as a function of the *z* coordinate, at a given time *t*). The electric field $\boldsymbol{E_x}$ is along the *x*-axis, and varies sinusoidally with *z*, at a given time. The magnetic field $\boldsymbol{B_y}$ is along the *y*-axis, and again varies sinusoidally with *z*. The electric and magnetic fields $\boldsymbol{E_x}$ and $\boldsymbol{B_y}$ are perpendicular to each other, and to the direction *z* of propagation.



E → Electric Field (along X-axis)

B → Magnetic Field (along Y- axis)

Electromagnetic Waves along Z-axis

We can write $\boldsymbol{E_x}$ and $\boldsymbol{B_y}$ as follows:

$$E_x = E_0 \sin(k z - \omega t) \longrightarrow (1)$$

$$B_y = B_0 \sin(k z - \omega t) \longrightarrow (2)$$

where, $k = \frac{2\pi}{\lambda}$ → magnitude of the wave vector (or) propagation vector. Its direction describes the direction of propagation of the wave.

and ω → angular frequency

The speed of propagation of EM waves is $c = \frac{\omega}{k} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ ⟶ (3)

where, μ_0 → permeability of free space

and, ε_0 → permittivity of free space

Since $\omega = 2\pi\upsilon$ and $k = \frac{2\pi}{\lambda}$, $c = \frac{\omega}{k} = 2\pi\upsilon \times \frac{\lambda}{2\pi}$

(or) $$c = \upsilon\lambda \qquad \longrightarrow \qquad (4)$$

Also, it can be shown that

$$B_0 = \frac{E_0}{c} \qquad \longrightarrow \qquad (5)$$

where, $B_0 \rightarrow$ amplitude of magnetic field and

$E_0 \rightarrow$ amplitude of electric field

PROPERTIES OF ELECTROMAGNETIC WAVES:

(1) Electromagnetic waves are produced by accelerated charges.

(2) They do not require any material medium for propagation.

(3) In an electromagnetic wave, the electric ($\vec{E}$) and magnetic ($\vec{B}$) field vectors are at right angles to each other and to the direction of propagation. Hence electromagnetic waves are transverse in nature.

(4) Variation of maxima and minima in both $\vec{E}$ and $\vec{B}$ occur simultaneously.

(5) EM waves can be diffracted, refracted and polarised.

(6)They travel in vacuum or free space with a velocity 3×10^8 m s^{-1}. It is given by the relation

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

where, $\mu_0 \rightarrow$ permeability of free space and $\varepsilon_0 \rightarrow$ permittivity of free space

(7) Since the energy density (energy per unit volume) associated with the electric field is $\frac{1}{2} \varepsilon_0 E^2$ and the energy density associated with magnetic field is $\frac{B^2}{2\mu_0}$, there is a non zero energy density associated with the electromagnetic waves.

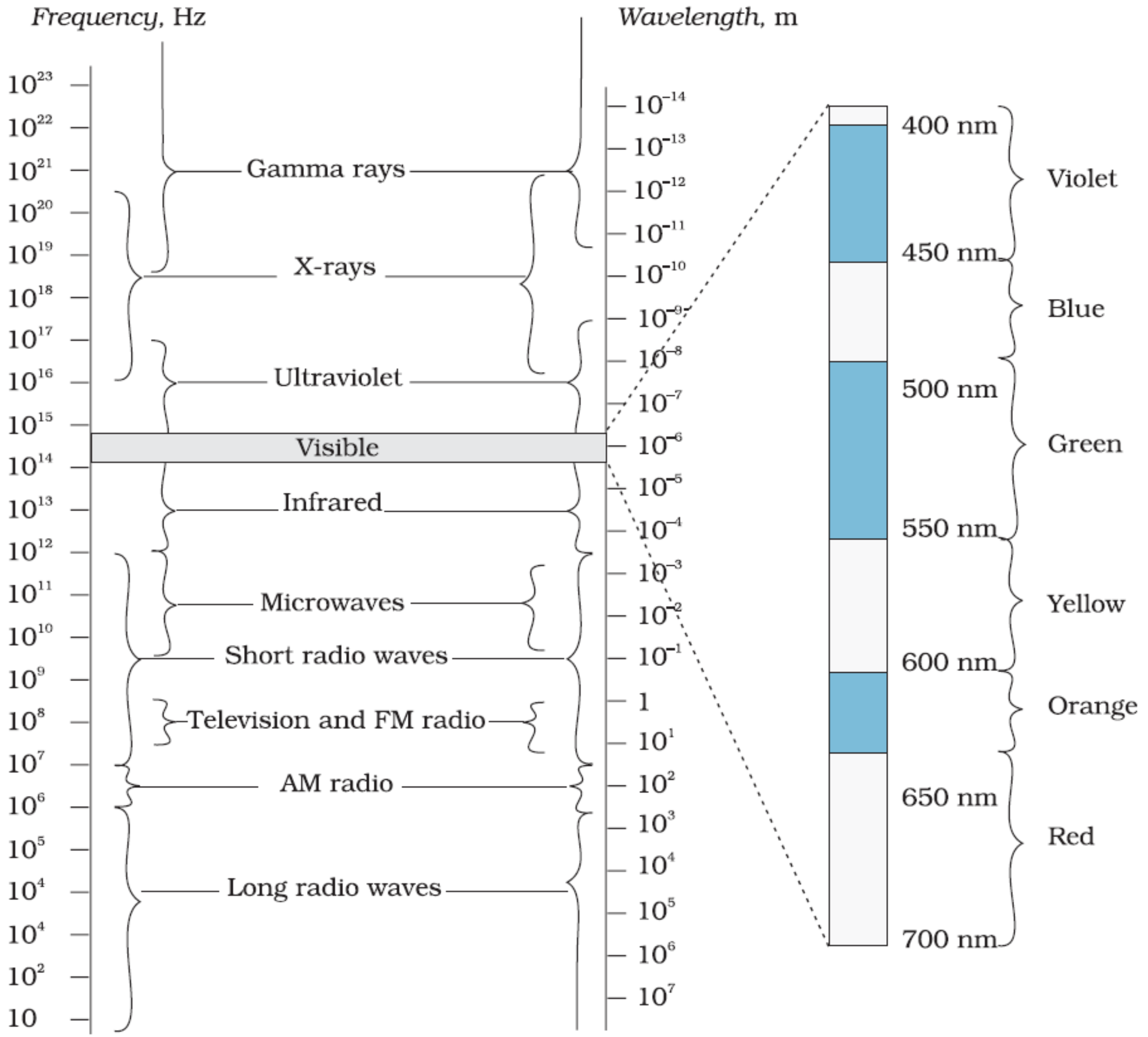
(8) Electromagnetic waves possess energy and momentum. Hence EM waves exert pressure called 'radiation pressure'.

(9) If the total energy transferred to a surface in time *t* is U, it can be shown that the magnitude of the total momentum delivered to this surface (for complete absorption) is, p = U/c.

(10) Electromagnetic waves are not deflected by electric and magnetic fields.

<u>ELECTROMAGNETIC SPECTRUM</u>:

Electromagnetic spectrum is an orderly distribution of electromagnetic waves in terms of wavelength or frequency



Electromagnetic spectrum covers a wide range of wavelengths (or) frequencies. There is no sharp division between one kind of wave and the next. The overlapping in certain parts of the spectrum shows that the particular wave can be produced by different methods. We briefly describe these different types of electromagnetic waves, in order of decreasing wavelengths or increasing frequencies.

1. Radio waves
2. Micro waves
3. Infra red waves
4. Visible rays
5. Ultra violet rays
6. X-rays
7. Gamma rays

RADIO WAVES :

(1) Radio waves are produced by the accelerated motion of charges in conducting wires.

(2) They are used in radio and television communication systems.

(3) They are generally in the frequency range from 500 kHz to about 1000 MHz.

(4) The AM (amplitude modulated) band is from 530 kHz to 1710 kHz.

(5) Higher frequencies upto 54 MHz are used for short wave bands.

(6) TV waves range from 54 MHz to 890 MHz.

(7) The FM (frequency modulated) radio band extends from 88 MHz to 108 MHz.

(8) Cellular phones use radio waves to transmit voice communication in the ultrahigh frequency (UHF) band.

MICRO WAVES:

(1) Microwaves are short-wavelength radio waves, with frequencies in the gigahertz (GHz) range.

(2) They are produced by special vacuum tubes (called klystrons, magnetrons and Gunn diodes).

(3) Due to their short wavelengths, they are suitable for the radar systems used in aircraft navigation.

(4) Radar also provides the basis for the speed guns used to time fast balls, tennis serves, and automobiles.

(5) Micro waves are used in very long distance wireless communication through satellites.

(6) Micro waves are used in micro wave oven to cook food.

Working: It is used to cook the food in a short time. When the oven is operated, the microwaves are generated, which in turn produce a non–uniform oscillating electric field. The water molecules in the food which are the electric dipoles are excited by an oscillating torque. Hence few bonds in the water molecules are broken, and heat energy is produced. This is used to cook food.

INFRA RED WAVES:

(1) Infrared waves are produced by hot bodies and molecules.

(2) This band lies adjacent to the low-frequency or long-wave length end of the visible spectrum.

(3) Infrared waves are sometimes referred to as '***heat waves'***.

(4) Infrared lamps are used in physical therapy.

(5) Infrared radiation also plays an important role in maintaining the earth's warmth or average temperature through the greenhouse effect.

(6) Infrared detectors are used in Earth satellites, both for military purposes and to observe growth of crops.

(7) 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.

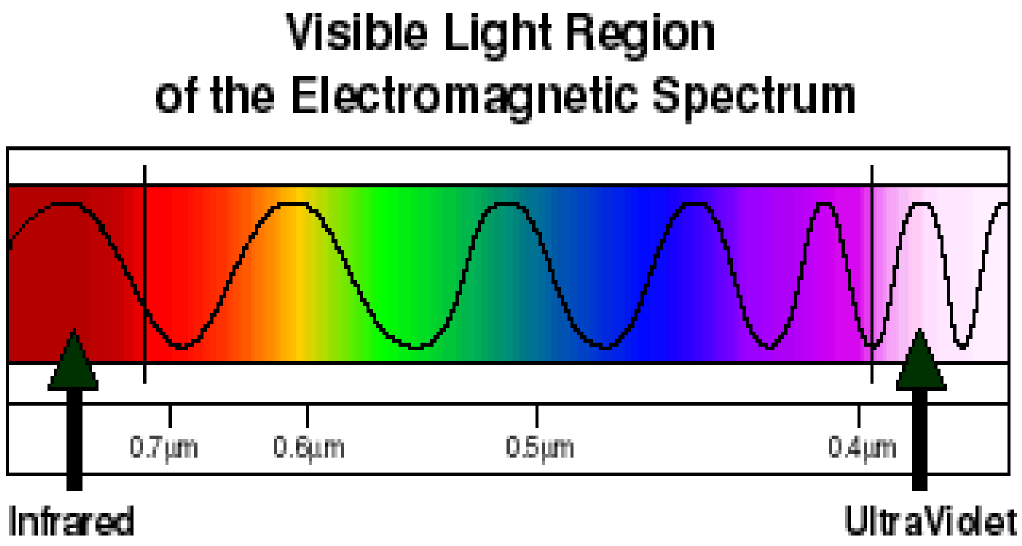
VISIBLE RAYS:

(1) It is the part of the spectrum that is detected by the human eye.

(2) Its frequency ranges from about 4×10^{14} Hz to about 7×10^{14} Hz or a wavelength range of about 700 nm to 400 nm.

(3) Visible light emitted or reflected from objects around us provides us information about the world.

(4) It is produced by incandescent bodies



ULTRA VIOLET RAYS:

(1) It covers wavelengths ranging from about 4×10^{-7} m (400 nm) down to 6×10^{-10} m (0.6 nm).

(2) Ultraviolet (UV) radiation is produced by special lamps and very hot bodies.

(3) The Sun is an important source of ultraviolet light.

(4) UV light in large quantities has harmful effects on humans.

(5) UV radiation is absorbed by ordinary glass. (**Application**: Welders wear special glass goggles or face masks with glass windows to protect their eyes from large amount of UV produced by welding arcs)

(6) Due to its shorter wavelengths, UV radiations can be focussed into very narrow beams for high precision applications such as LASIK (Laser assisted in situ kerato mileusis) eye surgery.

(7) UV lamps are used to kill germs in water purifiers.

X-RAYS:

(1) X-rays lie beyond the UV region of the electromagnetic spectrum.

(2) It covers wavelengths from about 10^{-8} m (10 nm) down to 10^{-13} m (10^{-4} nm).

(3) X-rays are used as a diagnostic tool in medicine and as a treatment for certain forms of cancer.

(4) X-rays damage or destroy living tissues and organisms.

(5) One common way to generate X-rays is to bombard a metal target by high energy electrons.

GAMMA RAYS:

(1) They lie in the upper frequency range of the electromagnetic spectrum and have wavelengths from about 10^{-10} m to less than 10^{-14} m.

(2) They are the high frequency radiation produced in nuclear reactions and also emitted by radioactive nuclei..

(3) They are used in medicine to destroy cancer cells.

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ELECTROMAGNETIC WAVES

BIBLIOGRAPHY:

I acknowledge that the contents are taken from NCERT Text book in Physics for class XII (2020-21)

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