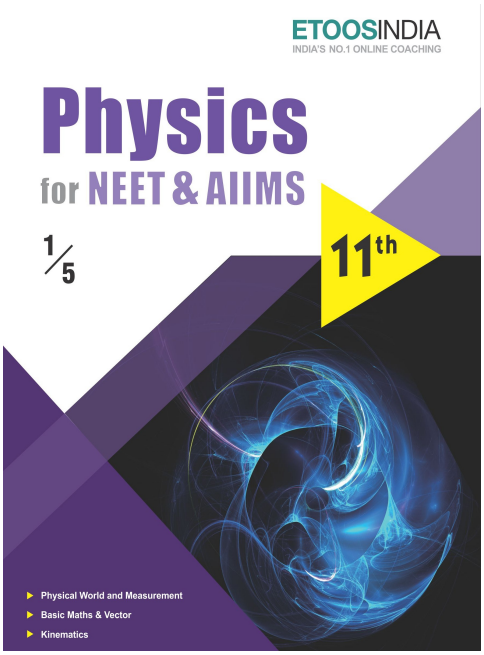
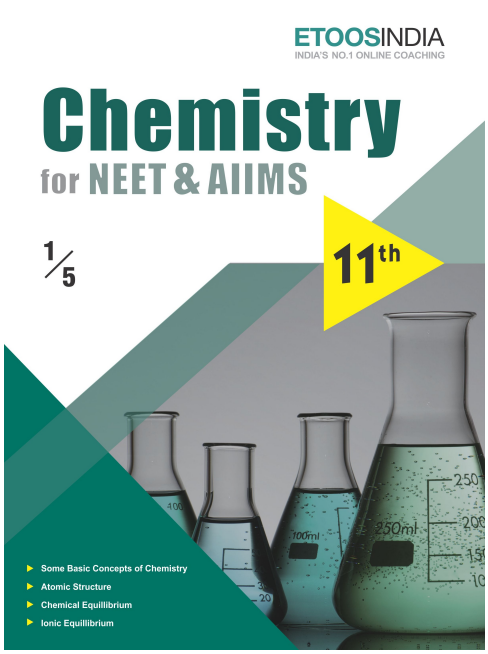
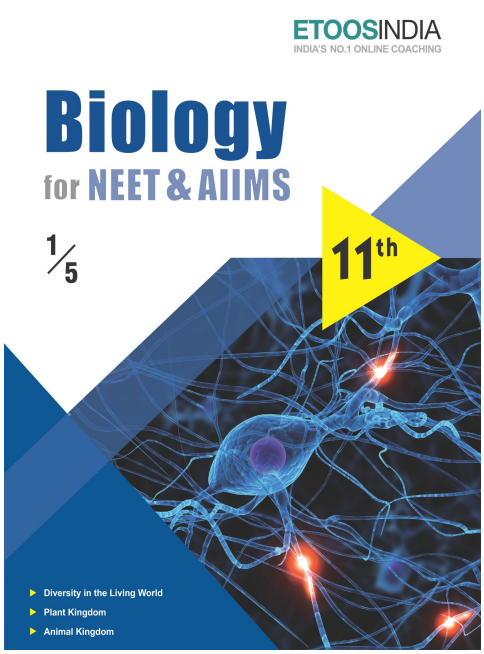
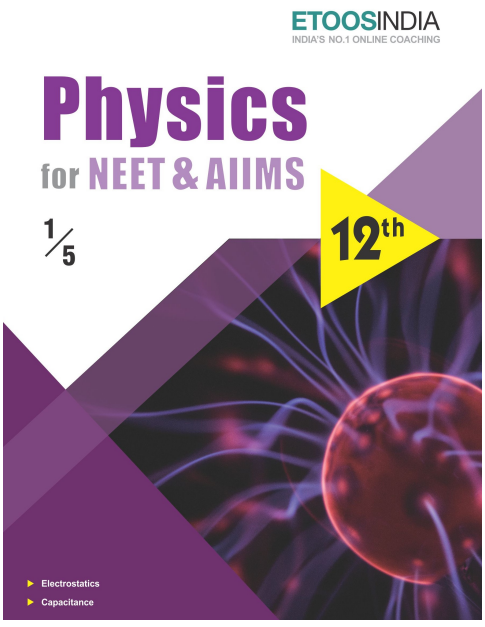
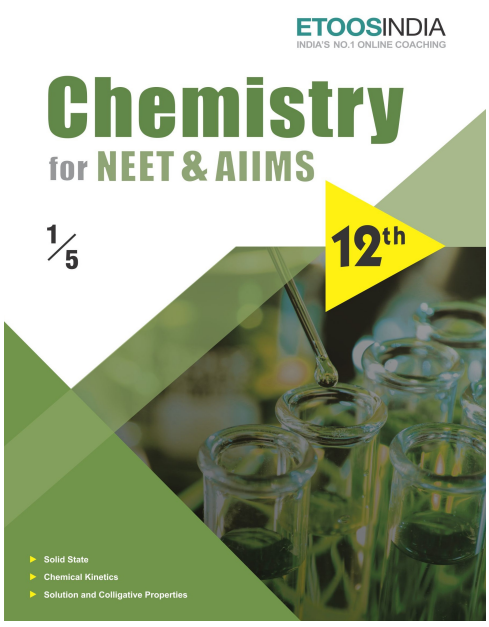
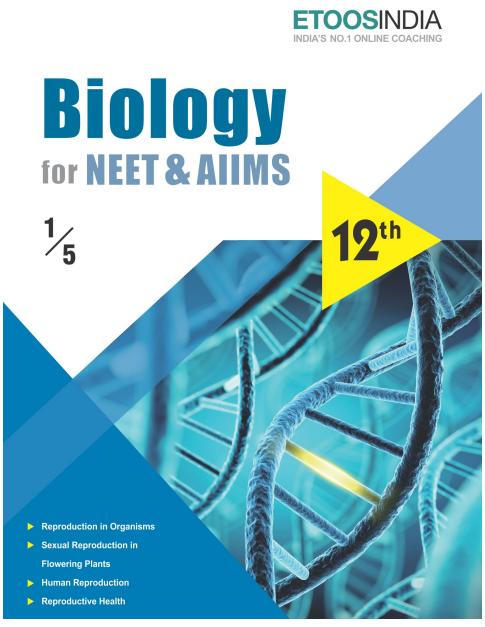












CHAPTER 11

ELECTROMAGNETIC WAVES

I happen to have discovered a direct relation between magnetism and light, also electricity and light, and the field it opens is so large and I think rich.

"MICHAEL FARADAY"

INTRODUCTION

We have seen that in certain situations light may be described as a wave. The wave equation for light propagating in x-direction in vacuum may be written ass

$$E = E_0 \sin \omega(t - x/c)$$

where E is the sinusoidally varying electric field at the position x at time t. The constant c is the speed of light in vacuum. The electric field E is in the Y-Z plane, that is perpendicular to the direction of propagation.

There is also a sinusoidally varying magnetic field associated with the electric field when light propagates. This magnetic is perpendicular to the direction of propagation as well as to the electric field E. It is given by

$$B = B_0 \sin \omega(t - x/c)$$

Such a combination of mutually perpendicular electric and magnetic fields is referred to as an electromagnetic wave in vacuum. The theory of electromagnetic wave was mainly developed by Maxwell around 1864.

Now if the charge Q on the capacitor plates changes with time, there is a current i = (dQ / dt), so that using Eq. (3), we have

$$\frac{d\Phi_E}{dt} = \frac{d}{dt}\left(\frac{Q}{\varepsilon_0}\right) = \frac{1}{\varepsilon_0}\frac{dQ}{dt}$$

This implies that for consistency,

$$\varepsilon_0\left(\frac{d\Phi_E}{dt}\right) = i \qquad \text{..... (4)}$$

This is the missing term in Ampere's circuital law. If we generalis this law by adding to the total current carried by conductors through the surface, another term which is ε_0 times the rate of change of electric flux through the same surface, the total has the same value of current i for all surfaces. If this is done, there is no contradiction in the value of B obtained anywhere using the generalized Ampere's law. B at the point P is non-zero no matter which surface is used for calculating it. B at a point P outside the plates [Fig.1 (a)] is the same as at a point M just inside, as it should be. The current carried by conductors due to flow of charges is called conduction current. The current, given by Eq. (4), is a new term, and is due to changing electric field (or electric displacement). It is therefore called displacement current or Maxwell's displacement current. Figure 2 shows the electric and magnetic fields inside the parallel plates capacitor discussed above. The generalisation made by Maxwell then is the following. The source of a magnetic field is not just the conduction electric current due to flowing charges, but also the time rate of change of electric field. More precisely, the total current i is the sum of the conduction current denoted by i_C, and the displacement current denoted by i_d ($= \varepsilon_0 (d\Phi_E)/ dt$). So we have

$$i = i_e + i_d = i_c + \varepsilon_0\frac{d\Phi_E}{dt} \qquad \text{..... (5)}$$

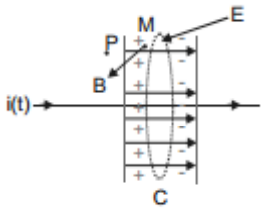


Figure 2 (a)

In explicit terms, this means that outside the capacitor plates, we have only conduction current $i_c = i$, and no displacement current, i.e., $i_d = 0$. On the other hand, inside the capacitor, there is no conduction current, i.e., $i_c = 0$, and there is only displacement current, so that $i_d = i$.

The generalised (and correct) Ampere's circuital law has the same form as Eq, (1), with one difference: " the total current passing through any surface of which the closed loop is the perimeter" is the sum of the conduction current and the displacement current The generalised law is

$$\oint B \bullet d\ell = \mu_0 i_c + \mu_0\varepsilon_0\frac{d\Phi_E}{dt} \qquad \text{..... (6)}$$

and is known as Ampere-Maxwell law.

Etoos Tips & Formulas

1. Cathode Rays :

(a) Generated in a discharge tube in which a high vaccum is maintained.

(b) They are electrons accelerated by high potential difference (10 to 15 kV)

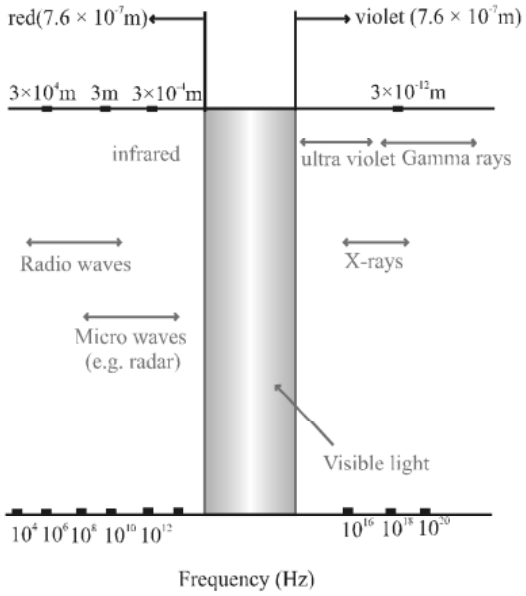
(c) K.E. of C.R. particle accelerated by a p.d V is $eV = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

(d) Can be deflected by Electric & magnetic fields.

2. Electromagnetic Spectrum

Ordered arrangement of the big family of electro magneti waves (EMW) either in ascending order of frequencies or decending order of wave lengths.

Speed of E.M.W. in vaccum : $c = 3 \times 10^8$ m/s = $v\lambda$



3. Plancks Quantam Theory

A beam of EMW is a stream of discrete packets of energy called photons; each photon having a frequancy v and energy = E = hv

where h = planck's constant = 6.63×10^{-34} J-s.

(a) According to Planck the energy of a photon is directly proportional to the frequency of the radiation.

$$E = \frac{hc}{\lambda} = \frac{12400}{\lambda} eV - \mathring{A} \left[\because \frac{hc}{e} = 12400 (\mathring{A} - eV) \right]$$

(b) Effective mass of photon $m = \frac{E}{c^2} = \frac{hc}{c^2\lambda} = \frac{h}{c\lambda}$ i.e. $m \propto \frac{1}{\lambda}$

SOLVED EXAMPLE

Ex.1 A parallel-plate capacitor with plate area A and separation between the plates d, is charged by a constant current i. Consider a plane surface of are A/2 parallel to the plates and drawn symmetrically between the plates. Find the displacement current through this area.

Sol. Suppose the charge on the capacitor at time t is Q.The electric field between the plates of the capacitor is $E = \frac{Q}{\varepsilon_0 A}$. The flux through the area considered is

$$\Phi_E = \frac{Q}{\varepsilon_0 A}\cdot\frac{A}{2} = \frac{Q}{2\varepsilon_0}$$

The displacement current is

$$i_d = \varepsilon_0 \frac{d\Phi_E}{dt} = \varepsilon_0\left(\frac{1}{2\varepsilon_0}\right)\frac{dQ}{dt} = \frac{i}{2}$$

Ex.2 A plane electromagnetic wave propagating in the x-direction hass a wavelength of 5.0 mm. The electric field is in the y-direction and its maximum magnitude is 30 V m^{-1}. Write suitable equations for the electric and magnetic fields as a function of x and t.

Sol. The equation for the electric and the magnetic fields in the wave may be written as

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

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

We have,

$$\omega = 2\pi v = \frac{2\pi}{\lambda}c$$

Thus, $E = E_0 \sin\left[\frac{2\pi}{\lambda}(ct - x)\right]$

$$= (30\ \text{V m}^{-1}) \sin\left[\frac{2\pi}{5.0\,\text{mm}}(ct - x)\right]$$

The maximum magnetic field is

$$B_0 = \frac{E_0}{c} = \frac{30\ \text{V m}^{-1}}{3\times10^8\ \text{ms}^{-1}} = 10^{-7}\ \text{T}$$

So, $B = B_0 \sin\left[\frac{2\pi}{\lambda}(ct - x)\right]$

$$= (10^{-7}\ \text{T}) \sin\left[\frac{2\pi}{5.0\,\text{mm}}(ct - x)\right].$$

The magnetic field is along the z-axis.

Ex.3 A light beam travelling in the x-direction is described by the electric field $E_y = (300\ \text{V m}^{-1}) \sin\omega(t - x/c)$. An electron is constrained to move along the y-direction with a speed of 2.0×10^7 m s^{-1}. Find the maximum electric force and the maximum magnetic force on the electron.

Sol. The maximum electric field is $E_0 = 300\ \text{V m}^{-1}$. The maximum magnetic field is

$$B_0 = \frac{E_0}{c} = \frac{300\ \text{V m}^{-1}}{3\times10^8\ \text{ms}^{-1}} = 10^{-6}\ \text{T}$$

along the z-direction.

The maximum electric force on the electron is

$$F_e = qE_0 = (1.6\times10^{-19}\ \text{C})\times(300\ \text{V m}^{-1})$$
$$= 4.8\times10^{-17}\ \text{N}.$$

The maximum magnetic force on the electron is

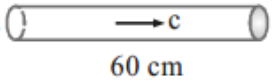
$$F_b = \left|q\vec{v}\times\vec{B}\right|_{max} = qvB_0$$

$$= (1.6\times10^{-19}\ \text{C})\times(2.0\times10^7\ \text{ms}^{-1})\times(10^{-6}\ \text{T})$$

$$= 3.2\times10^{-18}\ \text{N}.$$

Ex.4 Find the energy stored in a 60 cm length of a laser beam operating at 4mW .

Sol.



The time taken by the electromagnetic wave to move through a distance of 60 cm is $t = \frac{60\,\text{cm}}{c} = 2\times10^{-9}\,\text{s}$.

Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. The ionosphere does not allow to pass the waves which are termed as
(A) microwaves
(B) visible light waves
(C) 1 and 2 both
(D) amplitude modulated waves

2. Practically ozone layer absorbs the radiation of wavelength
(A) less than 3×10^{-7} m
(B) greater than 3×10^{-7} m
(C) equal to 3×10^{-7} m
(D) all the above

3. The waves which can travel directly along surface of the earth are known as
(A) ground waves (B) X–rays
(C) α–rays (D) sky waves

4. The ionosphere bends the e. m. waves having the frequencies
(A) less than 40 MHz
(B) beyond 40 MHz
(C) nothing is certain
(D) depends on the moisture present

5. The S.I unit of displacement current is
(A) H (B) A
(C) Fm^{-1} (D) C

6. Transmission of T. V. signals from the surface of the moon can be received on earth. But transmitted T. V. Signals from Delhi can not be received beyond 110 km distance. The reason is
(A) there is no atmosphere on the moon
(B) strong gravitational effect on T. V. signals
(C) T. V. signals travel along a straight line, they do not follow the curvature of earth
(D) there is atmosphere around the earth

7. The number of radio frequency carrier waves transmitted by a television transmitter is
(A) three (B) two
(C) one (D) four

8. The speed of electromagnetic waves is independent of
(A) wavelength
(B) frequency
(C) intensity
(D) medium, in which it travels

9. An electromagnetic radiation of frequency ν, wavelength λ, travelling with velocity c in air, enters a glass slab of refractive index μ. The frequency, wavelength and velocity of light in the glass slab will be respectively :
(A) $\frac{\nu}{\mu}, \frac{\lambda}{\mu}$ and $\frac{c}{\mu}$ (B) $\nu, \frac{\lambda}{\mu}$ and $\frac{c}{\mu}$
(C) $\nu, 2\lambda$ and $\frac{c}{\mu}$ (D) $\frac{2\nu}{\mu}, \frac{\lambda}{\mu}$ and c

10. If ε_0 and μ_0 are the electric permittivity and magnetic permeability in free space, ε and μ are the corresponding quantities in a medium, then index of refraction of the medium is
(A) $\sqrt{\frac{\varepsilon_0\mu}{\varepsilon\mu_0}}$ (B) $\sqrt{\frac{\varepsilon}{\varepsilon_0}}$
(C) $\sqrt{\frac{\varepsilon_0\mu_0}{\varepsilon\mu}}$ (D) $\sqrt{\frac{\varepsilon\mu}{\varepsilon_0\mu_0}}$

11. Dimension of $\varepsilon_0\mu_0$ is :
(A) LT^{-1} (B) $L^{-1}T$
(C) L^2T^{-2} (D) $L^{-2}T^2$

12. For television transmission, the frequency employed is normally in the range
(A) 30–300 MHz (B) 30–300 GHz
(C) 300–300 kHz (D) 30–300 Hz

13. Red light differs from blue light in its
(A) speed. (B) frequency
(C) intensity (D) amplitude

14. If an electromagnetic wave propagating through vacuum is described by
$E = E_0 \sin(kx - \omega t)$; $B = B_0 \sin(kx - \omega t)$,
(A) $E_0 k = B_0 \omega$ (B) $E_0 B_0 = \omega k$
(C) $E_0 \omega = B_0 k$ (D) $E_0 B_0 = \omega / k$

Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. The fundamental source of e. m. waves
(A) is varying magnetic field
(B) constant magnetic and electric fields
(C) are continous oscillations of electric charge
(D) is planets

2. The displacement current was first postulated by
(A) Ampere (B) Maxwell
(C) Hertz (D) Marconi

3. An accelerated electric charge emits
(A) β – rays (B) γ – rays
(C) e.m. waves (D) none of the above

4. The speed of e. m. waves is given by the relation
(A) $\mu_0\varepsilon_0$ (B) $\sqrt{\mu_0\varepsilon_0}$
(C) $1/\mu_0\varepsilon_0$ (D) $1/\sqrt{(\mu_0\varepsilon_0)}$

5. Electromagnetic waves in nature are
(A) longitudinal
(B) longitudinal stationary
(C) transverse
(D) transverse – stationary

6. An accelerated charge
(A) emits an electromagnetic wave
(B) does not emits electromagnetic wave
(C) produces a gravitational field
(D) none of the above

7. Electromagnetic waves
(A) are longitudinal waves
(B) travel in free space at the speed of light
(C) are produced by charges moving with uniform velocity
(D) travel with the same speed in all media

8. Choose the only wrong statement from the following about electromagnetic waves
(A) are transverse
(B) travels free space at the speed of light
(C) are produced by accelerating charges
(D) travel with the same speed in all media

9. In an electromagnetic wave, electric field E and magnetic field B are
(A) mutually perpendicular to each other
(B) all parallel
(C) at 30^0 to each other
(D) at 60^0 to each other

10. Electromagnetic wave obey the principle of
(A) superposition (B) interference
(C) 1 and 2 both (D) none of the above

11. If E and B be the electric and magnetic fields of electromagnetic waves, then the direction of propagation of e. m. wave is along the direction of
(A) E (B) B
(C) $E \times B$ (D) None of the above

12. Which of the following pairs of space and time varying E and B fields would generate a plane electromagnetic wave travelling in the Z– direction
(A) E_x, B_y (B) E_y, B_x
(C) E_x, B_z (D) E_z, B_x

13. Choose the correct statement about electromagnetic waves
(A) they are supersonic waves
(B) they are the electric charged particles
(C) they travel with the speed of light
(D) they can only be produced in laboratory.

14. Hertz produced electromagnetic wave by using
(A) L C R circuit (B) C R circuit
(C) L C circuit (D) None of the above

15. The shortest wavelength is for
(A) γ – rays (B) x – rays
(C) ultraviolet rays (D) microwaves

16. Visible range of wavelength in cm is
(A) 3×10^{-6} to 10^{-10}
(B) 7×10^{-5} to 4×10^{-5}
(C) 4×10^{-5} to 3×10^{-6}
(D) 6×10^{4} to 1.5×10^{3}

Exercise # 3

ASSERTION & REASONING

These questions contains, Statement I (assertion) and Statement II (reason).

(A) If both assertion and reason are true and the reason is the correct explanation of the assertion.

(B) If both assertion and reason are true but reason is not the correct explanation of the assertion.

(C) If assertion is true but reason is false.

(D) If assertion is false but reason is true.

(E) If the assertion and reason both are false.

1. **Assertion :** Sound waves are not electromagnetic waves.

   Reason : Sound waves require a material medium for propagation.

2. **Assertion :** Displacement current arises on account of change in electric flux.

   Reason : $I_d = \epsilon_0 \left(\frac{d\Phi_E}{dt} \right)$

3. **Assertion :** A changing electric field produces a magnetic field

   Reason : A changing magnetic field produces an electric field.

4. **Assertion :** In an e.m. wave magnitude of magnetic field vector $\vec{B}$ is much smaller than the magnitude of vector $\vec{E}$.

   Reason : This is because in an e.m. wave $E/B = c = 3 \times 10^8$ m / s.

5. **Assertion :** Electromagnetic waves exert pressure called radiation pressure.

   Reason : This is because they carry energy.

6. **Assertion :** Electromagnetic waves are transverse in nature

   Reason : The electric and magnetic fields of an e.m. wave are perpendicular to each other and also perpendicular to the direction of wave propagation.

Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. The frequency of γ-rays, X-rays and ultraviolet rays are a, b and c respectively.
Then, [CBSE AIPMT 2000]
(A) $a > b > c$ (B) $a < b < c$
(C) $a = b = c$ (D) $a > c > b$

2. In a certain region of space electric field E and magnetic field B are perpendicular to each other and an electron enters in region perpendicular to the direction of B and E both and moves undeflected, then velocity of electron is [CBSE AIPMT 2001]
(A) $\frac{|E|}{|B|}$ (B) $E \times B$
(C) $\frac{|B|}{|E|}$ (D) $E \cdot B$

3. The velocity of electromagnetic wave is along the direction of [CBSE AIPMT 2002]
(A) $B \times E$ (B) $E \times B$
(C) E (D) B

4. Which of the following has minimum wavelength? [CBSE AIPMT 2002]
(A) X-rays
(B) Ultraviolet rays
(C) γ-rays
(D) Cosmic rays

5. Which of the following rays are not electromagnetic waves? [CBSE AIPMT 2003]
(A) β-rays (C) Heat rays
(C) X-rays (D) γ-rays

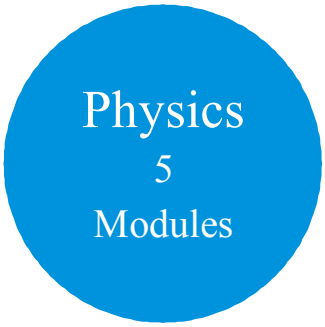
6. If λ_v, λ_x and λ_m represent the wavelengths of visible light, X-rays and microwaves respectively, then [CBSE AIPMT 2005]
(A) $\lambda_m > \lambda_x > \lambda_v$
(B) $\lambda_v > \lambda_m > \lambda_x$
(C) $\lambda_m > \lambda_v > \lambda_x$
(D) $\lambda_v > \lambda_x > \lambda_m$

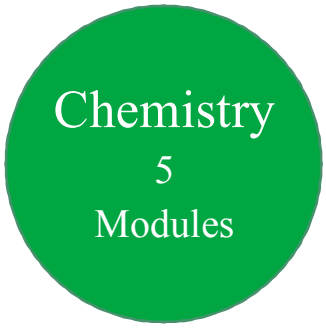
7. The electric field part of an electromagnetic wave in a medium is represented by $E_x = 0$;
$$E_y = 2.5\frac{N}{C}\cos\left[\left(2\pi\times10^6\frac{rad}{m}\right)t-\left(\pi\times10^{-2}\frac{rad}{s}\right)x\right];.$$
$E_Z = 0$.
The wave is [CBSE AIPMT 2009]
(A) moving along y-direction with frequency $2\pi \times 10^6$ Hz and wavelength 200 m
(B) moving along x-direction with frequency 10^6 Hz and wavelength 100 m
(C) moving along x-direction with frequency 10^6 Hz and wavelength 200 m
(D) moving along – x-direction with frequency 10^6 Hz and wavelength 200 m.

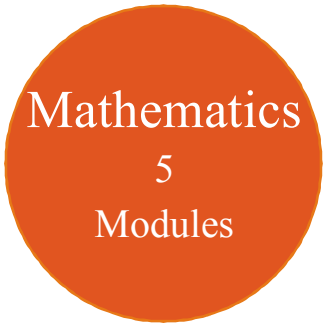
8. Which of the following statement is false for the properties of electromagnetic waves? [CBSE AIPMT 2010]
(A) Both electric and magnetic field vectors attain the maxima and minima at the same place and same time
(B) The energyin electromagnetic wave is divided equally between electric and magnetic vectors
(C) Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of wave
(D) These waves do not require any material medium for propoagation

9. The decreasing order of wavelengthof infrared, microwave, ultraviolet and gamma rays is [CBSE AIPMT 2011]
(A) gamma rays, ultraviolet, infrared, microwaves
(B) microwaves, gamma rays, infrared, ultraviolet
(C) infrared, microwave, ultraviolet, gamma rays
(D) microwave, infrared, ultraviolet, gamma rays

11th Class Modules Chapter Details

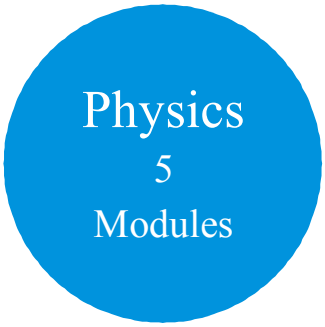


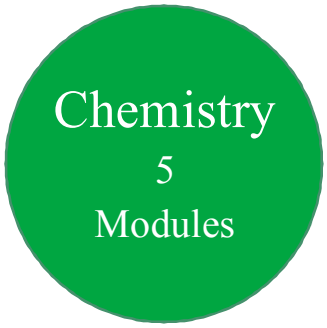


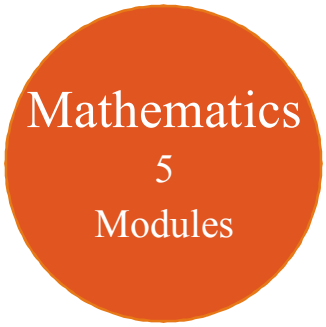


PHYSICS	CHEMISTRY	BIOLOGY
Module-1 1. Physical World & Measurements 2. Basic Maths & Vector 3. Kinematics **Module-2** 1. Law of Motion & Friction 2. Work, Energy & Power **Module-3** 1. Motion of system of particles & Rigid Body 2. Gravitation **Module-4** 1. Mechanical Properties of Matter 2. Thermal Properties of Matter **Module-5** 1. Oscillations 2. Waves	**Module-1(PC)** 1. Some Basic Conceps of Chemistry 2. Atomic Structure 3. Chemical Equilibrium 4. Ionic Equilibrium **Module-2(PC)** 1. Thermodynamics & Thermochemistry 2. Redox Reaction 3. States Of Matter (Gaseous & Liquid) **Module-3(IC)** 1. Periodic Table 2. Chemical Bonding 3. Hydrogen & Its Compounds 4. S-Block **Module-4(OC)** 1. Nomenclature of Organic Compounds 2. Isomerism 3. General Organic Chemistry **Module-5(OC)** 1. Reaction Mechanism 2. Hydrocarbon 3. Aromatic Hydrocarbon 4. Environmental Chemistry & Analysis Of Organic Compounds	**Module-1** 1. Diversity in the Living World 2. Plant Kingdom 3. Animal Kingdom **Module-2** 1. Morphology in Flowering Plants 2. Anatomy of Flowering Plants 3. Structural Organization in Animals **Module-3** 1. Cell: The Unit of Life 2. Biomolecules 3. Cell Cycle & Cell Division 4. Transport in Plants 5. Mineral Nutrition **Module-4** 1. Photosynthesis in Higher Plants 2. Respiration in Plants 3. Plant Growth and Development 4. Digestion & Absorption 5. Breathing & Exchange of Gases **Module-5** 1. Body Fluids & Its Circulation 2. Excretory Products & Their Elimination 3. Locomotion & Its Movement 4. Neural Control & Coordination 5. Chemical Coordination and Integration

12th Class Modules Chapter Details







PHYSICS

Module-1

1. Electrostatics
2. Capacitance

Module-2

1. Current Electricity
2. Magnetic Effect of Current and Magnetism

Module-3

1. Electromagnetic Induction
2. Alternating Current

Module-4

1. Geometrical Optics
2. Wave Optics

Module-5

1. Modern Physics
2. Nuclear Physics
3. Solids & Semiconductor Devices
4. Electromagnetic Waves

CHEMISTRY

Module-1(PC)

1. Solid State
2. Chemical Kinetics
3. Solutions and Colligative Properties

Module-2(PC)

1. Electrochemistry
2. Surface Chemistry

Module-3(IC)

1. P-Block Elements
2. Transition Elements (d & f block)
3. Co-ordination Compound
4. Metallurgy

Module-4(OC)

1. HaloAlkanes & HaloArenes
2. Alcohol, Phenol & Ether
3. Aldehyde, Ketone & Carboxylic Acid

Module-5(OC)

1. Nitrogen & Its Derivatives
2. Biomolecules & Polymers
3. Chemistry in Everyday Life

BIOLOGY

Module-1

1. Reproduction in Organisms
2. Sexual Reproduction in Flowering Plants
3. Human Reproduction
4. Reproductive Health

Module-2

1. Principles of Inheritance and Variation
2. Molecular Basis of Inheritance
3. Evolution

Module-3

1. Human Health and Disease
2. Strategies for Enhancement in Food Production
3. Microbes in Human Welfare

Module-4

1. Biotechnology: Principles and Processes
2. Biotechnology and Its Applications
3. Organisms and Populations

Module-5

1. Ecosystem
2. Biodiversity and Conservation
3. Environmental Issues