UNIT 5

ELECTROMAGNETIC WAVES

"One scientific epoch ended and another began with James Clerk Maxwell"

– Albert Einstein

Learning Objectives

In this unit, the student is exposed to

- the displacement current
- Maxwell's correction to Ampere's circuital law
- Maxwell's equation in integral form
- production and properties of electromagnetic waves – Hertz's experiment
- sources of electromagnetic waves
- electromagnetic spectrum

CGD1LP

5.1 INTRODUCTION

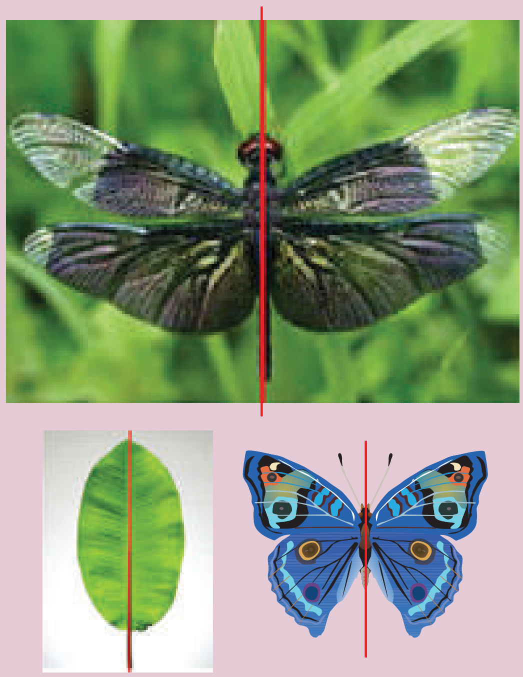
Figure 5.1 Visible spectrum – rainbow and lightning

We see the world around us through light. Light from the Sun is one of the sources of energy without which we human beings cannot survive in this planet. Light plays crucial role in understanding the structure and properties of various things from atom to universe. Without light, even our eyes cannot see objects. What is light?. This puzzle made many physicists sleepless until middle of 19th century. Earlier, many scientists thought that optics and electromagnetism are two different branches of physics. But from the work of James Clerk Maxwell, who actually enlightened the concept of light from his theoretical prediction is that light is an electromagnetic wave which moves with the speed equal to 3×10^8 m/s (in free space or vacuum). Later, it was confirmed that light is just only small portion of electromagnetic spectrum, which ranges from gamma rays to radio waves.

In the unit 4, we studied that time varying magnetic field produces an electric field (Faraday's law of electromagnetic induction). Maxwell strongly believed that nature must possess symmetry and he asked

UNIT-5(XII-Physics_Vol-1).indd 283 04-03-2019 11:05:37

the following question, "when the time varying magnetic field produces an electric field, why not the time varying electric field produce a magnetic field?"



Symmetry in nature

Later he proved that indeed it exists, which is often known as Maxwell's law of induction. In 1888, H. Hertz experimentally verified Maxwell's predication and hence, this understanding resulted in new technological invention, especially in wireless communication, LASER (Light Amplification by Stimulated Emission of Radiation) technology, RADAR (**Ra**dio **D**etection **A**nd **R**anging), etc.

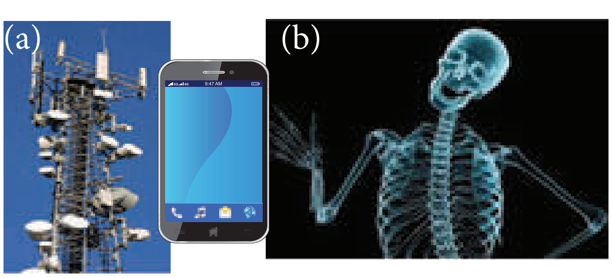


Figure 5.2 (a) cell phone and cell phone tower (b) X-ray radiograph of a human being

In today's digital world, cell phones (Figure 5.2 (a)) have greater influence in our day to day life. It is a faster and more effective mode of transferring information from one place to another. It works on the basis that light is an electromagnetic wave. In hospitals, the location of bone fracture can be detected using X-rays as shown in Figure 5.2 (b), which is also an electromagnetic wave. For cooking microwave oven is used. The microwave is also an electromagnetic wave. There are plenty of applications of electromagnetic waves in engineering, medical (example LASER surgery, etc), defence (example, RADAR signals) and also in fundamental scientific research. In this unit, basics of electromagnetic waves are covered.

5.1.1 Displacement current and Maxwell's correction to Ampere's circuital law

In unit 4, we studied Faraday's law of electromagnetic induction which states that the change in magnetic field produces an electric field. Mathematically

$$\oint_l \vec{E}\cdot\vec{dl} = -\frac{\partial}{\partial t}\Phi_B = -\frac{\partial}{\partial t}\oint_S \vec{B}\cdot\vec{dS} \qquad (5.1)$$

$$\underbrace{\oint_l \vec{E}\cdot\vec{dl}}_{\substack{\text{Electric field}\\ \text{induced along}\\ \text{a closed loop}}} = \underbrace{-\frac{\partial}{\partial t}\Phi_B}_{\substack{\text{Variation of}\\ \text{magnetic flux}\\ \text{with time}}} = \underbrace{-\frac{\partial}{\partial t}\oint_S \vec{B}\cdot\vec{dS}}_{\substack{\text{Changing magnetic}\\ \text{flux } \Phi_B \text{ in the region}\\ \text{enclosed by the loop}}}$$

where Φ_B is the magnetic flux and $\frac{\partial}{\partial t}$ is the partial derivative with respect to time. Equation (5.1) means that the electric field $\vec{E}$ is induced along a closed loop by the changing magnetic flux Φ_B in the region encircled by the loop. Now the question asked by James Clerk Maxwell is 'Is converse of this statement true?' Answer is 'yes'. He showed that the change in electric field also produces magnetic field which is

$$\oint_l \vec{B}\cdot\vec{dl} = -\frac{\partial}{\partial t}\Phi_E = -\frac{\partial}{\partial t}\oint_S \vec{B}\cdot\vec{dS} \qquad (5.2)$$

$$\underbrace{\oint_l \vec{E}\cdot\vec{dl}}_{\substack{\text{Magnetic field}\\ \text{induced along}\\ \text{a closed loop}}} = \underbrace{-\frac{\partial}{\partial t}\Phi_E}_{\substack{\text{Variation of}\\ \text{electric flux}\\ \text{with time}}} = \underbrace{-\frac{\partial}{\partial t}\oint_S \vec{B}\cdot\vec{dS}}_{\substack{\text{Changing electric}\\ \text{flux } \Phi_E \text{ in the region}\\ \text{enclosed by the loop}}}$$

where Φ_B is the electric flux. This is known as Maxwell's law of induction, which explains that the magnetic field $\vec{B}$ induced along a closed loop by the changing electric flux Φ_E in the region encircled by that loop. This in turn, explains the existence of radio waves, gamma rays, infrared rays, etc.

In order to understand how the changing electric field produces magnetic field, let us consider a situation of 'charging a parallel plate capacitor' shown in Figure 5.3 Assume that the medium in between the capacitor plates is a non-conducting medium.

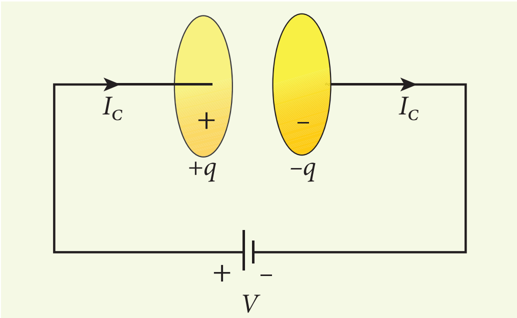


Figure 5.3 charging of capacitor

The electric current passing through the wire is the conduction current I_C. This current generates magnetic field around the wire (refer Unit 3) connected across the capacitor. Therefore, when a magnetic needle is kept near the wire, deflection is observed. In order to compute the strength of magnetic field at a point, we use Ampere's circuital law (from Unit 3) which states that 'the line integral of the magnetic field $\vec{B}$ around any closed loop is equal to μ_o times the net current I threading through the area enclosed by the loop'. Ampere's law in equation form is

$$\oint_l \vec{B}\cdot d\vec{l} = \mu_o I(t) \qquad (5.3)$$

where μ_o is the permeability of free space.

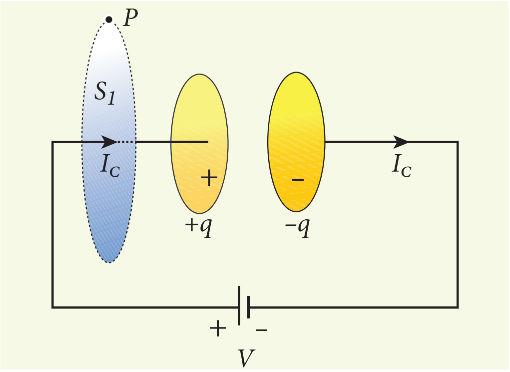


Figure 5.4 Applying Ampere's circuital law - loop enclosing surface

To calculate the magnetic field at a point P near the wire as shown in Figure 5.4, let us draw an amperian loop (circular loop) which encloses the surface S_1 (circular surface). Therefore, using Ampere's circuital law (equation 5.3), we get

$$\oint_{S_1} \vec{B}\cdot d\vec{l} = \mu_0 I_C \qquad (5.4)$$

where I_c is the conduction current.

Suppose the same loop is enclosed by balloon shaped surface S_2 as shown in Figure 5.5. This means that the boundaries of two surfaces S_1 and S_2 are same but shape of the enclosing surfaces are different (first surface (S_1) is circular in shape and second one is balloon shaped surface (S_2)). As the Ampere's law applied for a given closed loop does not depend on shape of the enclosing surface, the integrals will give the same answer. But by applying Ampere's circuital law (equation 5.3), we get

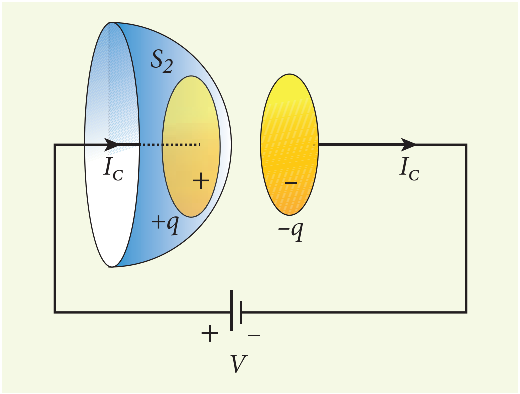


Figure 5.5 Applying Ampere's circuital law - loop enclosing surface S2

$$\oint_{\text{enclosing } S_2} \vec{B}\cdot d\vec{l} = 0 \tag{5.5}$$

The right hand side of equation is zero because the surface S_2 no where touches the wire carrying conduction current and further, there is no current in between the plates of the capacitor (there is a discontinuity). So the magnetic field at a point P is zero. Hence there is an inconsistency between equation (5.4) and equation (5.5). J. C.Maxwell resolved this inconsistency as follows:

Due to external source (battery or cell), the capacitor gets charged up because of current flowing through the capacitor. This produces an increasing electric field between the capacitor plates. So, there must be a current associated with the changing electric field in between the capacitor plates. In other words, the time varying electric flux (or time varying electric field) existing between the plates of the capacitor also produces a current known as displacement current.

> Note
>
> **Displacement current**
>
> The name stuck because Maxwell named it. The word displacement is poorly chosen because nothing is being displaced here.

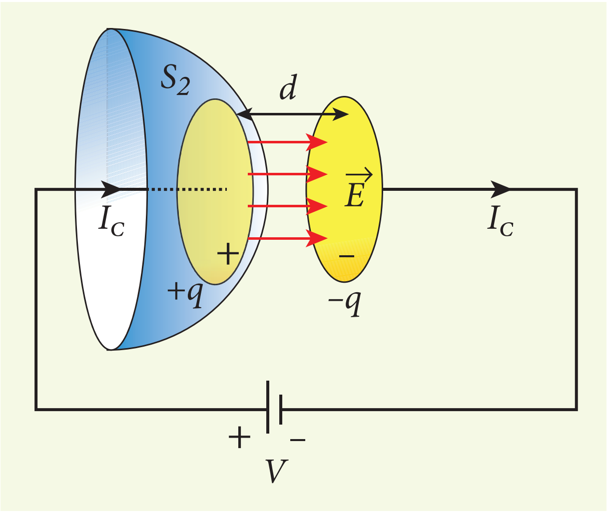


Figure 5.6 Applying Gauss's law between the plates of the capacitor

From Gauss's law (refer Unit 1), the electric flux between the plates of the capacitor (Figure 5.6) is

$$\Phi_E = \oiint \vec{E}\cdot d\vec{A} = EA = \frac{q}{\varepsilon_0}$$

where A is the area of the plates of capacitor.

The change in electric flux is

$$\frac{d\Phi_E}{dt} = \frac{1}{\varepsilon_\circ}\frac{dq}{dt} \Rightarrow \frac{dq}{dt} = I_d = \varepsilon_\circ \frac{d\Phi_E}{dt}$$

where I_d is known as displacement current. The **displacement current can be defined as the current which comes into play in the region in which the electric field and the electric flux are changing with time**. In other words, whenever the change in electric field takes place, displacement current is produced. Maxwell modified Ampere's law as

$$\oint \vec{B}\cdot d\vec{s} = \mu_\circ I = \mu_\circ\left(I_C + I_d\right) \tag{5.6}$$

where $I = I_c + I_d$ which means the total current enclosed by the surface is sum of conduction current and displacement current. When a constant current is applied, displacement current $I_d = 0$ and hence $I_c = I$. Between the plates, the conduction current $I_c = 0$ and hence $I_d = I$.

EXAMPLE 5.1

Consider a parallel plate capacitor which is maintained at potential of 200 V. If the separation distance between the plates of the capacitor and area of the plates are 1 mm and 20 cm². Calculate the displacement current for the time in μs.

Solution

Potential difference between the plates of the capacitor, V = 200 V

The distance between the plates,

$$d = 1 \text{ mm} = 1 \times 10^{-3} \text{ m}$$

Area of the plates of the capacitor,

$$A = 20 \text{ cm}^2 = 20 \times 10^{-4} \text{ m}^2$$

Time is given in micro-second, $\mu s = 10^{-6}$ s

Displacement current

$$I_d = \varepsilon_\circ \frac{d\Phi_B}{dt} \Rightarrow I_d = \varepsilon_\circ \frac{EA}{t}$$

But electric field, $E = \dfrac{V}{d}$

Therefore,

$$I = \frac{V}{d} I_d = \varepsilon_\circ \frac{VA}{t\,d} = 8.85 \times 10^{-12} \times \frac{200 \times 20 \times 10^{-4}}{10^{-6} \times 1 \times 10^{-3}}$$

$$= 35400 \times 10^{-7} = 3.5\ mA$$

5.1.3 Maxwell's equations in integral form

Electrodynamics can be summarized into four basic equations, known as Maxwell's equations. These equations are analogous to Newton's equations in mechanics. Maxwell's equations completely explain the behaviour of charges, currents and properties of electric and magnetic fields. These equations can be written in integral form (or integration form) or derivative form (or differentiation form). The differential form of Maxwell's equation is beyond higher secondary level because we need to learn additional mathematical operations like curl of vector fields and divergence of vector fields. So we focus here only in integral form of Maxwell's equations:

1. First equation is nothing but the Gauss's law. It relates the net electric flux to net electric charge enclosed in a surface. Mathematically, it is expressed as

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\varepsilon_\circ} \quad \text{(Gauss's law)} \quad (5.7)$$

where $\vec{E}$ is the electric field and $Q_{enclosed}$ is the charge enclosed. This equation is true for both discrete or continuous distribution of charges. It also indicates that the electric field lines start from positive charge and terminate at negative charge. This implies that the electric field lines do not form a continuous closed path. In other words, it means that isolated positive charge or negative charge can exist.

2. Second equation has no name. But this law is similar to Gauss's law in electrostatics. So this law can also be called as Gauss's law in magnetism. The

surface integral of magnetic field over a closed surface is zero. Mathematically,

$$\oint \vec{B} \cdot d\vec{A} = 0 \qquad \text{(No name)} \qquad (5.8)$$

where $\vec{B}$ is the magnetic field. This equation implies that the magnetic lines of force form a continuous closed path. In other words, it means that no isolated magnetic monopole exists.

3. Third equation is Faraday's law of electromagnetic induction. This law relates electric field with the changing magnetic flux which is mathematically written as

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt}\Phi_B \text{(Faraday's law)} \qquad (5.9)$$

where $\vec{E}$ is the electric field. This equation implies that the line integral of the electric field around any closed path is equal to the rate of change of magnetic flux through the closed path bounded by the surface. Our modern technological revolution is due to Faraday's laws of electromagnetic induction. The electrical energy supplied to our houses from electricity board by using Faraday's law of induction.

4. Fourth equation is modified Ampere's circuital law. This is also known as Ampere – Maxwell's law. This law relates the magnetic field around any closed path to the conduction current and displacement current through that path.

$$\oint \vec{B}.\vec{dl} = \mu_0 I_{enclosed} + \mu_0 \varepsilon_0 \frac{d}{dt} \int_s \vec{E}.\vec{dA} \qquad (5.10)$$
$$\text{(Ampere-Maxwell's law)}$$

where $\vec{B}$ is the magnetic field. This equation shows that both conduction and also displacement current produces magnetic field. These four equations are known as Maxwell's equations in electrodynamics. This equation ensures the existence of electromagnetic waves. The entire communication system in the world depends on electromagnetic waves. In fact our understanding of stars, galaxy, planets etc come by analysing the electromagnetic waves emitted by these astronomical objects.

5.2 ELECTROMAGNETIC WAVES

Electromagnetic waves are non-mechanical waves which move with speed equals to the speed of light (in vacuum). It is a transverse wave. In the following subsections, we discuss the production of electromagnetic waves and its properties, sources of electromagnetic waves and also classification of electromagnetic spectrum.

5.2.1 Production and properties of electromagnetic waves - Hertz experiment

Maxwell's prediction was experimentally confirmed by Heinrich Rudolf Hertz (Figure 5.7 (a)) in 1888. The experimental set up used is shown in Figure 5.7 (b).

It consists of two metal electrodes which are made of small spherical metals as shown in Figure 5.7. These are connected to larger spheres and the ends of them are connected to induction coil with very large number of turns. This is to produce very high electromotive force (emf). Since the

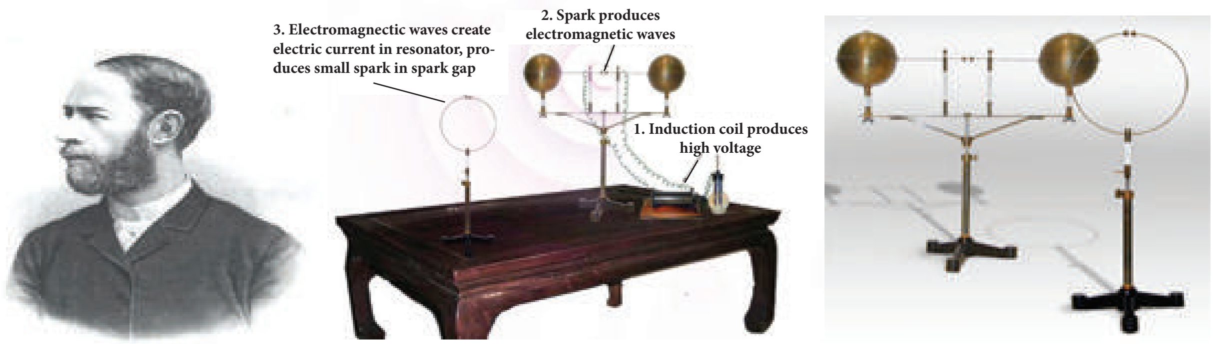


Figure 5.7 Hertz experiment (a) Heinrich Rudolf Hertz (1857 – 1894) (b) Hertz apparatus

coil is maintained at very high potential, air between the electrodes gets ionized and spark (spark means discharge of electricity) is produced. The gap between electrode (ring type – not completely closed and has a small gap in between) kept at a distance also gets spark. This implies that the energy is transmitted from electrode to the receiver (ring electrode) as a wave, known as electromagnetic waves. If the receiver is rotated by 90° - then no spark is observed by the receiver. This confirms that electromagnetic waves are transverse waves as predicted by Maxwell. Hertz detected radio waves and also computed the speed of radio waves which is equal to the speed of light (3×10^8 m s^{-1}).

Properties of electromagnetic waves

1. Electromagnetic waves are produced by any accelerated charge.
2. Electromagnetic waves do not require any medium for propagation. So electromagnetic wave is a non-mechanical wave.
3. Electromagnetic waves are transverse in nature. This means that the oscillating electric field vector, oscillating magnetic field vector and propagation vector (gives direction of propagation) are mutually perpendicular to each other. The electric and magnetic fields are in the y and z directions respectively and the direction of propagation is along x direction. This is shown in Figure 5.8.
4. Electromagnetic waves travel with speed which is equal to the speed of light in vacuum or free space, $c = \frac{1}{\sqrt{\varepsilon_\circ \mu_\circ}} = 3 \times 10^8 \, \text{m s}^{-1}$, where ε_o is the permittivity of free space or vacuum and μ_o is the permeability of free space or vacuum (refer Unit 1 for permittivity and Unit 3 for permeability).
5. In a medium with permittivity ε and permeability μ, the speed of electromagnetic wave is less than speed in free space or vacuum, that is, v < c. In a medium of refractive index,

$$\mu = \frac{c}{v} = \frac{\frac{1}{\sqrt{\varepsilon_\circ \mu_\circ}}}{\frac{1}{\sqrt{\varepsilon \mu}}} \Rightarrow \mu = \sqrt{\varepsilon_r \mu_r}, \text{ where } \varepsilon_r \text{ is}$$

the relative permittivity of the medium (also known as dielectric constant) and μ_r is the relative permeability of the medium.
6. Electromagnetic waves are not deflected by electric field or magnetic field.

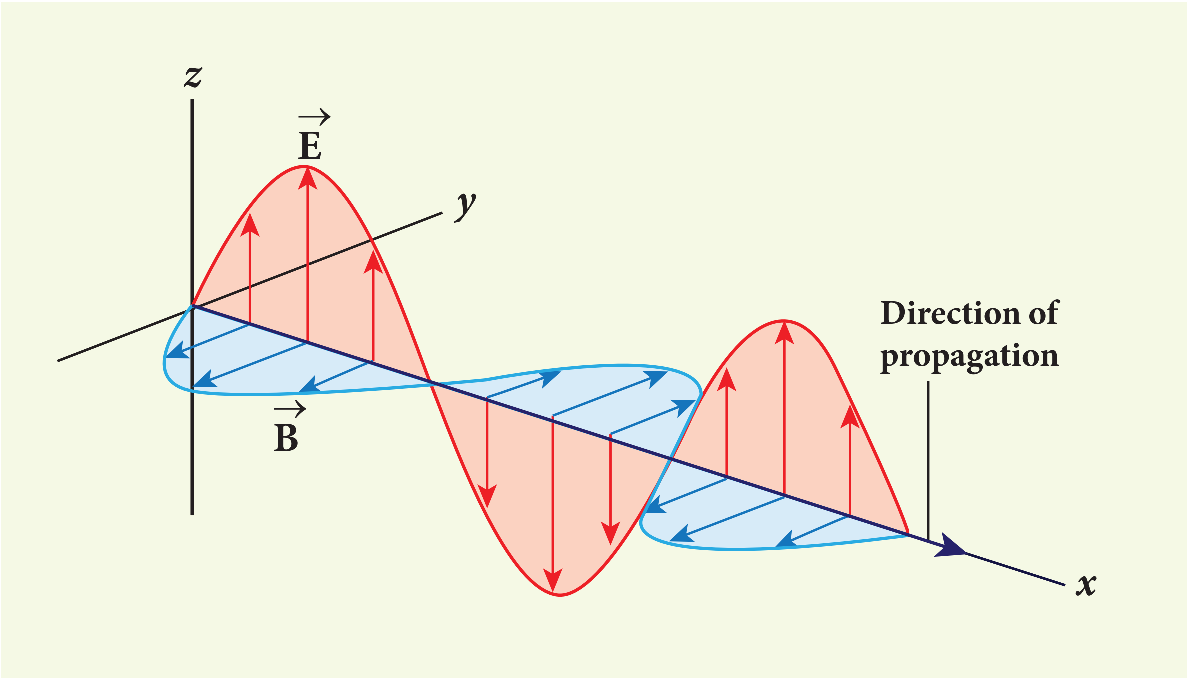


Figure 5.8 Electromagnetic waves – transverse wave

7. Electromagnetic waves can show interference, diffraction and can also be polarized.
8. The energy density (energy per unit volume) associated with an electromagnetic wave propagating in vacuum or free space is

$$u = \frac{1}{2}\varepsilon_{\circ}E^2 + \frac{1}{2\mu_{\circ}}B^2$$

where, $\frac{1}{2}\varepsilon_{\circ}E^2 = u_E$ is the energy density in an electric field and $\frac{1}{2\mu_0}B^2 = u_B$ is the energy density in a magnetic field.

Since, $E = Bc \Rightarrow u_B = u_E$.

The energy density of the electromagnetic wave is

$$u = \varepsilon_0 E^2 = \frac{1}{\mu_0}B^2$$

9. The average energy density for electromagnetic wave,

$$\langle u \rangle = \frac{1}{2}\varepsilon_{\circ}E^2 = \frac{1}{2}\frac{1}{\mu_{\circ}}B^2.$$

10. The energy crossing per unit area per unit time and perpendicular to the direction of propagation of electromagnetic wave is called the intensity.

Intensity, $I = \langle u \rangle c$ or

$$I = \frac{\text{total electromagnetic energy (U)}}{\text{Surface area (A)} \times \text{time (t)}}$$

$$= \frac{\text{Power (P)}}{\text{Surface area (A)}}$$

Note

For a point source,

$I = \frac{P}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$

For a line source, $I \propto \frac{1}{r}$

For a plane source, I is independent of r

11. Like other waves, electromagnetic waves also carry energy and momentum. For the electromagnetic wave of energy U propagating with speed c has linear momentum which

is given by $= \frac{\text{Energy}}{\text{speed}} = \frac{U}{c}$. The force exerted by an electromagnetic wave on unit area of a surface is called radiation pressure.

12. If the electromagnetic wave incident on a material surface is completely absorbed, then the energy delivered is U and momentum imparted on the surface is $p = \frac{U}{c}$.
13. If the incident electromagnetic wave of energy U is totally reflected from the surface, then the momentum delivered to the surface is $\Delta p = \frac{U}{c} - \left(-\frac{U}{c}\right) = 2\frac{U}{c}$.
14. The rate of flow of energy crossing a unit area is known as pointing vector for electromagnetic waves, which is $\vec{S} = \frac{1}{\mu_\circ}\left(\vec{E} \times \vec{B}\right) = c^2\varepsilon_\circ\left(\vec{E} \times \vec{B}\right)$. The unit for pointing vector is W m^{-2}. The pointing vector at any point gives the direction of energy transport from that point.
15. Electromagnetic waves carries not only energy and momentum but also angular momentum.

EXAMPLE 5.2

The relative magnetic permeability of the medium is 2.5 and the relative electrical permittivity of the medium is 2.25. Compute the refractive index of the medium.

Solution

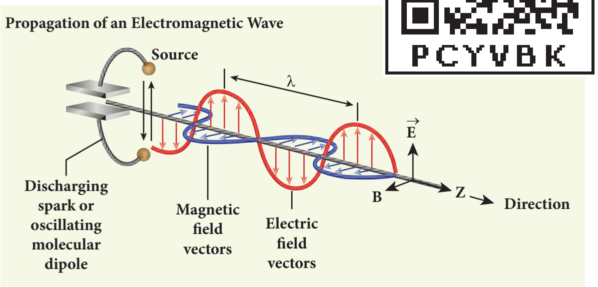
Dielectric constant (relative permeability of the medium) is $\varepsilon_r = 2.25$

Magnetic permeability is $\mu_r = 2.5$

Refractive index of the medium,

$$n = \sqrt{\varepsilon_r \mu_r} = \sqrt{2.25 \times 2.5} = 2.37$$

5.2.2 Sources of electromagnetic waves



PCYVBK

Figure 5.9 Oscillating charges - sources of electromagnetic waves

Any stationary source charge produces only electric field (refer Unit 1). When the charge moves with uniform velocity, it produces steady current which gives rise to magnetic field (not time dependent, only space dependent) around the conductor in which charge flows. If the charged particle accelerates, in addition to electric field it also produces magnetic field. Both electric and magnetic fields are time varying fields. Since the electromagnetic waves are transverse waves, the direction of propagation of electromagnetic waves is perpendicular to the plane containing electric and magnetic field vectors.

Any oscillatory motion is also an accelerating motion, so, when the charge oscillates (oscillating molecular dipole) about their mean position as shown in Figure 5.9, it produces electromagnetic waves.

Suppose the electromagnetic field in free space propagates along *z* direction, and if the electric field vector points along y axis then the magnetic field vector will be mutually perpendicular to both electric field and the propagation vector direction, which means

$$E_y = E_\circ \sin\left(kz - \omega t\right)$$

$$B_x = B_\circ \sin\left(kz - \omega t\right)$$

where, E_o and B_o are amplitude of oscillating electric and magnetic field, k is a wave number, ω is the angular frequency of the wave and $\hat{k}$ (unit vector, here it is called propagation vector) denotes the direction of propagation of electromagnetic wave.

Note that both electric field and magnetic field oscillate with a frequency (frequency of electromagnetic wave) which is equal to the frequency of the source (here, oscillating charge is the source for the production of electromagnetic waves). In free space or in vacuum, the ratio between E_o and B_o is equal to the speed of electromagnetic wave, which is equal to speed of light c.

$$c = \frac{E_o}{B_o}$$

In any medium, the ratio of E_o and B_o is equal to the speed of electromagnetic wave in that medium, mathematically, it can be written as

$$v = \frac{E_o}{B_o} < c$$

Further, the energy of electromagnetic waves comes from the energy of the oscillating charge.

EXAMPLE 5.3

Compute the speed of the electromagnetic wave in a medium if the amplitude of electric and magnetic fields are 3×10^4 N C^{-1} and 2×10^{-4} T, respectively.

Solution

The amplitude of the electric field, $E_o = 3 \times 10^4$ N C^{-1}

The amplitude of the magnetic field, $B_o = 2 \times 10^{-4}$ T. Therefore, speed of the electromagnetic wave in a medium is

$$v = \frac{3 \times 10^4}{2 \times 10^{-4}} = 1.5 \times 10^8 \, ms^{-1}$$

5.2.3 Electromagnetic spectrum

ELECTROMAGNETIC SPECTRUM

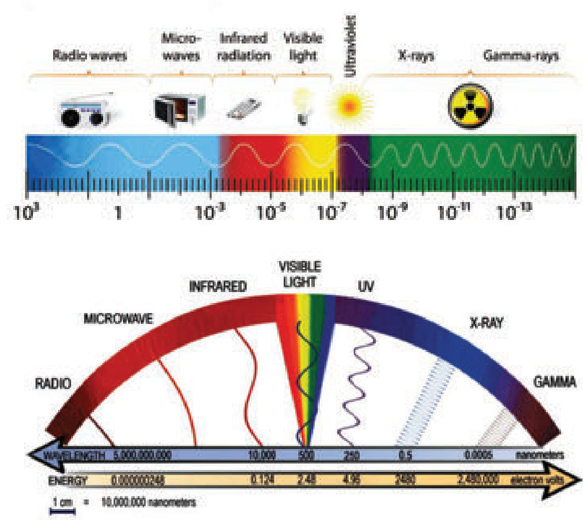


Figure 5.10 **Electromagnetic spectrum -**

Electromagnetic spectrum is an orderly distribution of electromagnetic waves in terms of wavelength or frequency as shown in Figure 5.10.

Radio waves

It is produced by oscillators in electric circuits. The wavelength range is 1×10^{-1} m to 1×10^4 m and frequency range is 3×10^9 Hz to 3×10^4 Hz. It obeys reflection and diffraction. It is used in radio and television communication systems and also in cellular phones to transmit voice communication in the ultra high frequency band.

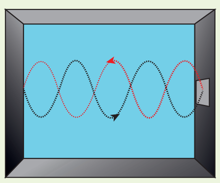
Microwaves

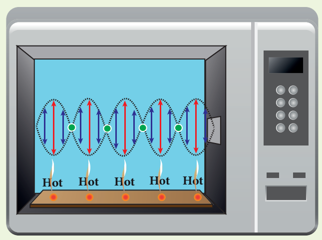
It is produced by electromagnetic oscillators in electric circuits. The wavelength range is 1×10^{-3} m to 3×10^{-1} m and frequency range is 3×10^{11} Hz to 1×10^9 Hz. It obeys reflection and polarization. It is used in radar system for aircraft navigation, speed of the vehicle, microwave oven for cooking and very long distance wireless communication through satellites.

ACTIVITY

Measuring the speed of light using the microwave oven

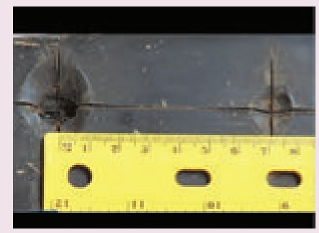
Nowadays the microwave oven is very commonly used to heat the food items. Micro waves of wavelengths 1 mm to 30 cm are produced in these ovens. Such waves form the standing waves between the interior walls of the oven. It is interesting to note that the speed of light can be measured using micro wave oven.


(a)



(b)


(c)


(d)

We studied about the standing waves in XI physics, Volume 2, Unit 11. The standing waves have nodes and antinodes at fixed points. At node point, the amplitude of the wave is zero and at antinodes point, the amplitude is maximum. In other words, the maximal energy of microwaves is located at antinode points. When we keep some food items like chappathi or choclate (after removing the rotating platform) inside the oven, we can notice that at antinode locations, chappathi will be burnt more than other locations. It is shown in the Figure (c) and (d). The distance between two successive burnt spots will give the wavelength of microwave. The frequency of microwave is printed in the panel of oven. By knowing wavelength and frequency of microwaves, using the formula $v\lambda = c$, we can calculate the speed of light *c*.

Infrared radiation

It is produced from hot bodies (also known as heat waves) and also when the molecules undergo rotational and vibrational transitions. The wavelength range is 8×10^{-7} m to 5×10^{-3} m and frequency range are 4×10^{14} Hz to 6×10^{10} Hz. It provides electrical energy to satellites by means of solar cells. It is used to produce dehydrated fruits, in green houses to keep the plants warm, heat therapy for muscular pain or sprain, TV remote as a signal carrier, to look through haze fog or mist and used in night vision or infrared photography.

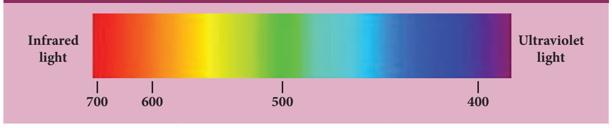
Visible light

It is produced by incandescent bodies and also it is radiated by excited atoms in gases. The wavelength range is 4×10^{-7} m to 7×10^{-7} m and frequency range are 7×10^{14} Hz to 4×10^{14} Hz. It obeys the laws of reflection, refraction, interference, diffraction, polarization, photo-electric effect and photographic action. It can be used to study the structure of molecules, arrangement of electrons in external shells of atoms and sensation of our eyes.

Ultraviolet radiation

It is produced by Sun, arc and ionized gases. The wavelength range is 6×10^{-10} m to 4×10^{-7} m and frequency range are 5×10^{17} Hz to 7×10^{14} Hz. It has less penetrating power. It can be absorbed by atmospheric ozone and harmful to human body. It is used to destroy bacteria, sterilizing the surgical instruments, burglar alarm, detect the invisible writing, finger prints and also in the study of molecular structure.

Table 5.1 visible region, frequency and wavelength of different types of radiation



Type of Radiation	Frequency Range (Hz)	Wavelength Range
gamma-rays	10^{20}-10^{24}	$<10^{-12}$m
x-rays	10^{17}-10^{20}	1 nm - 1pm
ultraviolet	10^{15}-10^{17}	400 nm - 1nm
visible	$4 - 7.5 \times 10^{14}$	750 nm - 400nm
near-infrared	1×10^{14}-4×10^{14}	2.5 μm - 750nm
infrared	10^{13}-10^{14}	25 μm - 2.5μm
microwaves	3×10^{11}-10^{13}	1 mm - 25 μm
radio waves	$< 3 \times 10^{11}$	> 1 mm

X-rays

It is produced when there is a sudden deceleration of high speed electrons at high-atomic number target, and also by electronic transitions among the innermost orbits of atoms. The wavelength range 10^{-13} m to 10^{-8} m and frequency range are 3×10^{21} Hz to 1×10^{16} Hz. X-rays have more penetrating power than ultraviolet radiation. X-rays are used extensively in studying structures of inner atomic electron shells and crystal structures. It is used in detecting fractures, diseased organs, formation of bones and stones, observing the progress of healing bones. Further, in a finished metal product, it is used to detect faults, cracks, flaws and holes.

Gamma rays

It is produced by transitions of atomic nuclei and decay of certain elementary particles. They produce chemical reactions on photographic plates, fluorescence, ionisation, diffraction. The wavelength range is 1×10^{-14} m to 1×10^{-10} m and frequency range are 3×10^{22} Hz to 3×10^{18} Hz. Gamma rays have high penetrating power than X-rays and ultraviolet radiations; it has no charge but harmful to human body. Gamma rays provide information about the structure of atomic nuclei. It is used in radio therapy for the treatment of cancer and tumour, in food industry to kill pathogenic microorganism.

EXAMPLE 5.4

A magnetron in a microwave oven emits electromagnetic waves (em waves) with frequency f = 2450 MHz. What magnetic field strength is required for electrons to move in circular paths with this frequency?.

Solution

Frequency of the electromagnetic waves given is f = 2450 MHz

The corresponding angular frequency is

$\omega = 2\pi f = 2 \text{ x } 3.14 \text{ x } 2450 \text{ x } 10^6$

$= 15{,}386 \text{ x } 10^6$ Hz

$= 1.54 \times 10^{10}\ s^{-1}$

The magnetic field $B = \dfrac{m_e \omega}{|q|}$

Mass of the electron, $m_e = 9.22 \text{ x } 10^{-31}$ kg

Charge of the electron

$q = -1.60 \times 10^{-19} C \Rightarrow |q| = 1.60 \times 10^{-19} C$

$$B = \frac{\left(9.22 \times 10^{-31}\right)\left(1.54 \times 10^{10}\right)}{\left(1.60 \times 10^{-19}\right)} = 8.87425 \times 10^{-2} T$$

B = 0.0887 T

This magnetic field can be easily produced with a permanent magnet. So, electromagnetic waves of frequency 2450 MHz can be used for heating and cooking food because they are strongly absorbed by water molecules.

5.3 TYPES OF SPECTRUM-EMISSION AND ABSORPTION SPECTRUM-FRAUNHOFER LINES

29KQ1G

Blackbody radiation curves

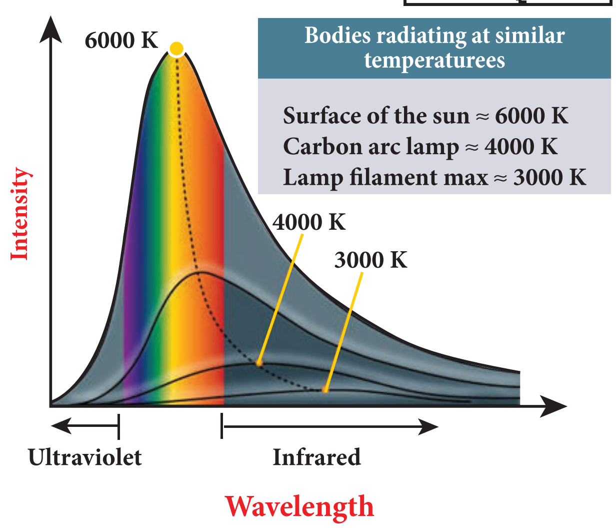


Figure 5.11 Black body radiation spectrum – variation with temperature

When an object burns, it emits colours. That is, it emits electromagnetic radiation which depends on temperature. If the object becomes hot then it glows in red colour. If the temperature of the object is further increased then it glows in reddish-orange colour and becomes white when it is hottest. The spectrum in Figure 5.11 usually called as black body spectrum (refer plus one volume two Unit 8). It is a continuous frequency (or wavelength) curve and depends on the body's temperature.

Suppose we allow a beam of white light to pass through the prism as shown in Figure 5.12, it is split into its seven constituent colours which can be viewed on the screen as continuous spectrum. This phenomenon is known as dispersion of light and the definite pattern of colours obtained on the screen after dispersion is called as spectrum. The plural for spectrum is spectra. The spectra can be broadly classified into two catagories:

Figure 5.12 White light passed through prism – dispersion

(a) Emission spectra

When the spectrum of self luminous source is taken, we get emission spectrum. Each source has its own characteristic emission spectrum. The emission spectrum can be divided into three types:

(i) Continuous emission spectra (or continuous spectra)

Figure 5.13 continuous emission spectra

If the light from incandescent lamp (filament bulb) is allowed to pass through prism (simplest spectroscope), it splits into seven colours. Thus, it consists of wavelengths containing all the visible colours ranging from violet to red (Figure 5.13). Examples: spectrum obtained from carbon arc, incandescent solids, liquids gives continuous spectra.

(ii) Line emission spectrum (or line spectrum):

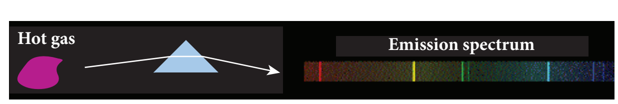


Figure 5.14 line emission spectra

UNIT-5(XII-Physics_Vol-1).indd 295 04-03-2019 11:05:50

Suppose light from hot gas is allowed to pass through prism, line spectrum is observed (Figure 5.14). Line spectra are also known as discontinuous spectra. The line spectra are sharp lines of definite wavelengths or frequencies. Such spectra arise due to excited atoms of elements. These lines are the characteristics of the element which means it is different for different elements. Examples: spectra of atomic hydrogen, helium, etc.

(3) Band emission spectrum (or band spectrum)

Band spectrum consists of several number of very closely spaced spectral lines which overlapped together forming specific bands which are separated by dark spaces, known as band spectra. This spectrum has a sharp edge at one end and fades out at the other end. Such spectra arise when the molecules are excited. Band spectrum is the characteristic of the molecule hence, the structure of the molecules can be studied using their band spectra. Examples, spectra of hydrogen gas, ammonia gas in the discharge tube etc.

(b) Absorption spectra

When light is allowed to pass through a medium or an absorbing substance then the spectrum obtained is known as absorption spectrum. It is the characteristic of absorbing substance. Absorption spectrum is classified into three types:

(i) Continuous absorption spectrum

When the light is passed through a medium, it is dispersed by the prism, we get continuous absorption spectrum. For instance, when we pass white light through a blue glass plate, it absorbs everything except blue. This is an example of continuous absorption spectrum.

(ii) Line absorption spectrum

Figure 5.15 line absorption spectra

When light from the incandescent lamp is passed through cold gas (medium), the spectrum obtained through the dispersion due to prism is line absorption spectrum (Figure 5.15). Similarly, if the light from the carbon arc is made to pass through sodium vapour, a continuous spectrum of carbon arc with two dark lines in the yellow region of sodium vapour is obtained.

(iii) Band absorption spectrum

When the white light is passed through the iodine vapour, dark bands on continuous bright background is obtained. This type of band is also obtained when white light is passed through diluted solution of blood or chlorophyll or through certain solutions of organic and inorganic compounds.

Fraunhofer lines

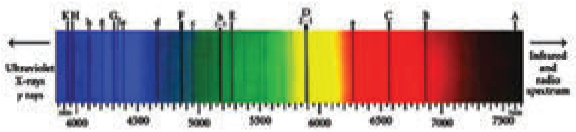


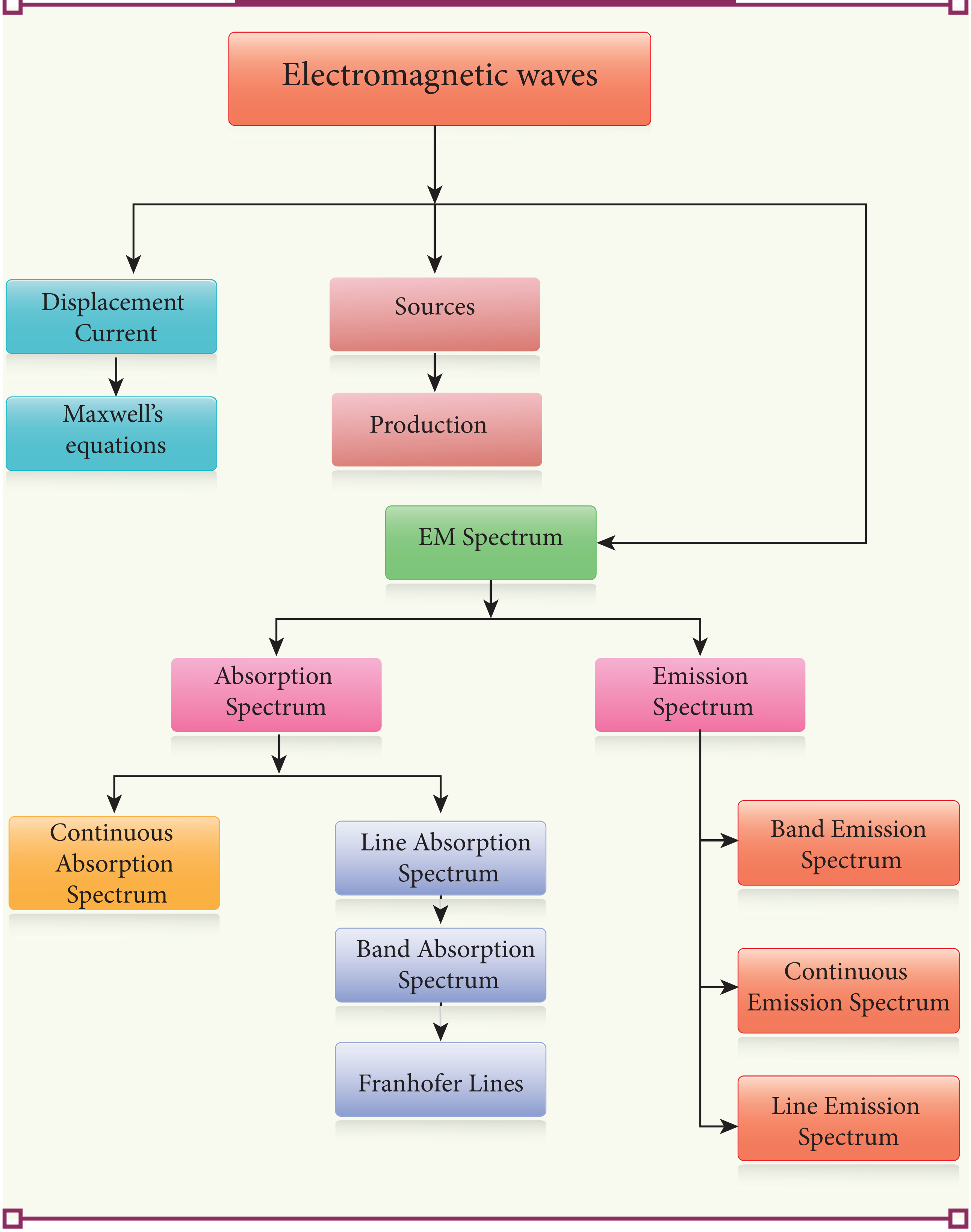
Figure 5.16 Solar spectrum - Fraunhofer lines

When the spectrum obtained from the Sun is examined, it consists of large number of dark lines (line absorption spectrum). These dark lines in the solar spectrum are known as Fraunhofer lines (Figure 5.16). The absorption spectra for various materials are compared with the Fraunhofer lines in the solar spectrum, which helps in identifying elements present in the Sun's atmosphere.

SUMMARY

- Displacement current can be defined as 'the current which comes into play in the region in which the electric field and the electric flux are changing with time'
- Maxwell modified Ampere's law as
$$\oint \vec{B}\cdot d\vec{S} = \mu_o I = \mu_o \left(I_c + I_d\right)$$
- An electromagnetic wave is radiated by an accelerated charge which propagates through space as coupled electric and magnetic fields, oscillating perpendicular to each other and to the direction of propagation of the wave
- Electromagnetic wave is a transverse wave. They are non-mechanical wave and do not require any medium for propagation
- The instantaneous magnitude of the electric and magnetic field vectors in electromagnetic wave are related by E = Bc
- Electromagnetic waves are transverse in nature. This means that the oscillating electric field vector, oscillating magnetic field vector and propagation vector are (gives direction of propagation) mutually perpendicular to each other
- Electromagnetic waves can show interference, diffraction and also can be polarized
- The average energy density $\langle u\rangle = 2u_e = 2u_m = \varepsilon_\circ E^2 = \frac{1}{\mu_\circ}B^2$
- The energy crossing per unit area per unit time and perpendicular to the direction of propagation of electromagnetic wave is called the intensity, which is $I = \langle u\rangle c$
- If the electromagnetic wave incident on a material surface is completely absorbed, then the energy delivered is U and momentum imparted on the surface is $p = \frac{U}{c}$
- If the incident electromagnetic wave of energy U is totally reflected from the surface, then the momentum delivered to the surface is $\Delta p = \frac{U}{c} - \left(-\frac{U}{c}\right) = 2\frac{U}{c}$
- The rate of flow of energy crossing a unit area is known as poynting vector for electromagnetic waves, which is $\vec{S} = \frac{1}{\mu_\circ}\left(\vec{E}\times\vec{B}\right) = c^2\varepsilon_\circ\left(\vec{E}\times\vec{B}\right)$.
- Electromagnetic waves carry not only energy and momentum but also angular momentum.
- Types of spectrum – emission and absorption
- When the spectrum of self luminous source is taken, we get emission spectrum. Each source has its own characteristic emission spectrum. The emission spectrum can be divided into three types: continuous, line and band.
- The spectrum obtained from the Sun is examined, it consists of large number of dark lines (line absorption spectrum). These dark lines in the solar spectrum are known as Fraunhofer lines.

CONCEPT MAP


Electromagnetic waves
Displacement Current
Maxwell's equations
Sources
Production
EM Spectrum
Absorption Spectrum
Emission Spectrum
Continuous Absorption Spectrum
Line Absorption Spectrum
Band Absorption Spectrum
Franhofer Lines
Band Emission Spectrum
Continuous Emission Spectrum
Line Emission Spectrum

I Multiple choice questions

1. The dimension of $\frac{1}{\mu_o \varepsilon_o}$ is

   (a) $[L\,T^{-1}]$ (b) $[L^2\,T^{-2}]$

   (c) $[L^{-1}\,T]$ (d) $[L^{-2}\,T^2]$

2. If the amplitude of the magnetic field is 3×10^{-6} T, then amplitude of the electric field for a electromagnetic waves is

   (a) 100 V m^{-1} (b) 300 V m^{-1}

   (c) 600 V m^{-1} (d) 900 V m^{-1}

3. Which of the following electromagnetic radiation is used for viewing objects through fog

   (a) microwave (b) gamma rays

   (c) X- rays (d) infrared

4. Which of the following are false for electromagnetic waves

   E67JQC

   (a) transverse

   (b) mechanical waves

   (c) longitudinal

   (d) produced by accelerating charges

5. Consider an oscillator which has a charged particle and oscillates about its mean position with a frequency of 300 MHz. The wavelength of electromagnetic waves produced by this oscillator is

   (a) 1 m (b) 10 m

   (c) 100 m (d) 1000 m

6. The electric and the magnetic field, associated with an electromagnetic wave, propagating along X axis can be represented by

   (a) $\vec{E} = E_\circ \hat{j}$ and $\vec{B} = B_\circ \hat{k}$

   (b) $\vec{E} = E_\circ \hat{k}$ and $\vec{B} = B_\circ \hat{j}$

   (c) $\vec{E} = E_\circ \hat{i}$ and $\vec{B} = B_\circ \hat{j}$

   (d) $\vec{E} = E_\circ \hat{j}$ and $\vec{B} = B_\circ \hat{i}$

7. In an electromagnetic wave in free space the rms value of the electric field is 3 V m^{-1}. The peak value of the magnetic field is

   (a) 1.414×10^{-8} T (b) 1.0×10^{-8} T

   (c) 2.828×10^{-8} T (d) 2.0×10^{-8} T

8. During the propagation of electromagnetic waves in a medium:

   (a) electric energy density is double of the magnetic energy density

   (b) electric energy density is half of the magnetic energy density

   (c) electric energy density is equal to the magnetic energy density

   (d) both electric and magnetic energy densities are zero

9. If the magnetic monopole exists, then which of the Maxwell's equation to be modified?.

   (a) $\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_\circ}$

   (b) $\oint \vec{E} \cdot d\vec{A} = 0$

   (c) $\oint \vec{E} \cdot d\vec{A} = \mu_\circ I_{enclosed} + \mu_\circ \epsilon_\circ \frac{d}{dt} \int \vec{E} \cdot d\vec{A}$

   (d) $\oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \Phi_B$

10. A radiation of energy E falls normally on a perfectly reflecting surface. The momentum transferred to the surface is

    (a) $\frac{E}{c}$ (b) $2\frac{E}{c}$

    (c) Ec (d) $\frac{E}{c^2}$

11. Which of the following is an electromagnetic wave?
    (a) α - rays (b) β - rays
    (c) γ - rays (d) all of them

12. Which one of them is used to produce a propagating electromagnetic wave?.
    (a) an accelerating charge
    (b) a charge moving at constant velocity
    (c) a stationary charge
    (d) an uncharged particle

13. Let $E = E_o \sin[10^6 x - \omega t]$ be the electric field of plane electromagnetic wave, the value of ω is
    (a) 0.3×10^{-14} rad s^{-1}
    (b) 3×10^{-14} rad s^{-1}
    (c) 0.3×10^{14} rad s^{-1}
    (d) 3×10^{14} rad s^{-1}

14. Which of the following is NOT true for electromagnetic waves?.
    (a) it transport energy
    (b) it transport momentum
    (c) it transport angular momentum
    (d) in vacuum, it travels with different speeds which depend on their frequency

15. The electric and magnetic fields of an electromagnetic wave are
    (a) in phase and perpendicular to each other
    (b) out of phase and not perpendicular to each other
    (c) in phase and not perpendicular to each other
    (d) out of phase and perpendicular to each other

Answers

1) b	**2)** d	**3)** d	**4)** c	**5)** a
6) b	**7)** a	**8)** c	**9)** b	**10)** b
11) c	**12)** a	**13)** d	**14)** d	**15)** a

II Short answer questions

1. What is displacement current?
2. What are electromagnetic waves?
3. Write down the integral form of modified Ampere's circuital law.
4. Explain the concept of intensity of electromagnetic waves.
5. What is meant by Fraunhofer lines?

III Long answer questions

1. Write down Maxwell equations in integral form.
2. Write short notes on (a) microwave (b) X-ray (c) radio waves (d) visible spectrum
3. Discuss briefly the experiment conducted by Hertz to produce and detect electromagnetic spectrum.
4. Explain the Maxwell's modification of Ampere's circuital law.
5. Write down the properties of electromagnetic waves.
6. Discuss the source of electromagnetic waves.
7. What is emission spectra?. Give their types.
8. What is absorption spectra?. Give their types.

IV Numerical problems

1. Consider a parallel plate capacitor whose plates are closely spaced. Let R be the radius of the plates and the current in the wire connected to the plates is 5 A, calculate the displacement current through the surface passing between the plates by directly calculating the rate of change of flux of electric field through the surface.

   Answer: $I_d = I_c = 5$ A

2. A transmitter consists of LC circuit with an inductance of 1 μH and a capacitance of 1 μF. What is the wavelength of the electromagnetic waves it emits?

   Answer: 18.84×10^{-6} m

3. A pulse of light of duration 10^{-6} s is absorbed completely by a small object initially at rest. If the power of the pulse is 60×10^{-3} W, calculate the final momentum of the object.

   Answer: 20×10^{-17} kg m s^{-1}

4. Let an electromagnetic wave propagate along the x direction, the magnetic field oscillates at a frequency of 10^{10} Hz and has an amplitude of 10^{-5} T, acting along the y - direction. Then, compute the wavelength of the wave. Also write down the expression for electric field in this case.

   Answer: $\lambda = 3 \times 10^{-18}$ m and

   $$\vec{E}(x,t) = 3\times10^{3}\sin\left(2.09\times10^{18}x - 6.28\times10^{10}t\right)\hat{i}\ \ NC^{-1}$$

5. If the relative permeability and relative permittivity of the medium is 1.0 and 2.25, respectively. Find the speed of the electromagnetic wave in this medium.

   Answer: v = 2 m s^{-1}

BOOKS FOR REFERENCE:

1. H. C. Verma, *Concepts of Physics – Volume 2*, Bharati Bhawan Publisher
2. Halliday, Resnick and Walker, *Fundamentals of Physics*, Wiley Publishers, 10th edition
3. Serway and Jewett, *Physics for scientist and engineers with modern physics*, Brook/Coole publishers, Eighth edition
4. David J. Griffiths, *Introduction to electrodynamics*, Pearson publishers
5. Paul Tipler and Gene Mosca, *Physics for scientist and engineers with modern physics*, Sixth edition, W.H.Freeman and Company

ICT CORNER

Electromagnetic waves

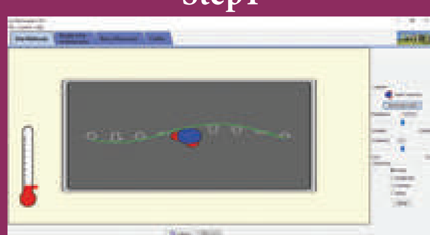
In this activity you will be able to how do microwaves heat food?

Physics of microwaves and heating food

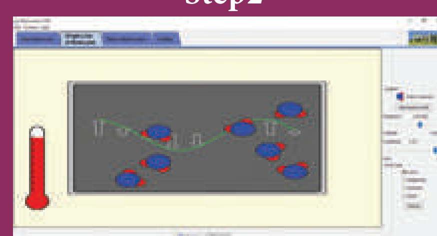
STEPS:

- Open the browser and type "phet.colorado.edu/en/simulation/microwaves" in the address bar. Run the simulation.
- select 'one molecule' tab. Turn on the microwave using the button in the right control panel. The arrows indicate the strength and direction of the force that would be exerted by the micro wave on the water molecules present in food. Observe the response of water molecule in response to this force?
- Observe how do microwaves heat food by rotating water molecule?
- Change amplitude and frequency of microwave and discuss how fast the water molecules are rotating?

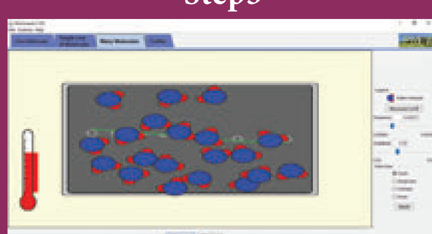
Step1



Step2



Step3



Step4

Discuss the relationship between rotating speed of the molecule with cooking time.

* Pictures are indicative only.

* If browser requires, allow **Flash Player** or **Java Script** to load the page.

B263_12_PHYSICS_EM

Higher Secondary Second Year

PHYSICS

PRACTICAL

LIST OF EXPERIMENTS

1. Determination of the specific resistance of the material of the given coil using metre bridge.
2. Determination of the value of the horizontal component of the Earth's magnetic field using tangent galvanometer.
3. Determination of the magnetic field at a point on the axis of a circular coil.
4. Determination of the refractive index of the material of the prism by finding angle of prism and angle of minimum deviation using spectrometer.
5. Determination of the wavelength of a composite light by normal incidence method using diffraction grating and spectrometer (The number of lines per metre length of the grating is given).
6. Investigation of the voltage-current (V-I) characteristics of PN junction diode.
7. Investigation of the voltage-current (V-I) characteristics of Zener diode.
8. Investigation of the static characteristics of a NPN Junction transistor in common emitter configuration.
9. Verification of the truth table of the basic logic gates using integrated circuits.
10. Verification of De Morgan's theorems using integrated circuits.

R2TEF8

1. SPECIFIC RESISTANCE OF THE MATERIAL OF THE COIL USING METRE BRIDGE

AIM

To determine the specific resistance of the material of the given coil using metre bridge.

APPARATUS REQUIRED

Meter bridge, galvanometer, key, resistance box, connecting wires, Lechlanche cell, jockey and high resistance.

FORMULA

$$\rho = \frac{X\pi r^2}{L} \ (\Omega\text{m})$$

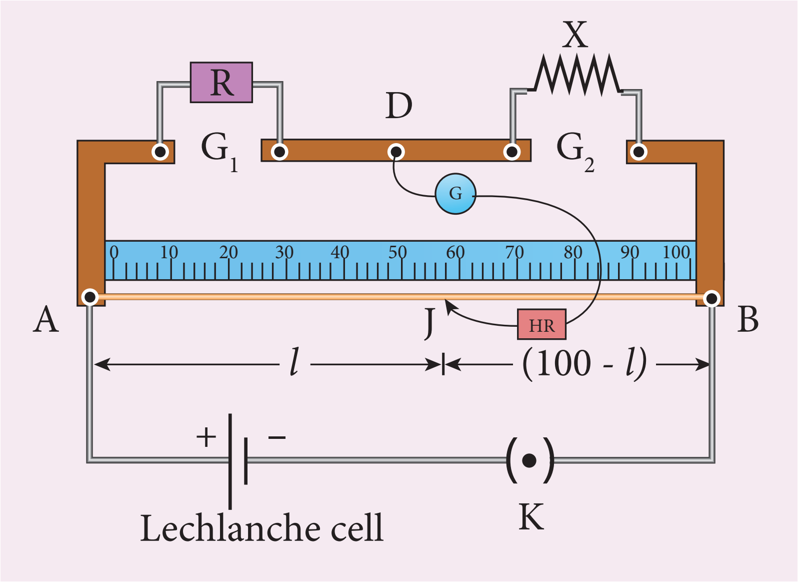
where, $X \rightarrow$ Resistance of the given coil (Ω)

$R \rightarrow$ Known resistance (Ω)

$L \rightarrow$ Length of the coil (m)

$r \rightarrow$ Radius of the wire (m)

CIRCUIT DIAGRAM



PROCEDURE

- A resistance box R is connected in the left gap and the unknown resistance X in the right gap.
- A Lechlanche cell is connected across the wire of length 1 m through a key.
- A sensitive galvanometer G is connected between the central strip and the jockey through a high resistance (HR).
- With a suitable resistance included in the resistance box, the circuit is switched on.
- To check the circuit connections, the jockey is pressed near one end of the wire, say A. The galvanometer will show deflection in one direction. When the jockey is pressed near the other end of the wire B, the galvanometer will show deflection in the opposite directions. This ensures that the circuit connections are correct.

- By moving the jockey over the wire, the point on the wire at which the galvanometer shows null deflection i.e., balancing point J is found.
- The balancing length $AJ = l$ is noted.
- The unknown resistance X_1 is found using the formula $X_1 = \frac{R(100-l)}{l}$.
- The experiment is repeated for different values of R.
- The same procedure is repeated after interchanging R and X.
- The unknown resistance X_2 is found using the formula $X_2 = \frac{Rl}{(100-l)}$.
- The experiment is repeated for same values of R as before.
- The resistance of the given coil is found from the mean value of X_1 and X_2.
- The radius of the wire r is found using screw gauge.
- The length of the coil L is measured using meter scale.
- From the values of X, r and L, the specific resistance of the material of the wire is determined.

OBSERVATION

length of the coil L = ______________________________ cm.

Table 1 To find the resistance of the given coil

S.No.	Resistance R (Ω)	Before interchanging		After interchanging		Mean
		Balancing length l (cm)	$X_1 = \frac{R(100-l)}{l}$ (Ω)	Balancing length l (cm)	$X_2 = \frac{Rl}{(100-l)}$ (Ω)	$X = \frac{X_1+X_2}{2}$ (Ω)
1						
2						
3						

Mean resistance, X = -----------Ω

Table 2 To find the radius of the wire

Zero error =

Zero correction = LC = 0.01 mm

Sl.No.	PSR (mm)	HSC (div.)	Total Reading = PSR + (HSC × LC) (mm)	Corrected Reading = TR ± ZC (mm)
1				
2				
3				
4				
5				
6				

Mean diameter 2r = ... cm

Radius of the wire r = ... cm

r = ... m

CALCULATION

(i) $\rho = \frac{X\pi r^2}{L} =$

RESULT

The specific resistance of the material of the given coil = ________________________(Ωm)

Note:

i) To check the circuit connections:

The meter bridge wire is touched near one end (say, end A) with jockey, galvanometer shows a deflection in any one direction. Now the other end (say, end B) is touched. If the galvanometer shows a deflection in the opposite direction, then the circuit connections are correct.

ii) The usage of high resistance (HR):

The galvanometer is a very sensitive device. If any high current flows through the galvanometer, its coil gets damaged. Therefore in order to protect the galvanometer, a high resistance (HR) is used. When HR is connected in series with the galvanometer, the current through it is reduced so that the galvanometer is protected. But the balancing length is not accurate.

iii) To find the accurate balancing length:

The HR is first included in the circuit (that is, the plug key in HR is removed), the approximate balancing length is found. Now HR is excluded in the circuit (that is, the plug key in HR is closed), then the accurate balancing length is found.

2. HORIZONTAL COMPONENT OF EARTH'S MAGNETIC FIELD USING TANGENT GALVANOMETER

AIM

To determine the horizontal component of the Earth's magnetic field using tangent galvanometer.

APPARATUS REQUIRED

Tangent galvanometer (TG), commutator, battery, rheostat, ammeter, key and connecting wires.

FORMULA

$$B_H = \frac{\mu_0 n k}{2r} \text{ (Tesla)}$$

$$k = \frac{I}{\tan\theta} \ (A)$$

where,
- B_H → Horizontal component of the Earth's magnetic field (T)
- μ_0 → Permeability of free space ($4\pi \times 10^{-7}$ H m^{-1})
- n → Number of turns of TG in the circuit (No unit)
- k → Reduction factor of TG (A)
- r → Radius of the coil (m)

CIRCUIT DIAGRAM

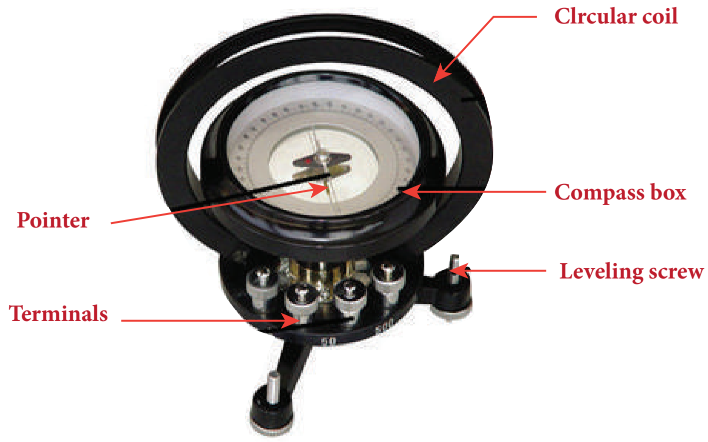
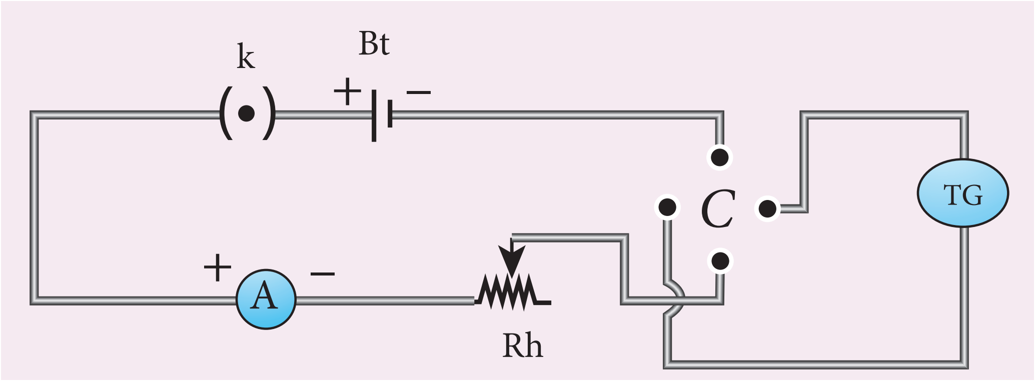


Figure (a) Tangent Galvanometer

Figure (b) Number of turns



(c) Circuit diagram

PROCEDURE

- The preliminary adjustments are carried out as follows.
  a. The leveling screws at the base of TG are adjusted so that the circular turn table is horizontal and the plane of the circular coil is vertical.
  b. The circular coil is rotated so that its plane is in the magnetic meridian i.e., along the north-south direction.
  c. The compass box alone is rotated till the aluminium pointer reads $0° - 0°$.
- The connections are made as shown in Figure (c).
- The number of turns *n* is selected and the circuit is switched on.
- The range of current through TG is chosen in such a way that the deflection of the aluminium pointer lies between $30° - 60°$.
- A suitable current is allowed to pass through the circuit, the deflections θ_1 and θ_2 are noted from two ends of the aluminium pointer.
- Now the direction of current is reversed using commutator C, the deflections θ_3 and θ_4 in the opposite direction are noted.
- The mean value θ of θ_1, θ_2, θ_3 and θ_4 is calculated and tabulated.
- The reduction factor k is calculated for each case and it is found that k is a constant.
- The experiment is repeated for various values of current and the readings are noted and tabulated.
- The radius of the circular coil is found by measuring the circumference of the coil using a thread around the coil.
- From the values of *r*, *n* and *k*, the horizontal component of Earth's magnetic field is determined.

Commutator:

It is a kind of switch employed in electrical circuits, electric motors and electric generators. It is used to reverse the direction of current in the circuit.

OBSERVATION

Number of turns of the coil n =

Circumference of the coil ($2\pi r$) =

Radius of the coil r =

S.No	Current I (A)	Deflection in TG (degree)				Mean θ (degree)	$k = \frac{I}{\tan\theta}$
		θ_1	θ_2	θ_3	θ_4		
1							
2							
3							
4							
						Mean	

CALCULATION

$$B_H = \frac{\mu_0 n k}{2r} =$$

RESULT

The horizontal component of Earth's magnetic field is found to be ________

Note:

i) The magnetic materials and magnets present in the vicinity of TG should be removed.

ii) The readings from the ends of the aluminium pointer should be taken without parallax error.

iii) The deflections of TG is restricted between 30° and 60°. It is because, the TG is most sensi tive for deflection around 45° and is least sensitive around 0° and 90°. We know that

$$I = k \tan\theta$$

$$\text{or } dI = k \sec^2\theta \, d\theta$$

$$\frac{d\theta}{dI} = \frac{\sin 2\theta}{2I}$$

For given current, sensitivity $\frac{d\theta}{dI}$ maximum for $\sin 2\theta = 1$ or $\theta = 45°$

3. MAGNETIC FIELD ALONG THE AXIS OF A CIRCULAR COIL-DETERMINATION OF B_H

AIM

To determine the horizontal component of Earth's magnetic field using current carrying circular coil and deflection magnetometer.

APPARATUS REQUIRED

Circular coil apparatus, compass box, rheostat, battery or power supply, ammeter, commutator, key and connecting wires.

FORMULA

$$B_H = \frac{\mu_0 n I r^2}{2\left(r^2 + x^2\right)^{3/2}} \left(\frac{1}{\tan\theta}\right) \text{ (Tesla)}$$

where, $B_H \rightarrow$ Horizontal component of Earth's magnetic field (T)

$\mu_o \rightarrow$ Permeability of the free space ($4\pi \times 10^{-7}$ H m^{-1})

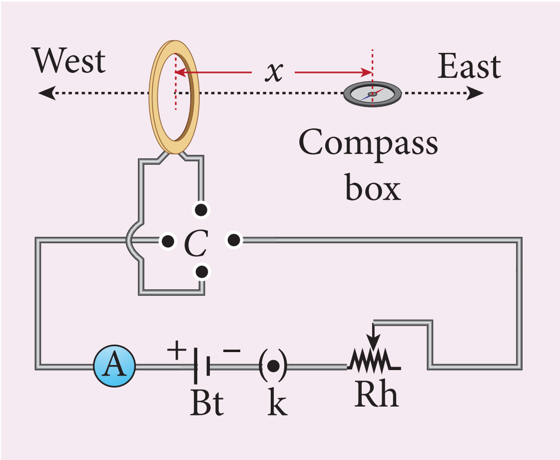
$n \rightarrow$ Number of turns included in the circuit (No unit)

$I \rightarrow$ Current flowing through the coil (A)

$r \rightarrow$ Radius of the circular coil (m)

$x \rightarrow$ Distance between center of compass box and centre of the coil (m)

CIRCUIT DIAGRAM



PROCEDURE

- The preliminary adjustments are carried out as follows.
  i. The leveling screws are adjusted so that the circular coil is vertical.
  ii. The wooden bench is adjusted to be along the magnetic east-west direction i.e., along aluminium pointer.
  iii. The circular coil is rotated so that its plane is in magnetic meridian i.e., along the north-south direction.
  iv. A compass box is placed with its centre coinciding with the axis of the coil.
  v. The compass box alone is rotated till the aluminium pointer reads $0° - 0°$
- Electrical connections are made as shown in the circuit diagram.
- The compass box is placed along its axis, with its centre at a distance x from the centre of the coil on one side.

- A suitable current (1A) is passed through the coil by adjusting rheostat so that the deflection of the aluminium pointer lies between 30º and 60º.
- The value of the current I is noted from ammeter.
- Two readings θ_1 and θ_2 corresponding to two ends of the pointer are noted.
- Now the direction of the current is reversed using commutator, two more readings θ_3 and θ_4 are noted.
- Now the compass box is taken to the other side and is kept at the same distance *x*.
- Four more readings θ_5, θ_6, θ_7 and θ_8 are taken as done before.
- These eight readings and their average value are tabulated.
- The experiment is repeated for another value of current, say 1.5 A by keeping the compass box at the same distance *x*.
- The radius of the circular coil is found by measuring the circumference of the coil using a thread around the coil.
- The number of turns n of the coil is noted.
- From the values of *n, r, x* and *I*/tanθ, the horizontal component of Earth's magnetic field is now found using the formula.

OBSERVATION

Number of turns in the coil *n*=

Circumference of the coil (2πr) =

Radius of the coil r =

To find horizontal component of the Earth's magnetic field

S.No	Distance x (cm)	Current I (A)	Deflection for eastern side				Deflection for western side				Mean θ	$\frac{I}{\tan\theta}$
			θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8		
											Mean	

CALCULATION

$$B_H = \frac{\mu_0 n I r^2}{2\left(r^2 + x^2\right)^{3/2}}\left(\frac{1}{\tan\theta}\right) =$$

RESULT

Horizontal component of the Earth's magnetic field at a place = __________T

4. REFRACTIVE INDEX OF THE MATERIAL OF THE PRISM

AIM

To determine the refractive index of the material of a prism using spectrometer.

APPARATUS REQUIRED

Spectrometer, prism, prism clamp, sodium vapour lamp, spirit level.

FORMULA

$$\mu = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} \quad \text{(No unit)}$$

where, $\mu \rightarrow$ Refractive index of the material of the prism (No unit)

$A \rightarrow$ Angle of the prism (degree)

$D \rightarrow$ Angle of minimum deviation (degree)

DIAGRAMS

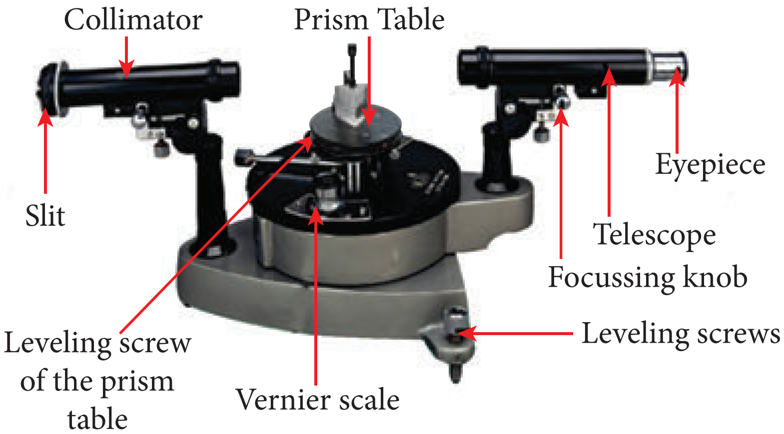


Figure (a) Angle of the prism

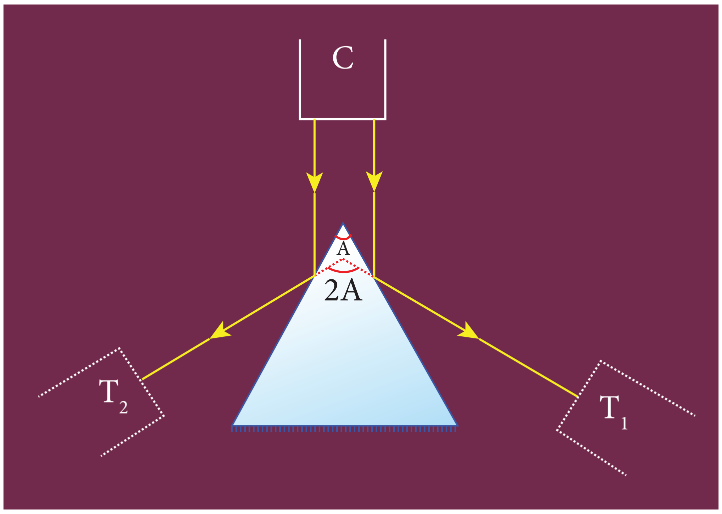


Figure (b) Angle of the prism

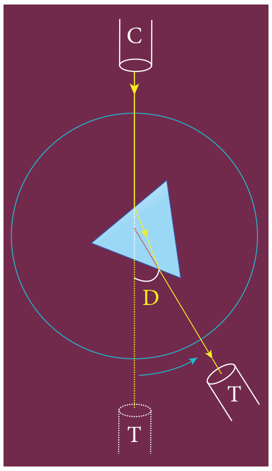


Figure (c) Angle of minimum deviation

PROCEDURE

1) Initial adjustments of the spectrometer

- Eye-piece: The eye-piece of the telescope is adjusted so that the cross-wires are seen clearly.
- Slit: The slit of the collimator is adjusted such that it is very thin and vertical.
- Base of the spectrometer: The base of the spectrometer is adjusted to be horizontal using leveling screws.
- Telescope: The telescope is turned towards a distant object and is adjusted till the clear inverted image of the distant object is seen. Now the telescope is adjusted to receive parallel rays.
- Collimator: The telescope is brought in line with the collimator. Collimator is adjusted until a clear image of the slit is seen in the telescope. Now the collimator gives parallel rays.
- Prism table: Using a spirit level, the prism table is adjusted to be horizontal with the three leveling screws provided in the prism table.

2) Determination of angle of the prism (A)

- The slit is illuminated by yellow light from sodium vapour lamp.
- The given equilateral prism is placed on the prism table in such a way that refracting edge of the prism is facing the collimator.
- The light emerging from the collimator is incident on both reflecting faces of the prism and is reflected.
- The telescope is rotated towards left to obtain reflected image of the slit from face 1 of the prism and is fixed.
- Using tangential screws, the telescope is adjusted until the vertical cross-wire coincides with the reflected image of the slit.
- The main scale reading and vernier coincidence are noted from both vernier scales.
- The telescope is now rotated towards right to obtain the reflected image from face 2 of the prism. As before, the readings are taken.
- The difference between the two readings gives 2A from which the angle of the prism A is calculated.

3) Determination of angle of minimum deviation (D)

- The prism table is rotated such that the light emerging from the collimator is incident on one of the refracting faces of the prism, gets refracted and emerges out from the other refracting face.
- The telescope is turned to view the refracted image.
- Looking through the telescope, the prism table is rotated in such a direction that the image moves towards the direct ray.

- At one particular position, the refracted ray begins to retrace its path. The position where the refracted image returns is the position of minimum deviation.
- The telescope is fixed in this position and is adjusted until the vertical cross-wire coincides with the refracted image of the slit.
- The readings are taken from both vernier scales.
- The prism is now removed and the telescope is rotated to obtain the direct ray image and the readings are taken.
- The readings are tabulated and the difference between these two readings gives the angle of minimum deviation D.
- From the values of A and D, the refractive index of the material of the glass prism is determined.

Least count

1 MSD = $30'$

Number of vernier scale divisions = 30

For spectrometer, 30 vernier scale divisions will cover 29 main scale divisions.

$\therefore$ 30 VSD = 29 MSD

Or 1 VSD = 29 / 30 MSD

Least count (LC) = 1 MSD – 1 VSD

= 1 / 30 MSD

= $1'$

OBSERVATION

Table 1 To find the angle of the prism (A)

Image	Vernier A (Degree)			Vernier B (Degree)		
	MSR	VSC	TR	MSR	VSC	TR
Reflected image from face 1						
Reflected image from face 2						
Difference 2A						

Mean 2A =

Mean A =

Table 2 To find the angle of minimum deviation (D)

Image	Vernier A (Degree)			Vernier B (Degree)		
	MSR	VSC	TR	MSR	VSC	TR
Refracted image						
Direct image						
Difference D						

Mean D =

RESULT

1. Angle of the Prism (A) = ... (degree)
2. Angle of the minimum deviation of the prism (D) =............ (degree)
3. Refractive index of the material of the Prism (μ) =............ (No unit)

Note:

i) Once initial adjustments are done, spectrometer should not be disturbed.

ii) Total reading TR = MSR + (VSC × LC)

Where

MSR → Main Scale Reading

VSC → Vernier Scale Coincidence

LC → Least count (= 1′)

5. WAVELENGTH OF THE CONSTITUENT COLOURS OF A COMPOSITE LIGHT USING DIFFRACTION GRATING AND SPECTROMETER

AIM

To find the wavelength of the constituent colours of a composite light using diffraction grating and spectrometer.

APPARATUS REQUIRED

Spectrometer, mercury vapour lamp, diffraction grating, grating table, and spirit level.

FORMULA

$$\lambda = \frac{\sin\theta}{nN} \text{ Å}$$

where, $\lambda \rightarrow$ Wavelength of the constituent colours of a composite light (Å)

$N \rightarrow$ Number of lines per metre length of the given grating (No unit) (the value of N for the grating is given)

$n \rightarrow$ Order of the diffraction (No unit)

$\theta \rightarrow$ Angle of diffraction (degree)

DIAGRAMS

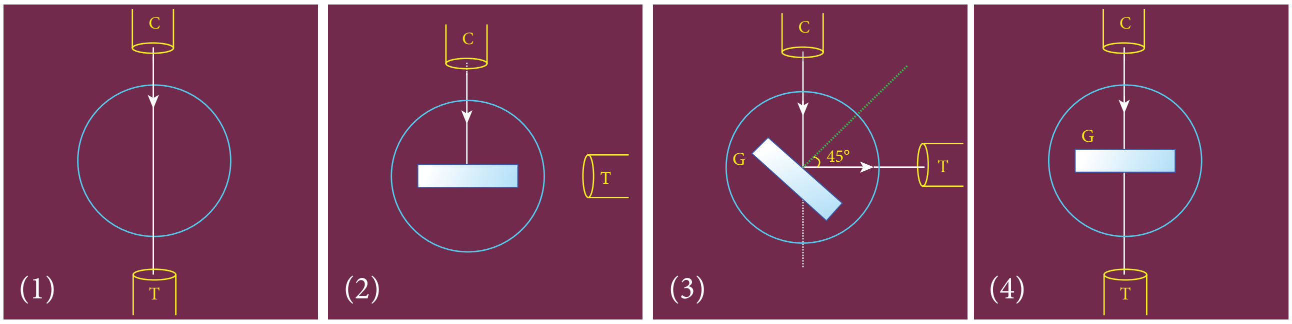


Figure (a) Normal incidence

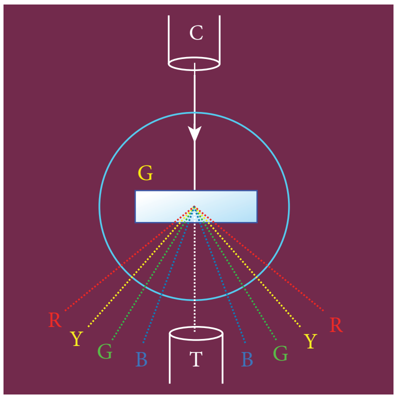


Figure (b) Angle of diffraction

PROCEDURE

1) **Initial adjustments of the spectrometer**

- ➢ Eye-piece: The eye-piece of the telescope is adjusted so that the cross-wires are seen clearly.
- ➢ Slit: The slit of the collimator is adjusted such that it is very thin and vertical.
- ➢ Base of the spectrometer: The base of the spectrometer is adjusted to be horizontal using leveling screws.

- Telescope: The telescope is turned towards a distant object and is adjusted till the clear image of the distant object is seen. Now the telescope is adjusted to receive parallel rays.
- Collimator: The telescope is brought in line with the collimator. Collimator is adjusted until a clear image of the slit is seen in the telescope. Now the collimator gives parallel rays.
- Grating table: Using a spirit level, the grating table is adjusted to be horizontal with the three leveling screws provided in the grating table.

2) Adjustment of the grating for normal incidence

- The slit is illuminated with a composite light (white light) from mercury vapour lamp.
- The telescope is brought in line with the collimator. The vertical cross-wire is made to coincide with the image of the slit (Figure (a)1).
- The vernier disc alone is rotated till the vernier scale reads 0^0 - 180^0 and is fixed. This is the reading for the direct ray.
- The telescope is then rotated (anti-clockwise) through an angle of 90^0 and fixed (Figure (a)2).
- Now the plane transmission grating is mounted on the grating table.
- The grating table alone is rotated so that the light reflected from the grating coincides with vertical cross-wire of the telescope. The reflected image is white in colour (Figure (a)3).
- Now the vernier disc is released. The vernier disc along with grating table is rotated through an angle of 45^0 in the appropriate direction such that the light from the collimator is incident normally on the grating (Figure (a)4).

3) Determination of wave length of the constituent colours of the mercury spectrum

- The telescope is released and is brought in line with the collimator to receive central direct image. This undispersed image is white in colour.
- The diffracted images of the slit are observed on either side of the direct image.
- The diffracted image consists of the prominent colours of mercury spectrum in increasing order of wavelength.
- The telescope is turned to any one side (say left) of direct image to observe first order diffracted image.
- The vertical cross-wire is made to coincide with the prominent spectral lines (violet, blue, yellow and red) and the readings of both vernier scales for each case are noted.
- Now the telescope is rotated to the right side of the direct image and the first order image is observed.
- The vertical cross-wire is made to coincide with the same prominent spectral lines and the readings of both vernier scales for each case are again noted.
- The readings are tabulated.
- The difference between these two readings gives the value of 2θ for the particular spectral line.
- The number of lines per metre length of the given grating N is noted from the grating.
- From the values of N, n and θ, the wave length of the prominent colours of the mercury light is determined using the given formula.

OBSERVATION

To find the wave length of prominent colours of the mercury spectrum

Colour of Light	Diffracted Ray Reading (Degree)												Difference 2θ (Degree)			θ (Degree)
	Left						Right									
	Vernier A			Vernier B			Vernier A			Vernier B						
	MSR	VSC	TR	MSR	VSC	TR	MSR	VSC	TR	MSR	VSC	TR	VER A	VER B	Mean	
Blue																
Green																
Yellow																
Red																

CALCULATION

(i) For blue, $\lambda = \frac{\sin\theta}{nN}$,

(ii) For green, $\lambda = \frac{\sin\theta}{nN}$

(iii) For yellow, $\lambda = \frac{\sin\theta}{nN}$,

(iv) For red, $\lambda = \frac{\sin\theta}{nN}$

RESULT

1. The wavelength of blue line = ----------------m
2. The wavelength of green line = ------------------m
3. The wavelength of yellow line = ----------------m
4. The wavelength of red line = ----------------m

Note:

i) Once initial adjustments are done, spectrometer should not be disturbed.

ii) Total reading TR = MSR + (VSC × LC)

Where

MSR → Main Scale Reading

VSC → Vernier Scale Coincidence

LC → Least count (= 1′)

6. VOLTAGE-CURRENT CHARACTERISTICS OF A PN JUNCTION DIODE

AIM

To draw the voltage-current (V- I) characteristics of the PN junction diode and to determine its knee voltage and forward resistance.

APPARATUS REQUIRED

PN junction diode (IN4007), variable DC power supply, milli-ammeter, micro-ammeter, voltmeter, resistance and connecting wires.

FORMULA

$$R_F = \frac{\Delta V_F}{\Delta I_F} \ (\Omega)$$

where, $R_F \rightarrow$ Forward resistance of the diode (Ω)

$\Delta V_F \rightarrow$ The change in forward voltage (volt)

$\Delta I_F \rightarrow$ The change in forward current (mA)

CIRCUIT DIAGRAM

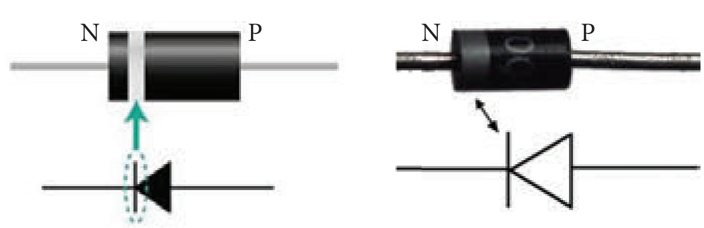


Figure (a) PN junction diode and its symbol (Silver ring denotes the negative terminal of the diode)

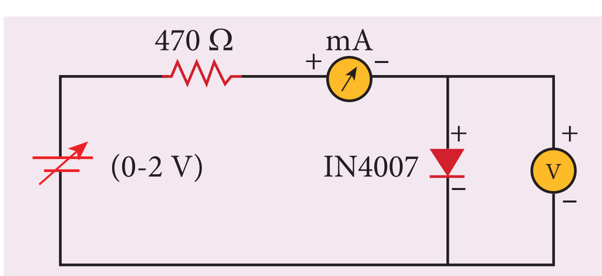


Figure (b) PN junction diode in forward bias

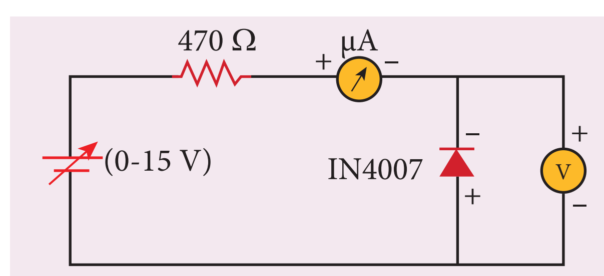


Figure (c) PN junction diode in reverse bias

Precaution

Care should be taken to connect the terminals of ammeter, voltmeter, dc power supply and the PN junction diode with right polarity.

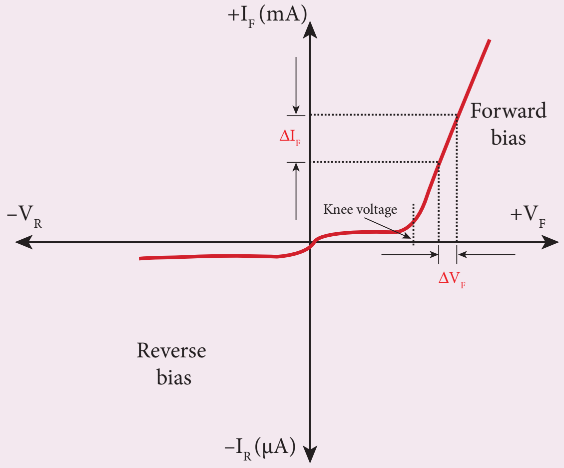
PROCEDURE

i) Forward bias characteristics

- In the forward bias, the P- region of the diode is connected to the positive terminal and N-region to the negative terminal of the DC power supply.
- The connections are given as per the circuit diagram.
- The voltage across the diode can be varied with the help of the variable DC power supply.
- The forward voltage (V_F) across the diode is increased from 0.1 V in steps of 0.1 V up to 0.8|V and the forward current (I_F) through the diode is noted from the milli-ammeter. The readings are tabulated.
- The forward voltage V_F and the forward current I_F are taken as positive.
- A graph is drawn taking the forward voltage (V_F) along the x-axis and the forward current (I_F) along the y-axis.
- The voltage corresponding to the dotted line in the forward characteristics gives the knee voltage or threshold voltage or turn-on voltage of the diode.
- The slope in the linear portion of the forward characteristics is calculated. The reciprocal of the slope gives the forward resistance of the diode.

ii) Reverse bias characteristics

- In the reverse bias, the polarity of the DC power supply is reversed so that the P- region of the diode is connected to the negative terminal and N-region to the positive terminal of the DC power supply
- The connections are made as given in the circuit diagram.
- The voltage across the diode can be varied with the help of the variable DC power supply.
- The reverse voltage (V_R) across the diode is increased from 1 V in steps of 1 V up to 5 V and the reverse current (I_R) through the diode is noted from the micro-ammeter. The readings are tabulated.
- The reverse voltage V_R and reverse current I_R are taken as negative.
- A graph is drawn taking the reverse bias voltage (V_R) along negative x-axis and the reverse bias current (I_R) along negative y-axis.



Slope = $\dfrac{\Delta I_F}{\Delta V_F}$

Forward resistance = $\dfrac{1}{\text{slope}}$

OBSERVATION

Table 1 Forward bias characteristic curve

S.No.	Forward bias voltage V_F (volt)	Forward bias current I_F (mA)

Table 2 Reverse bias characteristic curve

S.No.	Reverse bias voltage V_R (volt)	Reverse bias current I_R (μA)

CALCULATION

(i) Forward resistance R_F=

(ii) knee voltage =

RESULT

The V-I characteristics of the PN junction diode are studied.

i) Knee voltage of the PN junction diode =……………..V

ii) Forward resistance of the diode =……………..Ω

Practical Tips

- The DC power supply voltage should be increased only up to the specified range in the forward (0 – 2V) and reverse (0 – 15V) directions. Forward bias offers very low resistance and hence an external resistance of 470Ω is connected as a safety measure.
- The voltage applied beyond this limit may damage the resistance or the diode.
- In the forward bias, the current flow will be almost zero till it crosses the junction potential or knee voltage (approximately 0.7 V). Once knee voltage is crossed, the current increases with the applied voltage.
- The diode voltage in the forward direction should be increased in steps of 0.1 V to a maximum of 0.8 V after the threshold voltage to calculate the forward resistance.
- The diode voltage in the reverse direction is increased in steps of 1 V to a maximum of 5 V. The current must be measured using micro-ammeter as the strength of current in the reverse direction is very less. This is due to the flow of the minority charge carriers called the leakage current.

7. VOLTAGE-CURRENT CHARACTERISTICS OF A ZENER DIODE

AIM

To draw the voltage-current (V-I) characteristic curves of a Zener diode and to determine its knee voltage, forward resistance and reverse breakdown voltage.

APPARATUS REQUIRED

Zener diode IZ5.6V, variable dc power supply (0 – 15V), milli ammeter, volt meter, 470 Ω resistance, and connecting wires.

FORMULA

$$R_F = \frac{\Delta V_F}{\Delta I_F} \ (\Omega)$$

where, $R_F \rightarrow$ Forward resistance of the diode (Ω)

$\Delta V_F \rightarrow$ The change in forward voltage (volt)

$\Delta I_F \rightarrow$ The change in forward current (mA)

CIRCUIT DIAGRAM

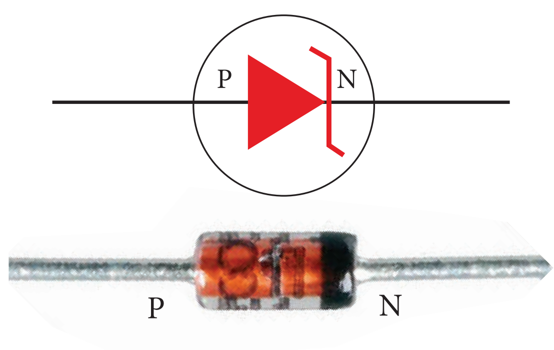


Figure (a) Zener diode and its symbol (The black colour ring denotes the negative terminal of the Zener diode)

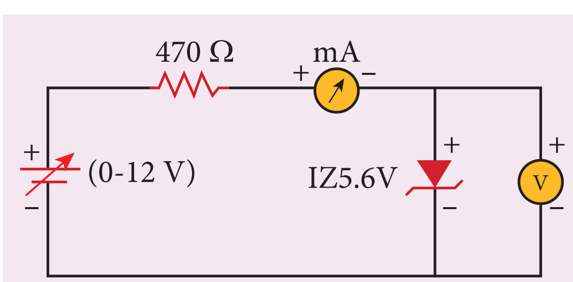


Figure (b) Zener diode in forward bias

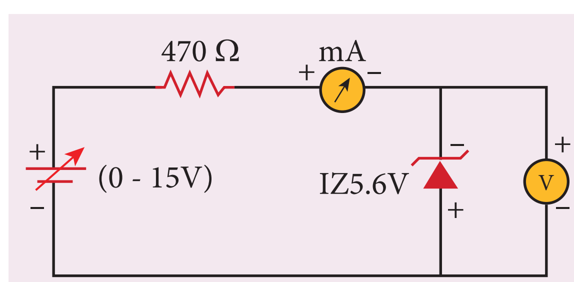


Figure (c) Zener diode in reverse bias

Precaution

Care should be taken to connect the terminals of ammeter, voltmeter, dc power supply and the Zener diode with right polarity.

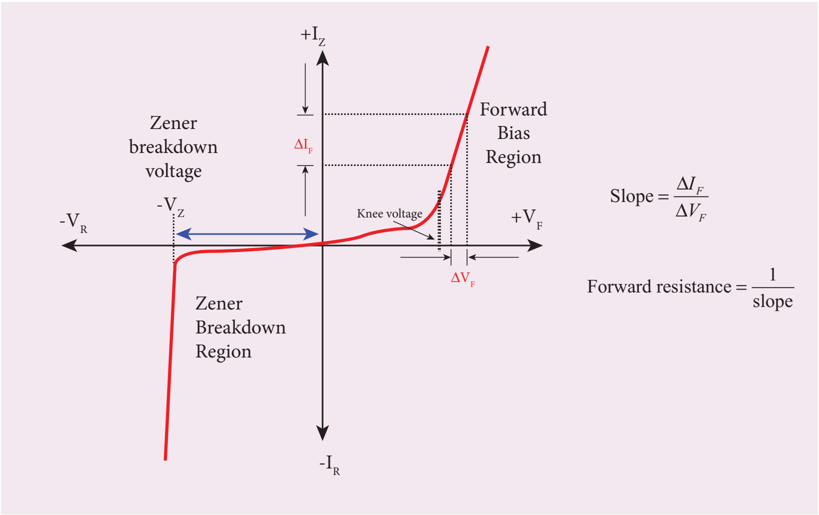
PROCEDURE

i) Forward bias characteristics

- In the forward bias, the P- region of the diode is connected to the positive terminal and N-region to the negative terminal of the DC power supply.
- The connections are given as per the circuit diagram.
- The voltage across the diode can be varied with the help of the variable DC power supply.
- The forward voltage (V_F) across the diode is increased from 0.1V in steps of 0.1V up to 0.8V and the forward current (I_F) through the diode is noted from the milli-ammeter. The readings are tabulated.
- The forward voltage and the forward current are taken as positive.
- A graph is drawn taking the forward voltage along the x-axis and the forward current along the y-axis.
- The voltage corresponding to the dotted line in the forward characteristics gives the knee voltage or threshold voltage or turn-on voltage of the diode.
- The slope in the linear portion of the forward characteristics is calculated. The reciprocal of the slope gives the forward resistance of the diode.

ii) Reverse bias characteristics

- In the reverse bias, the polarity of the DC power supply is reversed so that the P- region of the diode is connected to the negative terminal and N-region to the positive terminal of the DC power supply
- The connections are made as given in the circuit diagram.
- The voltage across the diode can be varied with the help of the variable DC power supply.
- The reverse voltage (V_R) across the diode is increased from 0.5V in steps of 0.5V up to 6V and the reverse current (I_R) through the diode is noted from the milli-ammeter. The readings are tabulated.
- Initially, the voltage is increased in steps of 0.5V. When the breakdown region is approximately reached, then the input voltage may be raised in steps of, say 0.1V to find the breakdown voltage.
- The reverse voltage and reverse current are taken as negative.
- A graph is drawn taking the reverse bias voltage along negative x-axis and the reverse bias current along negative y-axis.
- In the reverse bias, Zener breakdown occurs at a particular voltage called Zener voltage V_Z (~5.6 to 5.8V) and a large amount of current flows through the diode which is the characteristics of a Zener diode.
- The breakdown voltage of the Zener diode is determined from the graph as shown.



OBSERVATION

Table 1 Forward bias characteristic curve

S.No.	Forward bias voltage V_F (volt)	Forward bias current I_F (mA)

Table 2 Reverse bias characteristic curve

S.No.	Reverse bias voltage V_R (volt)	Reverse bias current I_R (mA)

CALCULATION

(i) Forward resistance R_F=

(ii) knee voltage =

(iii) The breakdown voltage of the Zener diode V_Z= ----V

RESULT

The V-I characteristics of the Zener diode are studied.

(i) Forward resistance R_F=

(ii) knee voltage =

(iii) The breakdown voltage of the Zener diode V_Z= ----V

Practical Tips

- The DC power supply voltage should to be increased only up to the specified range in the forward (0 – 2 V) and reverse (0 – 15 V) directions.
- The voltage applied beyond this limit may damage the resistor or the diode.
- Zener diode functions like an ordinary PN junction diode in the forward direction. Hence the forward characteristic is the same for both PN junction diode and Zener diode. Therefore, knee voltage and forward resistance can be determined as explained in the previous experiment.
- Unlike ordinary PN junction diode, the reverse current in Zener diode is measured using milli-ammeter due to the large flow of current.

8 CHARACTERISTICS OF A NPN-JUNCTION TRANSISTOR IN COMMON EMITTER CONFIGURATION

AIM

To study the characteristics and to determine the current gain of a NPN junction transistor in common emitter configuration.

APPARATUS REQUIRED

Transistor - BC 548/BC107, bread board, micro ammeter, milli ammeter, voltmeters, variable DC power supply and connecting wires.

FORMULA

$$r_i = \left[\frac{\Delta V_{BE}}{\Delta I_B}\right]_{V_{CE}} (\Omega), \quad r_o = \left[\frac{\Delta V_{CE}}{\Delta I_C}\right]_{I_B} (\Omega), \quad \beta = \left[\frac{\Delta I_C}{\Delta I_B}\right]_{V_{CE}} \text{ (No unit)}$$

Where, $r_i \rightarrow$ Input impedance (Ω)

$\Delta V_{BE} \rightarrow$ The change in base-emitter voltage (volt)

$\Delta I_B \rightarrow$ The change in base current (μA)

$r_o \rightarrow$ Output impedance (Ω)

$\Delta V_{CE} \rightarrow$ The change in collector-emitter voltage (volt)

$\Delta I_C \rightarrow$ The change in collector current (mA)

$\beta \rightarrow$ Current gain of the transistor (No unit)

CIRCUIT DIAGRAM

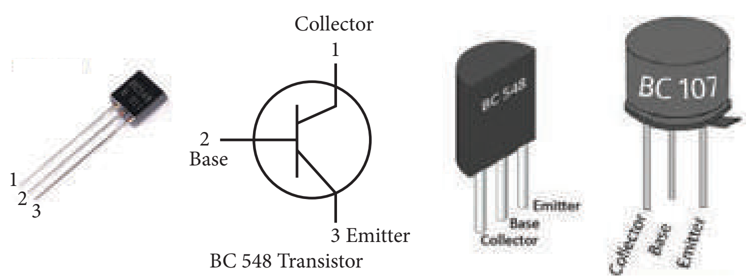


Figure (a) NPN - Junction transistor and its symbol (Transistor is held with the flat surface facing us)

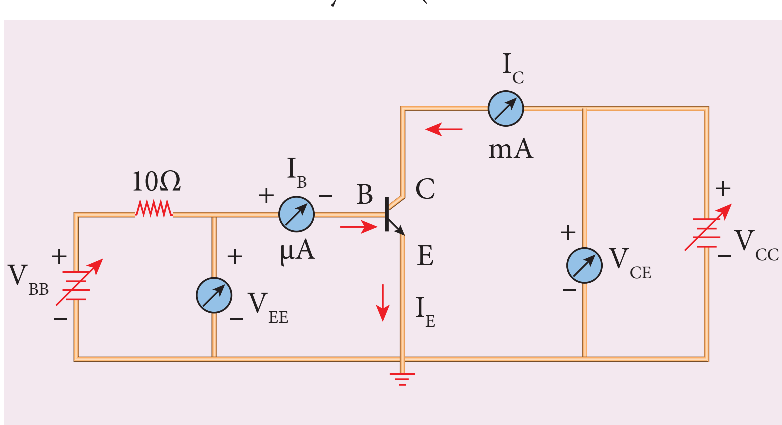


Figure (b) NPN junction transistor in CE configuration

> **Note**
>
> A resistor is connected in series with the base to prevent excess current flowing into the base.

Precautions

- Care should be taken to connect the terminals of ammeters, voltmeters, and dc power supplies with right polarity.
- The collector and emitter terminals of the transistor must not be interchanged.

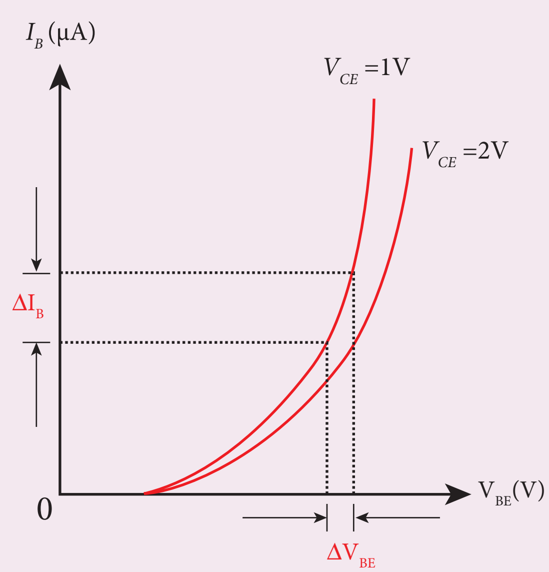
PROCEDURE

- The connections are given as shown in the diagram.
- The current and voltage at the input and output regions can be varied by adjusting the DC power supply.

(i) Input characteristic curve: V_{BE} vs I_B (V_{CE} constant)

- The collector-emitter voltage V_{CE} is kept constant.
- The base-emitter voltage V_{BE} is varied in steps of 0.1V and the corresponding base current (I_B) is noted. The readings are taken till V_{CE} reaches a constant value.
- The same procedure is repeated for different values of V_{CE}. The readings are tabulated.
- A graph is plotted by taking V_{BE} along x-axis and I_B along y-axis for both the values of V_{CE}.
- The curves thus obtained are called the input characteristics of a transistor.
- The reciprocal of the slope of these curves gives the input impedance of the transistor.

S. No	V_{CE} = 1V		V_{CE} = 2V	
	V_{BE} (V)	I_B (μA)	V_{BE} (V)	I_B (μA)



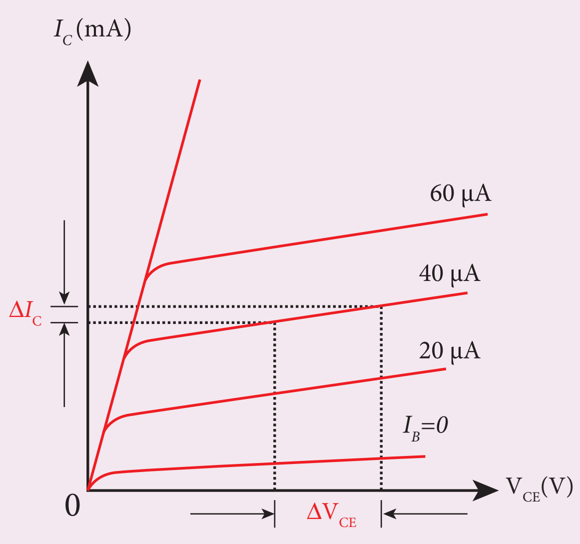
$$\text{Slope} = \frac{\Delta I_B}{\Delta V_{BE}}$$

$$\text{Input impedance} = \frac{1}{\text{slope}}$$

(ii) Output characteristic curve: V_{CE} vs I_C (I_B constant)

- The base current I_B is kept constant.
- V_{CE} is varied in steps of 1V and the corresponding collector current I_C is noted. The readings are taken till the collector current becomes almost constant.
- Initially I_B is kept at 0 mA and the corresponding collector current is noted. This current is the reverse saturation current I_{CEO}.
- The experiment is repeated for various values of I_B. The readings are tabulated.
- A graph is drawn by taking V_{CE} along x-axis and I_C along y-axis for various values of I_B.
- The set of curves thus obtained is called the output characteristics of a transistor.
- The reciprocal of the slope of the curve gives output impedance of the transistor.

S. No	I_B =20 μA		I_B =40 μA	
	V_{CE} (V)	I_C (mA)	V_{CE} (V)	I_C (mA)



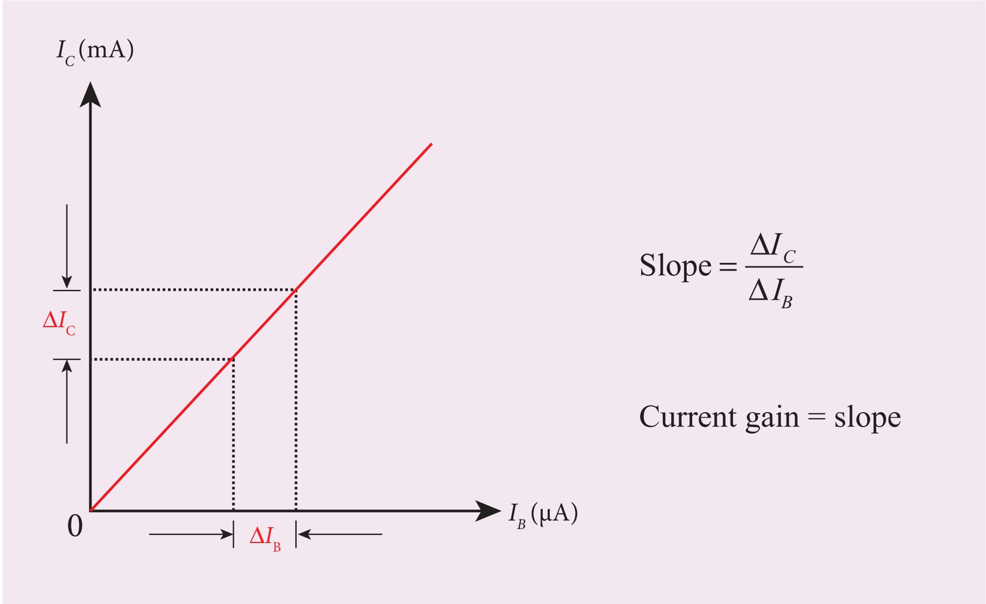
$$\text{Slope} = \frac{\Delta I_C}{\Delta V_{CE}}$$

$$\text{Output impedance} = \frac{1}{\text{slope}}$$

(iii) Transfer characteristic curve: I_B vs I_C (V_{CE} constant)

- The collector-emitter voltage V_{CE} is kept constant.
- The base current I_B is varied in steps of 10 μA and the corresponding collector current I_C is noted.
- This is repeated by changing the value of V_{CE}. The readings are tabulated.
- The transfer characteristics is a plot between the input current IB along x-axis and the output current I_C along y-axis keeping V_{CE} constant.
- The slope of the transfer characteristics plot gives the current gain β can be calculated.

S.No	V_{CE} =1V		V_{CE} =2V	
	I_B (μA)	I_C (mA)	I_B (μA)	I_C (mA)



RESULT

i) The input, output and transfer characteristics of the NPN junction in common emitter mode are drawn.

ii) (a) Input impedance = ________Ω

(b) Output impedance = ________Ω

(c) Current gain β = ____(no unit)

9. VERIFICATION OF TRUTH TABLES OF LOGIC GATES USING INTEGRATED CIRCUITS

AIM To verify the truth tables of AND, OR, NOT, EX-OR, NAND and NOR gates using integrated circuits

COMPONENTS REQUIRED AND gate (IC 7408), NOT gate (IC 7404), OR gate (IC 7432), NAND gate (IC 7400), NOR gate (IC 7402), X-OR gate (IC 7486), Power supply, Digital IC trainer kit, connecting wires.

BOOLEAN EXPRESSIONS

(i) AND gate $Y = A.B$

(ii) OR gate $Y = A+B$

(iii) NOT gate $Y = \overline{A}$

(iv) Ex OR gate $Y = \overline{A}B + A\overline{B}$

(v) NAND gate $Y = \overline{A.B}$

(vi) NOR gate $Y = \overline{A+B}$

CIRCUIT DIAGRAM

Pin Identification

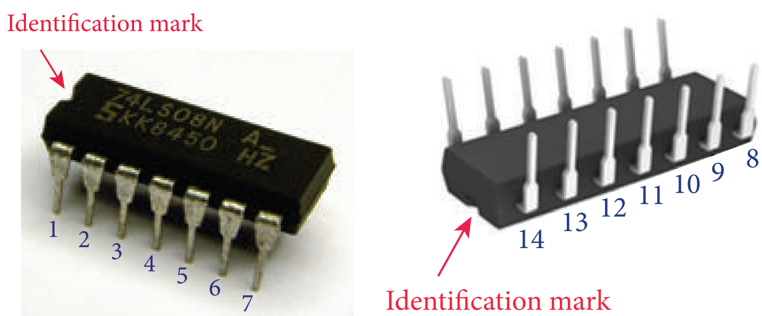
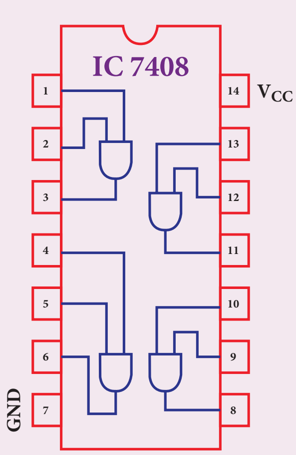


Figure (a) Integrated circuit

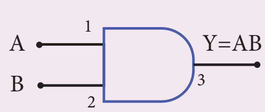
> **Note:**
>
> The chip must be inserted in the bread board in such a way that the identification mark should be on our left side. In this position, pin numbers are counted as marked in the picture above. Pin identification is the same for all chips that are mentioned below.

AND Gate:

PIN DIAGRAM-IC 7408



SYMBOL

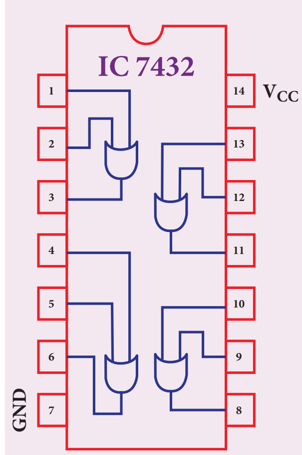


TRUTH TABLE

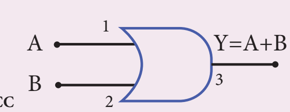
A	B	Y=AB
0	0	0
0	1	0
1	0	0
1	1	1

OR Gate:

PIN DIAGRAM-IC 7432



SYMBOL



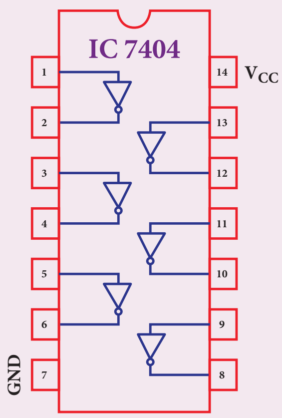
TRUTH TABLE

A	B	Y=A+B
0	0	0
0	1	1
1	0	1
1	1	1

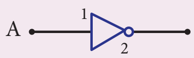
XII-Physics_Vol-1) PRACTICAL.indd 331 04-03-2019 11:06:52

NOT Gate:

PIN DIAGRAM-IC 7404



SYMBOL

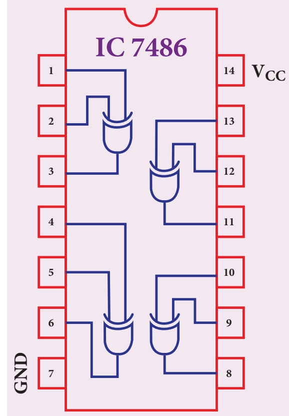


TRUTH TABLE

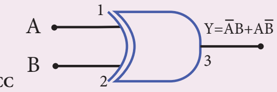
A	Y=$\bar{A}$
0	1
1	0

X-OR Gate :

PIN DIAGRAM-IC 7486



SYMBOL

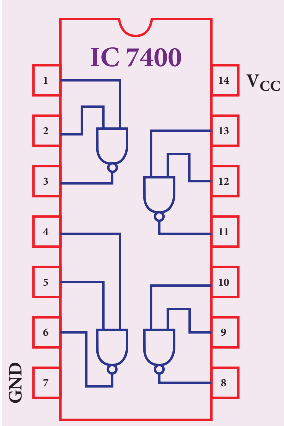


TRUTH TABLE

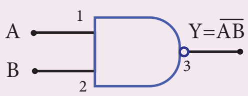
A	B	Y=$\bar{A}B+A\bar{B}$
0	0	0
0	1	1
1	0	1
1	1	0

NAND Gate:

PIN DIAGRAM-IC 7400



SYMBOL

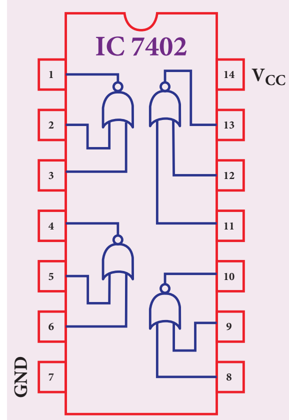


TRUTH TABLE

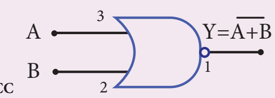
A	B	Y=$\overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

NOR Gate:

PIN DIAGRAM-IC 7402



SYMBOL



TRUTH TABLE

A	B	Y=$\overline{A+B}$
0	0	1
0	1	1
1	0	1
1	1	0

PROCEDURE

- To verify the truth table of a logic gate, the suitable IC is taken and the connections are given using the circuit diagram.
- For all the ICs, 5V is applied to the pin 14 while the pin 7 is connected to the ground.
- The logical inputs of the truth table are applied and the corresponding output is noted.
- Similarly the output is noted for all other combinations of inputs.
- In this way, the truth table of a logic gate is verified.

RESULT

The truth table of logic gates AND, OR, NOT, Ex-OR, NAND and NOR using integrated circuits is verified.

Precautions

(i) V_{CC} and ground pins must not be interchanged while making connections. Otherwise the chip will be damaged. (ii) The pin configuration for NOR gate is different from other gates

10. VERIFICATION OF DE MORGAN'S THEOREMS

AIM: To verify De Morgan's first and second theorems.

COMPONENTS REQUIRED: Power Supply (0 – 5V), IC 7400, 7408, 7432, 7404, and 7402, Digital IC trainer kit, connecting wires.

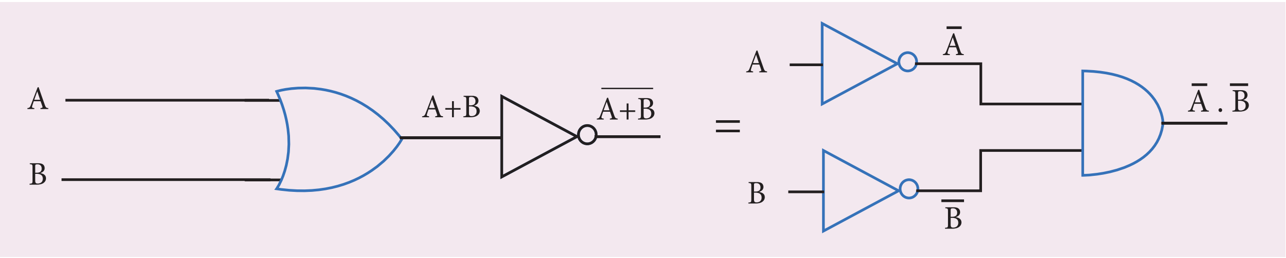
FORMULA

De Morgan's first theorem $\overline{A+B} = \overline{A}.\overline{B}$

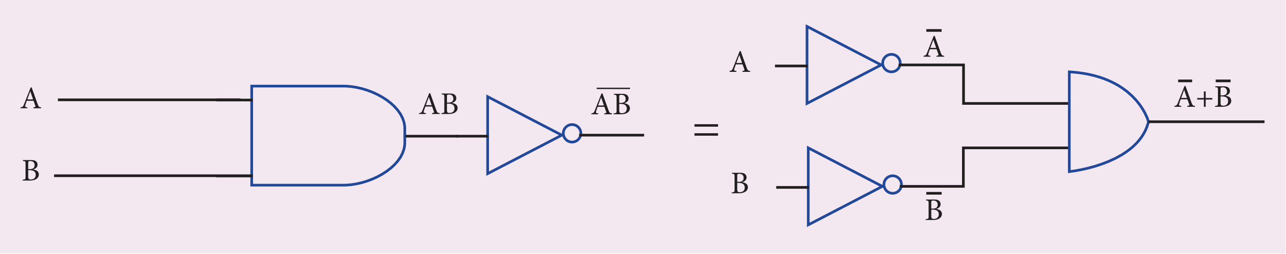
De Morgan's second theorem $\overline{A.B} = \overline{A}+\overline{B}$

CIRCUIT DIAGRAM:

De Morgan's first theorem



De Morgan's second theorem



PROCEDURE:

i) Verification of De Morgan's first theorem

- The connections are made for LHS $\left[\overline{A+B}\right]$ of the theorem as shown in the circuit diagram using appropriate ICs.
- The output is noted and tabulated for all combinations of logical inputs of the truth table.
- The same procedure is repeated for RHS $\left[\overline{A}.\overline{B}\right]$ of the theorem.
- From the truth table, it can be shown that $\overline{A+B} = \overline{A}.\overline{B}$.

ii) Verification of De Morgan's second theorem

- The connections are made for LHS $\left[\overline{A.B}\right]$ of the theorem as shown in the circuit diagram using appropriate ICs.
- The output is noted and tabulated for all combinations of logical inputs of the truth table.
- The same procedure is repeated for RHS $\left[\overline{A}+\overline{B}\right]$ of the theorem.
- From the truth table, it can be shown that $\overline{A.B}=\overline{A}+\overline{B}$.

OBSERVATION

De-Morgan's first theorem

Truth Table

A	B	$\overline{A+B}$	$\overline{A}.\overline{B}$
0	0		
0	1		
1	0		
1	1		

De-Morgan's second theorem

Truth Table

A	B	$\overline{A.B}$	$\overline{A}+\overline{B}$
0	0		
0	1		
1	0		
1	1		

RESULT

De Morgan's first and second theorems are verified.

Note

The pin diagram for IC 7408, IC 7432 and IC 7404 can be taken from previous experiment

Precautions

V_{CC} and ground pins must not be interchanged while making connections. Otherwise the chip will be damaged.

For the ICs used, 5V is applied to the pin 14 while the pin 7 is connected to the ground.

SUGGESTED QUESTIONS FOR THE PRACTICAL EXAMINATION

1. Determine the resistance of a given wire using metre bridge. Also find the radius of the wire using screw gauge and hence determine the specific resistance of the material of the wire. Take at least 4 readings.

2. Determine the value of the horizontal component of the Earth's magnetic field, using tangent galvanometer. Take at least 4 readings.

3. Determine the value of the horizontal component of the Earth's magnetic field using the magnetic field produced along the axial line of the carrying-current circular coil. Take at least 2 readings.

4. Using the spectrometer, measure the angle of the given prism and angle of minimum deviation. Hence calculate the refractive index of the material of the prism.

5. Adjust the grating for normal incidence using the spectrometer. Determine the wavelength of green, blue, yellow and red lines of mercury spectrum (The number of lines per metre length of the grating can be noted from the grating).

6. Draw the V-I characteristics of PN junction diode and determine its forward resistance and knee voltage from forward characteristics.

7. Draw the V-I characteristics of Zener diode and determine its forward resistance and knee voltage from forward characteristics. Also find break down voltage of the Zener diode from reverse characteristics.

8. Draw the input and transfer characteristic curves of the given NPN junction transistor in CE mode. Find the input impedance from input characteristics and current gain from transfer characteristics.

9. Draw the output and transfer characteristic curves of the given NPN junction transistor in CE mode. Find the output impedance from output characteristics and current gain from transfer characteristics.

10. Verify the truth table of logic gates AND, NOT, Ex-OR and NOR gates using integrated circuits.

11. Verify the truth table of logic gates OR, NOT, Ex-OR and NOR gates using integrated circuits.

12. Verify De Morgan's first and second theorems.

7SDAC3

Solved examples

UVRFM7

Competitive Exam corner

GLOSSARY
கலைச்சொற்கள்

JNZ51Y

1.	Absorption spectra	-	உட்கவர் நிறமாலை
2.	Armature	-	சுருள் தொகுப்பு
3.	Axial symmetry	-	அச்சுச் சமச்சீர்
4.	Average current	-	சராசரி மின்னோட்டம்
5.	Blackbody radiation	-	கரும்பொருள் கதிர்வீச்சு
6.	Charge	-	மின்னூட்டம்
7.	Continuous charge distribution	-	தொடர் மின்னூட்டப் பரவல்
8.	Conventional current	-	மரபு மின்னோட்டம்
9.	Conservation of charges	-	மின்னூட்டம் மாறாத் தன்மை
10.	Capacitor	-	மின்தேக்கி
11.	Corona discharge	-	ஒளிவட்ட மின்னிறக்கம் அல்லது சிதறொளி மின்னிறக்கம்
12.	Capacitance	-	மின்தேக்குத்திறன்
13.	Coercivity	-	காந்த நீக்குத்திறன்
14.	Current density	-	மின்னோட்ட அடர்த்தி
15.	Conductivity	-	மின்கடத்து எண்
16.	Configuration	-	நிலை அமைப்பு
17.	Conduction current	-	கடத்து மின்னோட்டம்
18.	Carbon Resistor	-	கார்பன் மின்தடை
19.	Current sensitivity	-	மின்னோட்ட உணர்வுநுட்பம்
20.	Dielectrics	-	மின்காப்புகள்
21.	Displacement current	-	இடப்பெயர்ச்சி மின்னோட்டம்
22.	Declination angle	-	காந்த ஒதுக்கக்கோணம்
23.	Dielectric strength	-	மின்காப்பு வலிமை
24.	Drift velocity	-	இழுப்பு திசைவேகம்
25.	Dielectric constant	-	மின்காப்பு மாறிலி
26.	Eddy current	-	சுழல் மின்னோட்டம்
27.	Electromagnetic damping	-	மின்காந்தத் தணிப்பு
28.	Electronic devices	-	மின்னணு சாதனங்கள்
29.	Electrostatics	-	நிலை மின்னியல்
30.	Electric charge	-	மின்னூட்டம்,மின்துகள்
31.	Electric field	-	மின்புலம்
32.	Electric dipole	-	மின்னிருமுனை (மின் இருமுனை)
33.	Equivalent capacitance	-	தொகுபயன் மின்தேக்குத்திறன் அல்லது இணை மின்தேக்குத்திறன்

34.	Electrostatic induction	-	நிலைமின் தூண்டல்
35.	Electrostatic potential energy	-	நிலை மின்னழுத்த ஆற்றல்
36.	Electric flux	-	மின்பாயம்
37.	Equi-potential surface	-	சமமின்னழுத்தப் பரப்பு
38.	Electrostatic equilibrium	-	நிலை மின் சமநிலை
39.	Electrostatic shielding	-	நிலை மின் தடுப்புறை
40.	Energy density	-	ஆற்றல் அடர்த்தி
41.	Electrostatic potential	-	நிலை மின்னழுத்தம்
42.	Electric battery	-	மின்கலத் தொகுப்பு
43.	Emission spectra	-	வெளியிடு நிறமாலை
44.	Equivalent Resistance	-	தொகுபயன் மின்தடை
45.	Flux leakage	-	பாயக்கசிவு
46.	Figure of merit of a galvanometer	-	கால்வானா மீட்டரின் தர ஒப்பீட்டு எண்
47.	Finite value	-	வரம்பிற்குட்பட்ட மதிப்பு
48.	Free electrons	-	கட்டுறா எலக்ட்ரான்கள்
49.	Horizontal component of the Earth's magnetic field	-	புவி காந்தப்புலத்தின் கிடைத்தளக்கூறு
50.	Hysteresis	-	காந்தத் தயக்கம்
51.	Helical path	-	சுருள்பாதை
52.	superposition principle	-	மேற்பொருந்தல் தத்துவம்
53.	Insulators	-	காப்பான்கள்
54.	Inverter	-	மின் புரட்டி
55.	Inductance	-	மின்தூண்டல் எண்
56.	Inductor	-	மின்தூண்டி
57.	Inclination angle	-	காந்தச் சரிவுக்கோணம்
58.	Intensity of magnetization	-	காந்தமாக்கும் செறிவு
59.	Impedance	-	மின்மறுப்பு
60.	Linear charge density	-	மின்னூட்ட நீள் அடர்த்தி
61.	Lighthing bolt	-	மின்னல் வெட்டு
62.	Laminated Core	-	மென்தகட்டு உள்ளகம்
63.	Lightning conductor	-	மின்னல் கடத்தி
64.	Mutual-induction	-	பரிமாற்று மின்தூண்டல்
65.	Metallic conductor	-	உலோகக் கடத்தி
66.	Moving Coil galvanometer	-	இயங்குசுருள் கால்வானா மீட்டர்
67.	Magnetic meridian	-	காந்த துருவத்தளம்
68.	Magnetic domain	-	காந்தப் பெருங்கூறு, காந்தக் களம்
69.	Magnetic induction	-	காந்தத்தூண்டல்
70.	Magnetising field	-	காந்தமாக்கு புலம்
71.	Magnetic Flux	-	காந்தப்பாயம்
72.	Magnetic susceptibility	-	காந்த ஏற்புத்திறன்
73.	Magnetic permeability	-	காந்த உட்புகுதிறன்
74.	Magnetic flux	-	காந்தப்பாயம்
75.	Magnetic dipole moment	-	காந்த இருமுனை திருப்புத்திறன்
76.	Magnetic declination	-	காந்த ஒதுக்கம்

77. Magnetic dip or inclination - காந்தச் சரிவு
78. Non ohmic conductor - ஓம் விதிக்கு உட்படாத கடத்தி
79. Propagation vector - பரவும் வெக்டர்
80. Phasor - கட்ட வெக்டர்
81. Power factor - திறன் காரணி
82. Potential difference - மின்னழுத்த வேறுபாடு
83. Permittivity - விடுதிறன்
84. Quantization - குவாண்டமாக்கல் அல்லது துளிமமாக்கல்
85. Resonance - ஒத்ததிர்வு
86. Rotor - சுழலி
87. Relative permeability - ஒப்புமை உட்புகுதிறன்
89. Resistors in series - மின்தடைகள் தொடரிணைப்பு
90. Retentivity - காந்தப்பற்றுத்திறன்
91. Surface charge density - மின்னூட்டப் பரப்படர்த்தி
92. Slip rings - நழுவு வளையங்கள்
93. Series and parallel - தொடரிணைப்பு, பக்கவினைப்பு
94. Self-induction - தன்மின்தூண்டல்
95. Successive collisions - அடுத்தடுத்த மோதல்கள்
96. Stator - நிலையான பகுதி
97. Superconductors - மீக்கடத்திகள்
98. Semiconductor - குறை கடத்தி
99. Solar spectrum - சூரிய நிறமாலை
100. Shunt resistance - இணை மின்தடை
101. Solenoid - வரிச்சுருள்
102. Temperature coefficient of Resistivity - வெப்பநிலை மின்தடை எண்
103. Toroid - வட்ட வரிச்சுருள்
104. Torsional constant - முறுக்குக் கோணம்
105. Transverse wave - குறுக்கலை
106. Torsion balance - முறுக்குத் தராசு
107. Transformer - மின்மாற்றி
108. Thermistor - வெப்பமாறு மின்தடை
109. Voltage sensitivity - மின்னழுத்த உணர்வுநுட்பம்
110. Volume element - பருமக் கூறு
111. Wave diagram - அலை வரைபடம்
112. Wattful current - முழுத்திறன் மின்னோட்டம்
113. Wattless current - சுழித்திறன் மின்னோட்டம்
114. Winding - கம்பிச் சுற்று

State Council of Educational Research and Training, Chennai-6

Higher Secondary Physics

List of Subject Experts in Textbook Writing

Domain Expert & Mentor

Prof. Rita John
Professor and Head
Department of Theoretical physics,
University of madras, Chennai.

Reviewers

Dr. V. Mani
Principal Scientist F, Head (C-MET)
Department of Electronics & Information Technology, Hyderabad,
Government of India.

Prof. P. Ravindran
Department of Physics,
School of Basic and Applied Sciences,
Central University of Tamil Nadu, Thiruvarur.

Dr. Rajeev shesha Joshi
Assistant Professor,
School of Physical Sciences,
Central University of Karnataka.

Content Writers

Mr. C. Joseph Prabagar
Assistant Professor,
PG and Research Department of Physics,
Loyola College (Autonomous), Chennai – 34

Dr. S. S. Naina Mohammed
Assistant Professor,
PG and Research Department of Physics,
Government Arts College
Udumalpet, Tiruppur District.

Dr. P.Balamurugan
Assistant Professor,
PG and Research Department of Physics,
Government Arts College for Men (Autonomous)
Nandanam, Chennai.

Dr.C. Ramachandra raja
Associate Professor of Physics
Government Arts College,
Kumbakonam.

Tamil Translators

Mr.E.Elangovan
Head Master,
Government Hr Sec School
Ramanayakanpettai,
Vellore District.

Dr.K.Vasudevan
PGT, Government ADW.Hr.Sec.School
Kalangani
Namakkal District.

Mr.V.Balamurugan
PG Assistant in Physics,
Government Hr.Sec.School,
Kadambattur,
Tiruvallur District

Mr. S. Ravishankar
PG Assistant in Physics,
S.R.M. Hr. Sec. School,
Ambattur,
Tiruvallur District

Content Readers

Dr.K.Rajarajan
Associate Professor of Physics,
R.V.Government Arts College,
Chengalpattu

Dr.M.Jeyarani Malliga
Associate Professor of Physics,
Bharathi Women's College
Chennai.

Dr.K.Rajakumari
Assistant Professor of Physics,
Queen Mary's College,
Chennai.

Mrs. Bhavani
Assistant Professor of Physics,
Ethiraj College for women,
Chennai.

SCERT Subject Coordinators

Mrs. P.Nantha
Senior Lecturer
SCERT, Chennai – 06.

Mrs.D.Shanmuga Sundari
Graduate Assistant
P.U.M.School, Melathulukkankulam
Kariyapatti Union, Virudhunagar District

Mr.G.Arulraja
Graduate Assistant
MKV Government Boys Hr.Sec.School
Arani, Thiruvallur District.

ICT Coordinator

Mr.G.Bergin
PG Assistant (Physics)
GBHSS, Sayalkudi,
Ramanathapuram District.

QR CODE Management Team

R. Jaganathan
SGT, PUMS - Ganesapuram,
Polur , Thiruvannamalai.

S. Albert Valavan Babu
B.T, G.H.S, Perumal Kovil,
Paramakudi, Ramanathapuram.

A. Devi Jesintha
B.T, G.H.S, N.M. Kovil, Vellore.

Typist

Mrs. D. Kavitha
SCERT

Art and Design Team

Layout & QC
M. Asker Ali

Illustration
K. Sasi Kumar
S. Durga Devi

Cover Design
Kathir Arumugam

Co-ordination
Ramesh Munisamy

This book has been printed on 80 G.S.M.
Elegant Maplitho paper.
Printed by offset at:

NOTE

NOTE

NOTE

NOTE

NOTE