Electromagnetic Spectrum and Uses of EM Waves

Content Outline

Unit Syllabus

Chapter-8: Electromagnetic Waves

Basic idea of displacement current, Electromagnetic waves, their characteristics, their transverse nature (qualitative ideas only).

Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses

Module Wise Distribution Of Unit Syllabus - 2 Modules

Module 1	• Displacement current • Characteristics of em waves • Why are they called waves? • E and B vectors and relation between them • Transverse nature of em waves
Module2	• Explanation of em waves spectrum • Range of frequency , wavelength • Sources of em waves • Properties • Uses of em waves

Module 2

Words You Must Know

- **Magnetic Field:** A region around a magnetic material or a moving electric charge within which the force of magnetism acts.
- **Electric Field:** A region around a charged particle or object within which a force would be exerted on other charged particles or objects.
- **Constant Magnetic Field:** Magnetic field intensity B is constant. Example: field inside a solenoid in its central region.
- **Constant Electric Field:** Electric field intensity E is constant. Example electric field between dissimilarly charged parallel plates.
- **Time Varying Magnetic Field:** Magnetic field which changes with time. Example field around a conductor connected in an ac circuit.
- **Time Varying Electric Field:** Electric field which varies with time. Example field between parallel plate capacitor connected in ac circuit.
- **Capacitor:** A device used to store an electric charge, consisting of one or more pairs of conductors separated by an insulator.
- **Inductor:** A wire coiled to create a magnetic field whenever current passes through it. Its resistance is minimal; however, a circuit offers impedance, inductive reactance.
- **Electromagnetic Induction:** An emf is induced in a closed loop of wire whenever the magnetic field linked with it changes.
- **Lenz's Law:** In Electromagnetic induction,the direction of induced emf in a conductor is such that it opposes the cause producing it.
- **Alternating Current and Direct Current:** Is an electric current in which the flow of electric charge periodically reverses direction, whereas in direct current (DC, also dc), the flow of electric charge is only in one direction.
- **Electromagnetic Energy:** In an LC circuit U = $\frac{1}{2}\frac{q^2}{C} + \frac{1}{2}Li^2$
- **Conduction Current:** The current in the conductor across which a potential difference is maintained. the potential different may be constant or variable.
- **Displacement Current:**
    - The magnetic field of a current distribution is given by Ampere's law:
    - $\int \vec{B}.\vec{dL} = \mu_0 I$

- ○ dL is the small segment of the imagined amperian loop, I is the current enclosed by the loop.
- ○ In case the current wire is broken and connected to a parallel-plate capacitor. A current will flow through the wire during charging or discharging of the capacitor plates. This current will generate a magnetic field . Ampere's law cannot be applied in this case as an Amperian loop does not contain any current.
- ○ The electric field changes between the plates. A magnetic field is associated with it.
- ○ Displacement current as proposed by Maxwell suggests a current that could be producing the magnetic field. By imagining displacement current, the current in the circuit is continuous.
- ○ Although the surface shown in Figure 35.1 does not intercept any current, it intercepts electric flux.

- **Electromagnetic Wave:** Energy waves that are propagated by simultaneous periodic variations of electric and magnetic field intensity and that include radio waves, infrared, visible light, ultraviolet, X-rays, and gamma rays.

Introduction

We have learnt Maxwell (1831-1879), presented arguments to support not only an electric current but also a time-varying electric field generates magnetic field. While applying the Ampere's circuital law to find magnetic field at a point outside a capacitor connected to a time-varying current, Maxwell noticed an inconsistency in the Ampere's circuital law. He suggested the existence of an additional current, called by him, the displacement current to remove this inconsistency.

Maxwell formulated a set of equations involving electric and magnetic fields, and their sources, the charge and current densities. These equations are known as Maxwell's equations. Together with the Lorentz force formula, we can mathematically express all the basic laws of electromagnetism.

The most important prediction to emerge from Maxwell's equations is the existence of electromagnetic waves, which are (coupled) time varying electric and magnetic fields that propagate in space.

The speed of the waves, according to these equations, turned out to be very close to the speed of light(3×10^8 m/s), obtained from optical measurements. This led to the remarkable conclusion that light is an electromagnetic wave.

How are electromagnetic waves produced?

Neither stationary charge nor charges in uniform motion (steady currents) can be sources of electromagnetic waves. The former produces only electrostatic fields, while the latter produces magnetic fields that, however, do not vary with time.

It is an important result of Maxwell's theory that accelerated charges radiate electromagnetic waves.

The proof of this basic result is beyond the scope of our study, but we can accept it on the basis of rough, qualitative reasoning.

Consider a charge oscillating with some frequency(or an 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 generate each other continuously, so to speak, as the wave propagates through 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 the source – the accelerated charge.

From the preceding discussion, it might appear easy to test the prediction that light is an electromagnetic wave. We might think that all we needed to do was to set up an ac circuit in which the current oscillates at the frequency of visible light, say, yellow light. But, alas that is not possible. The frequency of yellow light is about 6×10^{14} Hz, while the frequency that we get even with modern electronic circuits is much less, about 10^{11}Hz.

This was experimentally established by Hertz (1887).The demonstration of electromagnetic waves was in the low frequency region (called the radio wave region). Hertz's successful experimental test of Maxwell's theory created a sensation and sparked off other important works in this field.

Two important achievements in this connection deserve mention.

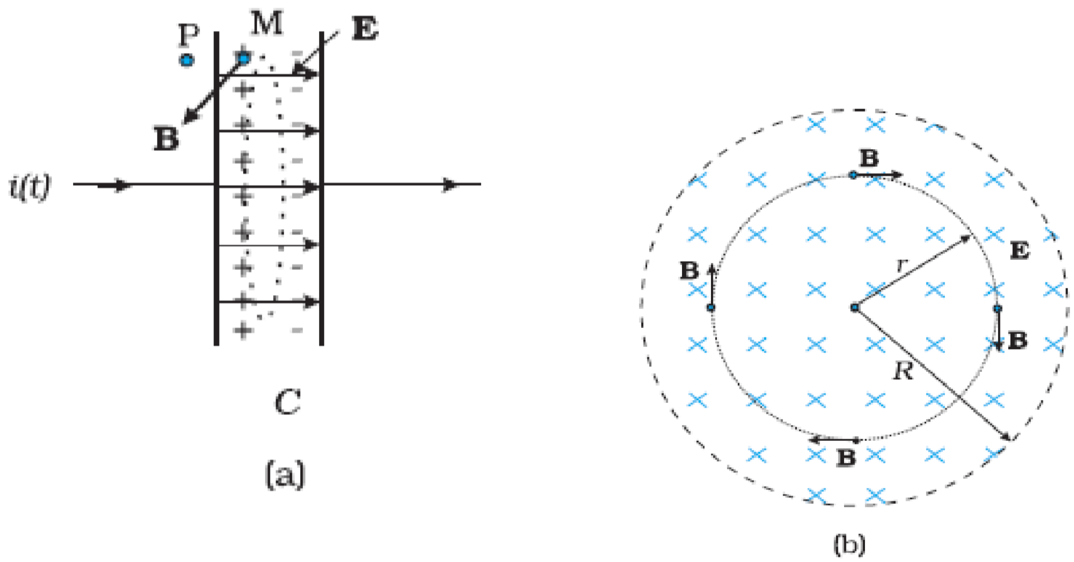
- Seven years after Hertz, Jagdish Chandra Bose, working at Calcutta (now Kolkata), succeeded in producing and observing electromagnetic waves of much shorter wavelength (25 mm to 5 mm).His experiment, like that of Hertz's was confined to the laboratory.

- Guglielmo Marconi in Italy followed Hertz's work and succeeded in transmitting electromagnetic waves over distances of many kilometers. Marconi's experiment marks the beginning of the field of communication using electromagnetic waves.

Nature of Electromagnetic Waves

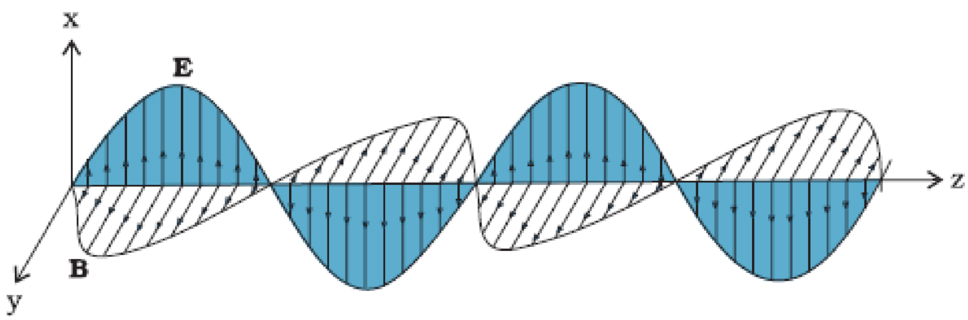
It can be shown from Maxwell's equations that electric and magnetic fields in an electromagnetic wave are perpendicular to each other, and to the direction of propagation. It appears reasonable, say from our discussion of the displacement current.

Consider the figure:



The electric field inside the plates of the capacitor is directed perpendicular to the plates. The magnetic field this gives rise to via the displacement current is along the perimeter of a circle parallel to the capacitor plates. So B and E are perpendicular in this case.

This is a general feature.



The above figure shows 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 E_x is along the x-axis, and varies sinusoidally with z at a given time.
- The magnetic field B_y is along the y-axis and again varies sinusoidally with z.
- The electric and magnetic fields E_x and B_y are perpendicular to each other, and to the direction z of propagation.
- We can write E_x and B_y as, we had written for waves in general
- $E_x = E_0 sin\,(kz - \omega t)$
- $B_y = B_0\, sin(kz - \omega t)$
- E_0, B_0 are peak values,
- E, B are in the same phase
- K is the magnitude of the wave vector and is related to wavelength λ

  $k = \frac{2\pi}{\lambda}$
- ω is the angular frequency , it has no physical significance for a wave, but its value is 2πf , where f is the frequency of the wave.
- The speed of propagation of the wave is (ω/k).
- From standard relation for waves we have

  $\boldsymbol{\omega = ck}$**,** where $\mathbf{c} = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$
- This relation is often written in terms of frequency, $f=\omega/2\pi)$ and wavelength,

  $\boldsymbol{\lambda = 2\pi/k}$
- $\mathbf{f\,\lambda = \mathit{c}}$
- Speed of the electromagnetic waves in vacuum is the same for all frequency waves and is same as that of light 3×10^8m/s
- It is also seen from Maxwell's equations that the magnitude of the electric and the magnetic fields in an electromagnetic wave are related as:

  $B_0 = (E_0/c)$
- The velocity of electromagnetic waves in free space or vacuum is an important fundamental constant. It has been shown by experiments on electromagnetic waves of different wavelengths that this velocity is the same (independent of wavelength) to within a few meters per second, out of a value of 3×10^8 m/s. The constancy of the

velocity of em waves in vacuum is so strongly supported by experiments and the actual value is so well known now that this is used to define a standard of *length*.

For example, the metre is now *defined* as the distance travelled by light in vacuum in a time ($1/c$) seconds = $(2.99792458 \times 10^8)^{-1}$ s. This has come about for the following reason.

- **The basic unit of time can be defined very accurately in terms of some atomic frequency, i.e., frequency of light emitted by an atom in a particular process. This process as we understand is the electron transition from one energy state to another due to excitation and the release of em waves as a consequence of it getting back to an unexcited state .The frequency corresponds to the frequency of electron jumps.**
- **The basic unit of length is harder to define as accurately in a direct way. Earlier measurement of c using earlier units of length (metre rods, etc.) converged to a value of about 2.9979246×10^8 m/s. Since c is such a strongly fixed number, the unit of length can be defined in terms of c and the unit of time!**
- Hertz not only showed the existence of electromagnetic waves, but also demonstrated that the waves, which had wavelength ten million times that of the light waves, could be diffracted, refracted and polarized. Thus, he conclusively established the wave nature of the radiation. Further, he produced stationary electromagnetic waves and determined their wavelength by measuring the distance between two successive nodes. Since the frequency of the wave was known (being equal to the frequency of the oscillator), he obtained the speed of the wave using the formula
- $v = f\lambda$ and found that the waves travelled with the same speed as the speed of light.
- Electromagnetic waves carry energy and momentum like other waves.
- From our study of electrostatics we have seen that in the region of free space with electric field E, there is an energy density ($\varepsilon_0 E^2/2$)
- An associated magnetic field B is a magnetic energy density ($B^2/2\mu_0$).

  As electromagnetic waves contain both electric and magnetic fields, there is a non-zero energy density associated with it.

Now consider a plane perpendicular to the direction of propagation of the electromagnetic wave. If there are, on this plane, electric charges, they will be set and sustained in motion by the electric and magnetic fields of the electromagnetic wave. The charges thus acquire energy and momentum from the waves. This just illustrates the

fact that an electromagnetic wave (like other waves) carries energy and momentum. Since it carries momentum, an electromagnetic wave also exerts pressure, called radiation pressure.

When the sun shines on your hand, you feel the energy being absorbed from the electromagnetic waves (your hands get warm).

Electromagnetic waves also transfer momentum to your hand but because *c* is very large, the amount of momentum transferred is extremely small and you do not feel the pressure.

Properties of Electromagnetic Waves

All electromagnetic waves do not have the same frequency and wavelength but the product of frequency and wavelength for all is the same. We list some general properties of the electromagnetic wave.

- **The electromagnetic waves are produced by accelerated charge and do not require any material medium of their propagation.**
- **They are self-sustaining oscillations of electric and magnetic fields in free space.**
- **They do not need any material medium for propagation, electric and magnetic fields oscillating in space and time can sustain each other in vacuum.**
- **The electromagnetic waves are transverse in nature, they travel with the same speed in vacuum =3 $\times 10^8$m/s.** $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ **where electric permittivity and magnetic permeability of vacuum are being considered.**
- **In any material medium the speed changes it is given by** $v = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = \frac{c}{refractive\ index}$ **, here the electric permittivity and magnetic permeability of the medium is taken into account ,also refractive index =** $\frac{velocity\ of\ em\ wave\ in\ vacuum\ (c)}{velocity\ of\ em\ wave\ in\ the\ material}$
- **The electromagnetic waves carry energy as they travel through space or through any medium the energy is shared equally by electric and magnetic fields. the average energy density of the wave in free space or vacuum is given by**

  $$\frac{1}{2}\left[\varepsilon_0 E_0^2 + \frac{B_0^2}{\mu_0}\right]$$

  $this\ makes\ them\ useful\ for\ taking\ signals\ for\ radio\ ,\ TV\ mobiles\ from\ one\ place\ to\ anothe$

- **Electromagnetic waves transport linear momentum and em waves incident on a surface exert pressure on the surface. This pressure is called radiation pressure.**
- **Electromagnetic waves are not deflected by electric and magnetic fields.**
- **Electromagnetic waves follow the principle of superposition.**
- **Electromagnetic waves show properties of reflection, refraction, interference, diffraction and polarization.**
- **The electric field vector is responsible for optical effects as $E_0 >> B_0$**

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

Problems for Conceptual Understanding

Example

A plane electromagnetic wave of frequency 25 MHz travels in free space along the *x*-direction. At a particular point in space and time, E = 6.3 $\hat{j}$ V/m. What is B at this point?

Solution

The magnitude of B is

$$B = \frac{E}{c}$$

$$= \frac{6.3\,\text{V/m}}{3 \times 10^8\,\text{m/s}} = 2.1 \times 10^{-8}\,\text{T}$$

To find the direction, we note that E is along the y-direction and the wave propagates along the x-axis. Therefore, B should be in a direction perpendicular to both *x*- and *y*-axes. Using vector algebra, E × B should be along the x-direction. Since $(+\hat{j}) \times (+\hat{k}) = \hat{i}$, B is along the *z*-direction.

Thus, $B = 2.1 \times 10^{-8}\,\hat{k}$ T

What do we learn from this example?

This example shows us that:

- **We can give numerical values to E and B vectors**
- **We can describe the directions of E and B vectors**
- **It also shows that vector B is very small as compared to vector E**

- **So when we show the em waves by a sinusoidal waveform the frequency and wavelength is the same for E and B vectors but the scale representing E vector and B vector is such that the two seem to have the same amplitude.**

Example

The magnetic field in a plane electromagnetic wave is given by $B_y = 2 \times 10^{-7}$ sin (0.5×103 x + 1.5 × 1011 t) T

a. What is the wavelength and frequency of the wave?
b. Write an expression for the electric field.

Solution

Comparing the given equation with:

$$B_y = B_0 sin\left[2\pi\left(\frac{x}{\lambda} + \frac{t}{T}\right)\right]$$

We get,

$$\lambda = \frac{2\pi}{0.5\times10^3} m = 1.26\ cm$$

and

$$\frac{1}{T} = \vartheta = \frac{\left(1.5\times10^{11}\right)}{2\pi} = 23.9\ G\ Hz$$

$E_0 = B_0\, c = 2\times10^{-7}$ T × 3 × 10^8 m/s = 6 × 10 V/m

The electric field component is perpendicular to the direction of propagation and the direction of magnetic field. Therefore, the electric field component along the z-axis is obtained as:

E_z = 60 sin (0.5 × $10^3 x$ + 1.5 × 10^{11} t) V/m

What do we learn from this example?

This example shows us:

- **Application of general Wave equation to em waves**

  $$y = A\, sin\, 2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

- **The wave equation gives us the vector E or B at a point located at a distance x , in space around the source at an instant t.**
- **Frequency and wavelength are the same for wave equation representing electric and magnetic fields.**
- **Wavelength is calculated using the coefficient of x from the equation.**
- **Frequency is calculated using the coefficient of t.**

Example

Light with an energy flux of 18 W/cm^2 falls on a non reflecting surface at normal incidence, if the surface has an area of 20 cm^2, find the average force exerted on the surface during a 30 minute time span.

Solution

The total energy falling on the surface is:

U = energy flux ×surface area ×time in seconds

= (18 W/cm^2) × (20 cm^2) × (30 × 60)

= 6.48 × 10 ^{5}J

Therefore, the total momentum delivered (for complete absorption) is:

$$p = \frac{U}{c} = \frac{6.48 \times 10^5 \text{J}}{3 \times 10^8 \text{m/s}} = 2.16 \times 10^{-3} \text{ kg m/s}$$

The average force exerted on the surface is:

$$F = \frac{p}{t} = \frac{2.16 \times 10^{-3}}{0.18 \times 10^4} = 1.2 \times 10^{-6} \text{N}$$

What do we learn from this example?

- **Light energy falling on any surface is independent of the nature of surface.**
- **Energy falling on a surface is calculated in the same way.**
- **The momentum delivered to the surface of the body depends upon how much energy is absorbed.**
- **How will your result be modified if the surface is a perfect reflector?**
- **What if the light rays were obliquely incident instead of normal incidence?**

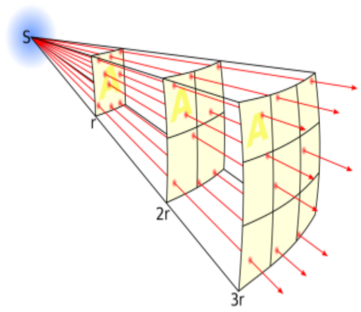
Example

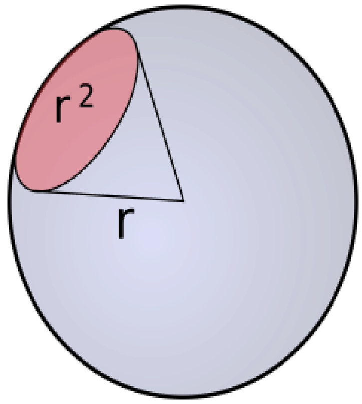
Calculate the electric and magnetic fields produced by the radiation coming from a 100 W bulb at a distance of 3 m. Assume that the efficiency of the bulb is 2.5% and it is a point source.

Solution

The bulb, as a point source, radiates light in all directions uniformly. At a distance of 3 m, the surface area of the surrounding

$$A = 4\pi r^2 = 4\pi(3)^2 = 113 \text{m}^2$$





The diagram can be used to imagine the light bulb located at the center of the sphere

The intensity at this distance is

$$I = \frac{\text{Power}}{\text{Area}} = \frac{100\,\text{W} \times 2.5\,\%}{113\,\text{m}^2}$$
$$= 0.022\ \text{W/m}^2$$

Half of this intensity is provided by the electric field and half by the magnetic field.

$$\frac{1}{2} I = \frac{1}{2}\left(\varepsilon_0 E_{rms}^2 c\right)$$
$$= \frac{1}{2}\left(0.022\,\text{W/m}^2\right)$$

$$E_{rms} = \sqrt{\frac{0.022}{\left(8.85 \times 10^{-12}\right)\left(3 \times 10^{8}\right)}}\ \text{V/m}$$
$$= 2.9\ \text{V/m}$$

The value of E found above is the root mean square value of the electric field. Since the electric field in a light beam is sinusoidal, the peak electric field, E_0 is

$$E_0 = \sqrt{2} E_{\text{rms}} = \sqrt{2} \times 2.9\,\text{V/m}$$
$$= 4.07\ \text{V/m}$$

Thus, you see that the electric field strength of the light that you use for reading is fairly large.The electric field strength of TV or FM waves, which is of the order of a few micro volts per metre is much less as compared to light.

Now, let us calculate the strength of the magnetic field. It is

$$B_{rms} = \frac{E_{rms}}{c} = \frac{2.9\ \ \text{V m}^{-1}}{3 \times 10^{8}\,\text{m s}^{-1}} = 9.6 \times 10^{-9}\ \text{T}$$

Again, since the field in the light beam is sinusoidal, the peak magnetic field is

$B_0 = 2\ B_{rms} = 1.4 \times 10^{-8}$ T.

Note that although the energy in the magnetic field is equal to the energy in the electric field, the magnetic field strength is evidently very weak.

Electromagnetic Spectrum

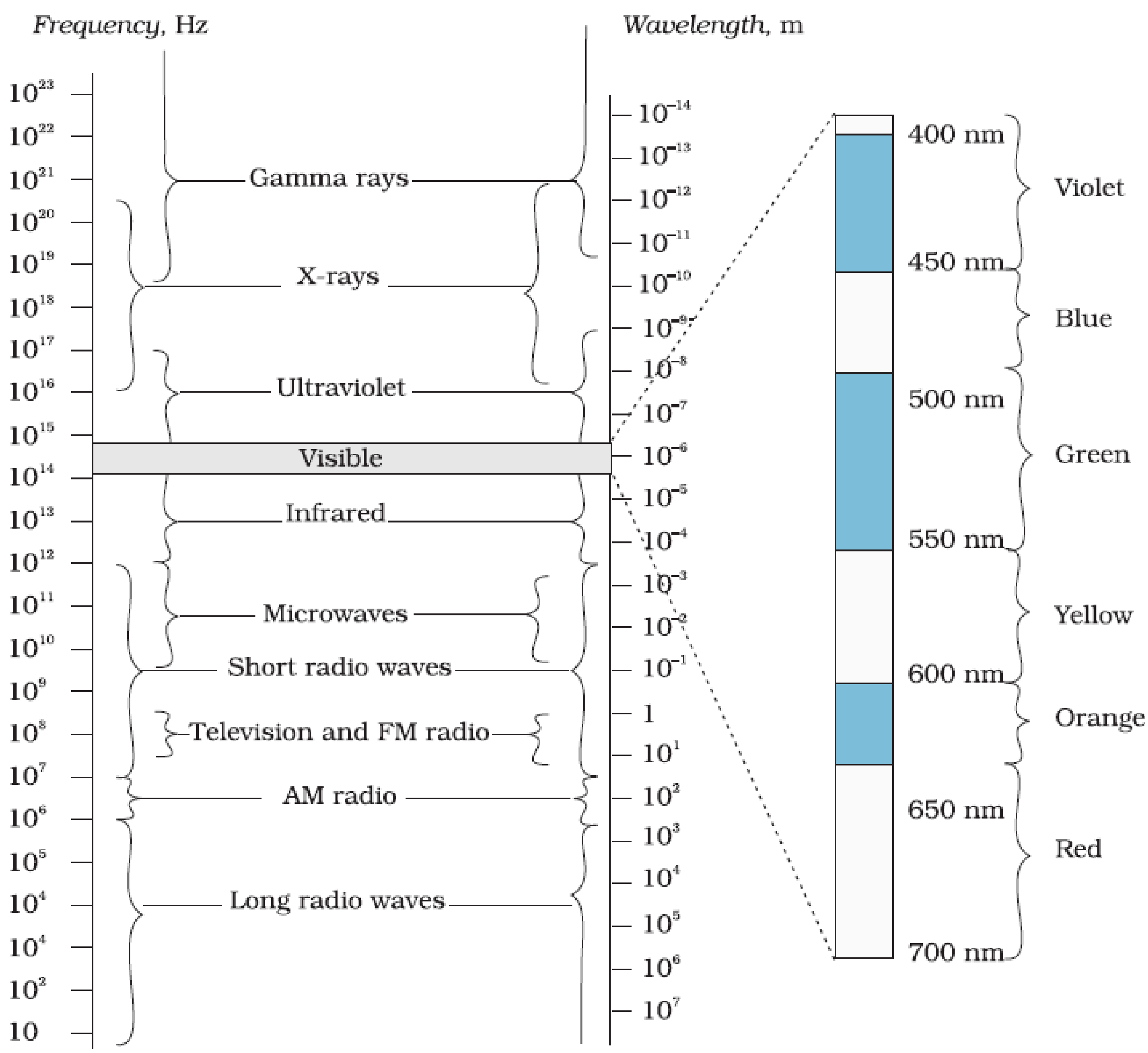
Maxwell predicted the existence of electromagnetic waves, at that time the only familiar electromagnetic waves were the visible light waves. The existence of ultraviolet and infrared waves was barely established. By the end of the nineteenth century, X-rays and gamma rays had also been discovered.

We now know that electromagnetic waves include visible light waves, X-rays, gamma rays, radio waves, and microwaves, ultraviolet and infrared waves.

The classification of em waves according to frequency is the electromagnetic spectrum

There *is* no sharp division between one kind of wave and the next. The classification is based roughly on how the waves are produced and/or detected.You are familiar with specific wave names of this spectrum.

Let us now understand them:



Take A Look At These

- **What is meant by frequency 10^7 Hz?**

  The number of wave cycles per second for the wave is 10^7

- **Name the waves associated with this frequency**

  Radio waves used for AM radio application, transmission and detection.

- **The frequency of gamma waves is much higher (10^{21-22}). What is the ratio of frequency of gamma waves to that of radio waves**?

  $10^{22}/10^7 = 10^{15}$

- **What is the range of value for wavelength for visible light?**

  The range is 400 nm (violet) to 700nm (red)

- **How much is a nanometer?**

  10^{-9}m

- **What is the value of the wavelength of violet light in meters?**

$400nm = 4 \times 10^{-7}m$

- **What is the ratio of velocity of radio waves and light waves in vacuum?**
  Both are em waves and travel with the same speed in vacuum so the ratio is 1.
  (Radio waves producing sound and music are converted to sound waves by suitable circuits and travel in vacuum, while sound waves cannot travel in vacuum. You will learn about the method in another unit.)
- **A patient goes for x ray for a broken bone, what is the frequency of electromagnetic waves the patient is subjected to?**
  10^{15}-10^{20} Hz
- **Find out, investigate by going to a radiologist - whether a single machine can give different frequencies, why do we need different frequency x-rays for diagnosis?**

We now describe various regions of the electromagnetic spectrum.

The basic difference between various types of electromagnetic waves lies in their wavelengths or frequencies.

Since all waves travel through vacuum with the same speed, consequently, the waves differ considerably in ways that they interact with matter. The detection methods and processes are based on the interaction with materials on which the rays are incident.

We have learnt that accelerated charged particles radiate electromagnetic waves. The wavelength of the electromagnetic wave is often correlated with the characteristic size of the system that radiates. Thus, gamma radiation, having wavelengths of 10^{-14} m to 10^{-15} m, typically originates from an atomic nucleus.

X-rays are emitted from heavy atoms. Radio waves are produced by accelerating electrons in a circuit. A transmitting antenna can most efficiently radiate waves having a wavelength of about the same size as the antenna. Visible radiation emitted by atoms is, however, much longer in wavelength than atomic size.

Different parts of the electromagnetic spectrum have different names, different methods of production and detection. Also they have different uses.

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-

Special Uses of Em Waves

Radio Waves

Frequency band	application
540-1600kHz	Medium wave AM band police network
3-39MHz	Shortwave AM band local radio
88-108 MHz	FM broadcast
54-890 MHz	TV waves
840-935MHz	Mobile phones

Microwaves

- Radar navigation system.
- Long distance communication system using geostationary satellites.
- Cooking food in microwave ovens.

Infrared Waves

Infrared waves are produced by hot bodies and molecules. This band lies adjacent to the low-frequency or long-wavelength end of the visible spectrum. Infrared waves are sometimes referred to as heat waves. This is 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.

Applications

- Infrared lamps are used for physiotherapy.
- Utilize greenhouse effect and maintain the temperature of earth's atmosphere.
  Incoming visible light (which passes relatively easily through the atmosphere) is absorbed by the earth's surface and re radiated as infrared (longer wavelength) radiations. This radiation is trapped by greenhouse gases such as carbon dioxide and water vapors.
- Infrared detectors are used in earth's satellites both for military services and for farming.
- Light emitting diodes LED are used with remote switching devices for household systems like TV sets ,video recorders , wi-fi systems, car locking systems etc
- Archeology and heritage conservation.

Visible Light

It is the most familiar form of electromagnetic waves. It is the part of the spectrum that is detected by the human eye. It runs from about 4×10^{14} Hz to about 7×10^{14} Hz or 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
- Used for chemical reaction in photodiode circuits

Ultraviolet Rays

It covers wavelengths ranging from about 4×10^{-7} m (400 nm) down to 6×10^{-7} m (0.6 nm). Ultraviolet (UV) radiation is produced by special lamps and very hot bodies.

- The sun is an important source of ultraviolet light. But fortunately, 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 the 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, and hence its depletion by chlorofluorocarbons (CFCs) gas (such as Freon) is a matter of international concern.

X-Rays

Beyond the UV region of the electromagnetic spectrum, the X-ray region lies. We are familiar with X-rays because of its medical applications. It covers wavelengths from about 10^{-8} m (10 nm) down to 10^{-13} m (10^{-4} nm). One common way to generate X-rays is to bombard a metal target with 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.
- X rays are used for fault detection in metals
- Study of crystal structure
- For detection of explosives firearms diamond gold etc
- In radiotherapy to cure skin diseases and malignant growths

Gamma Rays

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

This high frequency radiation is produced in nuclear reactions and also emitted by radioactive nuclei.

- They are used in medicine to destroy cancer cells
- In manufacture of polythene from ethylene
- To initiate nuclear reactions for research
- To preserve food for a long time because soft gamma rays can affect microorganisms
- For sterilization of materials used in hospitals

Summary

- An accelerating charge produces electromagnetic waves.
- An electric charge oscillating harmonically with frequency ν, produces electromagnetic waves of the same frequency ν.
- An electric dipole is a basic source of electromagnetic waves.
- Electromagnetic waves with wavelengths of the order of a few meters were first produced and detected in the laboratory by Hertz in 1887. He thus verified a basic prediction of Maxwell's equations.
- Electric and magnetic fields 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 ν, wavelength λ, propagating along *z*-direction, we have:

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

- $B = B_y(t) = B_0 sin\,(kz - \omega t) = B_0 sin\left[2\pi\left(\frac{z}{\lambda} - vt\right)\right] = B_0 sin\left[2\pi\left(\frac{z}{\lambda} - \frac{t}{T}\right)\right]$
- They are related by $E_0/B_0 = c$
- The speed *c* of electromagnetic wave in vacuum is related to μ_0 and ε_0 (the free space permeability

  and permittivity constants) as follows:

  $$c = 1/\ \mu_0\ \varepsilon_{\ 0}$$

  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.
- The speed of light, or of electromagnetic waves in a material medium is given by $v = 1/\ \mu\ \varepsilon$

  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.
- 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 $p = U/c$.

- The spectrum of electromagnetic waves stretches, in principle, over an infinite range of wavelengths. Different regions are known by different names microwaves and radio waves in order of increasing wavelength from 10^{-12} m to 10^{6} m.
- They interact with matter via their electric and magnetic fields which set in oscillation charges present in all matter.
- The detailed interaction and so the mechanism of absorption, scattering, etc., depend on the wavelength of the electromagnetic wave, and the nature of the atoms and molecules in the medium.