SAMPLE CONTENT

Challenger

NEET - UG & JEE (Main)
PHYSICS Vol - II

As per latest syllabus issued by NMC & NTA

2015 MCQs with Hints

For all Medical and Engineering Entrance Examinations held across India.

Total internal reflection

Mirror like reflection of turtle is formed in water when light undergoes total internal reflection in water.

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Challenger

NEET (UG) & JEE (Main)

Physics Vol. II

Now with more study techniques

Updated as per latest syllabus for:
NEET (UG) 2024 issued by **NMC on 6th October, 2023**
JEE (Main) 2024 issued by **NTA on 1st November, 2023**

Salient Features

- Concise theory for every topic.
- Eclectic coverage of MCQs under each sub-topic.
- Exhaustive coverage of questions including selective questions from previous years' NEET (UG) and JEE (Main) examinations updated upto year 2023:
  - **2015** MCQs
  - **88** Numerical Value Type (NVT)
  - Solutions to the questions are provided for better understanding
- Inclusion of '**Problems To Ponder**' to engage students in scientific enquiry.
- Multiple Study Techniques to Enhance Understanding and Problem Solving.
- Includes Question Papers and Answer Keys (Solutions through Q.R. code) of:
  - NEET (UG) 2021
  - NEET (UG) 2022
  - NEET (UG) 2023
  - JEE (Main) 2021 24th February (Shift - I)
  - JEE (Main) 2022 25th July (Shift - I)
  - JEE (Main) 2023 24th Jan (Shift - II)
- Q.R. codes provide:
  - Video links for boosting conceptual retention
  - Question Paper along with Answers and Solutions of NEET (UG) 2023 (Manipur)
  - Solutions of previous years' exam papers of years 2021 to 2023
- Separate list of questions excluded from the NEET (UG) and JEE (Main) 2024 syllabus

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PREFACE

'Challenger Physics Vol - II' is a compact guidebook, extremely handy for preparation of various competitive exams like NEET, JEE (Main). This edition provides an unmatched comprehensive amalgamation of theory with MCQs. The chapters are aligned with the syllabus for NEET (UG) and JEE (MAIN) examinations and run parallel to NCERT curriculum. The book provides the students with scientifically accurate context, several study techniques and skills required to excel in these examinations.

In this book the Theoretical Concepts are presented in the form of pointers, tables, charts and diagrams that form a vital part of preparation of any competitive examination.

Multiple Choice Questions have been specially created and compiled with the following objective in mind – to help students solve complex problems which require strenuous effort and understanding of multiple-concepts. The assortment of MCQs is a beautiful blend of questions based on higher order thinking, theory, and multiple concepts.

MCQs in each chapter are segregated into following sections.

- **Concept Building Problems** section is designed to boost prerequisite understanding of concepts.
- **Practice Problems** section contains questions crafted for thorough revision .
- **Numerical Value Type** section cater to newly added NVT questions in JEE (MAIN).
- **Problems to Ponder** section offers questions of diverse pattern created to instill the attitude of concentrating on the problems and to understand the application of various concepts in Physics.

All the features of this book pave the path of a student to excel in examination.The features are designed keeping the following elements in mind: Time management, easy memorization or revision and non-conventional yet simple methods for MCQ solving.

Previous Years' Question Papers:

To keep students updated, Question Papers along with Answers and Solutions (through Q.R. code) of following papers have been provided to offer students glimpse of the complexity of questions asked in entrance examination. These papers of latest competitive examinations have been provided and split unit-wise to let the students know which of the units were more relevant as per latest Question paper.

- NEET (UG) **2021, 2022, 2023** and **2023 (Manipur)**
- JEE (Main) **2021** 24^{th} February (Shift - I), **2022** 25^{th} July (Shift - I), **2023** 24^{th} January (Shift - II)

Considering the latest modifications in the syllabus of NEET (UG) and JEE (Main) examinations, a list of questions based on the concepts excluded from the syllabus is provided. The purpose of providing these questions is to display various question types and their level of difficulty that have been asked in previous examinations.

We hope the book benefits the learner as we have envisioned.

A book affects eternity; one can never tell where its influence stops.

Publisher

Edition: Fifth

The journey to create a complete book is strewn with triumphs, failures and near misses. If you think we've nearly missed something or want to applaud us for our triumphs, we'd love to hear from you.

Please write to us on: mail@targetpublications.org

KEY FEATURES

Time Saver

'Time Saver' illustrates quick method over lengthy conventional method of solving numerical. *This is our attempt to benefit students by saving their time wherever possible.*

Smart tip

'Smart tips' comprise important theoretical or formula based short tricks considering their usage in solving MCQ.
This is our attempt to highlight content that would come handy while solving questions.

Smart Code

'Smart Code' showcases simple and smart mnemonic created for selected concepts.
This is our attempt to offer students a memory technique that facilitates easy recollection.

Caution

'Caution' apprises students about mistakes which are made while solving an MCQs.
This is our attempt to make a student aware of possible common mistakes.

Q.R. Codes

'Q.R. code' provides access to a video in order to boost understanding of a concept or activity.
This is our attempt to facilitate learning with visual aids.

Formulae

'Formulae' includes all of the key formulae in the chapter.
This is our attempt to offer students tools of formulae accessible while solving problems and last minute revision at a glance.

KEY FEATURES

Learning Pointers

'Learning Pointers' provide compilation of additional notes which involve fusion of two concepts from different chapters or come as indirect extensions of subtopics.
This is our attempt to offer gist of knowledge required from examination point of view as a snippet.

Mind Over Matter

'Mind Over Matter' offers insight in solving brain-racking questions.
This is our attempt to build a framework for focused, guided thinking.

Clock Symbol

'Clock Symbol' instructs students that given MCQ can be solved apace by applying either Smart Tips, Learning Pointers, Time Saver or Thinking Hatke.
This is our attempt to make students attentive towards their perception of approaches possible for solving an MCQ.

Miscellaneous

Miscellaneous MCQs covers concept of different sub-topics of same chapter or from different chapters.
This is our attempt to develop cognitive thinking in the students essential to solve questions involving fusion of multiple key concepts.

Thinking Hatke

'Thinking Hatke' reveals quick witted approach to crack the specific question.
This is our attempt to develop skill of lateral thinking in students.

Memory Map

'Memory Map' summarizes the key points in the chapter.
This is our attempt to provide chapter overview succinctly.

Frequently Asked Questions

- **Why Challenger Series?**

Gradually, every year the nature of competitive entrance exams is inching towards conceptual understanding of topics. Moreover, it is time to bid adieu to the stereotypical approach of solving a problem using a single conventional method.

To be able to successfully crack the NEET examination, it is imperative to develop skills such as data interpretation, appropriate time management, knowing various methods to solve a problem, etc. With Challenger Series, we are sure, you'd develop all the aforementioned skills and take a more holistic approach towards problem solving. The way you'd tackle advanced level MCQs with the help of hints, Smart tips, Smart codes and Thinking Hatke section would give you the necessary practice that would be a game changer in your preparation for the competitive entrance examinations.

- **What is the intention behind the launch of Challenger Series?**

The sole objective behind the introduction of Challenger Series is to severely test the student's preparedness to take competitive entrance examinations. With an eclectic range of critical and advanced level MCQs, we intend to test a student's MCQ solving skills within a stipulated time period.

- **What do I gain out of Challenger Series?**

After using Challenger Series, students would be able to:

a. assimilate the given data and apply relevant concepts with utmost ease.

b. tackle MCQs of different pattern such as match the columns, diagram based questions, multiple concepts and assertion-reason efficiently.

c. garner the much needed confidence to appear for competitive exams.

d. easy and time saving methods to tackle tricky questions will help ensure that time consuming questions do not occupy more time than you can allot per question.

- ***Can the Questions presented in Problems to Ponder section be a part of the NEET Examination?***

No, the questions would not appear as it is in the NEET Examination. However, there are fair chances that these questions could be covered in parts or with a novel question construction.

Best of luck to all the aspirants!

CONTENTS

Note: ◑ *Part of the chapter excluded from the NEET (UG) and JEE (Main) 2024 syllabus (in index)*

☒ *Complete chapter excluded from the NEET (UG) and JEE (Main) 2024 syllabus (in index)*

Scan the adjacent QR Code in Quill - The Padhai App to view ***Question Paper and Solution of NEET (UG) 2023 (Manipur).***

Questions that are based on the concepts excluded from NEET (UG) and JEE (Main) 2024 Syllabus

Chapter and Excluded Subtopic		Questions excluded from 2024 Syllabus	Page No.
1. Electrostatics 1.1 Electric charges and their conservation, Conductors and insulators, Free and bound charges inside a conductor *(Free and bound charges inside a conductor)*	Theory	-	2
2. Capacitors 2.6 Van de Graaff ganerator	Theory	-	71
	Concept Building	All Questions	79 and 80
	Practice Problems	All Questions	84 and 85
3. Current Electricity 3.1 Electric current and Flow of electric charges in a metallic conductor *(Flow of electric charges in a metallic conductor)*	Theory	-	105
3.5 Carbon resistors, Colour code for carbon resistors	Theory	-	109
	Concept Building	All Questions	122
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3.14 Potentiometer	Theory	-	117 and 118
	Concept Building	All Questions	130
	Practice Problems		135
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	Concept Building	6 to 12	179
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Problems to Ponder	-	1	211 and 212
5. Magnetism 5.2 Current loop as a magnetic dipole and its magnetic dipole moment *(Magnetic dipole moment of a revolving electron)*	Theory	-	218 and 219
	Concept Building	1, 4 to 6	230 and 231
	Practice Problems	3, 4, 6	237

5.5 Earth's magnetism	Theory	-	221 to 223
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8. Ray Optics 8.6 Refraction and *dispersion* of light through prism	Theory		340 to 342
	Concept Building	8, 9, 14	355 and 356
	Practice Problems	2, 7	363 and 364
8.7 Some natural phenomena due to sunlight *(Scattering of light)*	Theory	-	342 and 343
	Concept Building	All Questions	356
	Practice Problems		364
8.8 Optical instruments: Human eye	Theory	-	343 and 344
	Concept Building	All Questions	356 and 357
	Practice Problems		364
Miscellaneous	Practice Problems	8	365
10. Diffraction and Polarisation of Light 10.2 Resolving power of optical instruments	Theory	-	436 and 437
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14. **Communication Systems**			
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JEE (Main) 2021 - 24th February (Shift - I) Multiple Choice Questions	-	9	615
Numerical Value Type Questions (NVT)	-	5, 6	615
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JEE (Main) 2022 - 25th July (Shift - I) Multiple Choice Questions	-	10	-
Numerical Value Type Questions (NVT)	-	5	-
NEET (UG) 2023 Section A	-	6, 10, 17	-
NEET (UG) 2023 (Manipur) Section A	-	22	-
Section B	-	25	-
JEE (Main) 2023 - 24th January (Shift- II) Multiple Choice Questions	-	12	-
Numerical Value Type Questions (NVT)	-	10	-

Note: i. *The above table contains the list of chapters/subtopics/question numbers that are excluded from the latest syllabus of NEET (UG) and JEE (Main) 2024.*

ii. *Only the concepts highlighted in italics are excluded from the latest syllabus within the specified subtopics.*

iii. *These questions are covered to give an idea about the variety and difficulty levels of questions asked in the examination over the years.*

7 Electromagnetic Waves

7.1 NEED FOR DISPLACEMENT CURRENT AND ORIGIN OF ELECTROMAGNETIC WAVES

As we have seen previously, the varying electric current produces magnetic field around it. Maxwell showed that changing electric fields also produce magnetic field.

➢ **Need for displacement current:**

i. According to Ampere's circuital law, the line integral of magnetic field $\vec{B}$ around any closed path or circuit is equal to μ_0 (absolute permeability of free space) times the total current (I) threading the closed circuit.

$$\oint \vec{B}.\vec{dl} = \mu_0 I$$

ii. However, when Ampere's circuital law was applied to an electric circuit containing a capacitor as one of the circuit elements, the law appeared to be inconsistent or incomplete.

iii. To overcome this inconsistency, James Clerk Maxwell introduced the concept of displacement current which he assumed to flow across the gap between the plates of the capacitor.

iv. Thus, through the conducting wires, there is a flow of conduction current I_C and through the gaps across the plates of capacitor, there is flow of displacement current I_D.

v. Maxwell modified Ampere's circuital law, by treating the current I as the sum of the conduction current I_C and the displacement current I_D.

$\therefore \quad \oint \vec{B}.\vec{dl} = \mu_0(I_C + I_D)$

$\therefore \quad \oint \vec{B}.\vec{dl} = \mu_0\left(I_C + \varepsilon_0 \frac{d\phi_E}{dt}\right) \quad \ldots\left[\because I_D = \varepsilon_0 \frac{d\phi_E}{dt}\right]$

This equation is known as Ampere – Maxwell's circuital law or modified Ampere's circuital law.

• **Ampere-Maxwell's circuital law:**

The line integral of magnetic field $\vec{B}$ over a closed path in vacuum is equal to μ_0 times the sum of the conduction current (I) and displacement current (I_D).

$$\oint \vec{B}.\vec{dl} = \mu_0\left(I + \varepsilon_0 \frac{d\phi_E}{dt}\right)$$

where, μ_0 = absolute permeability of free space.

➢ **Displacement current:**

The current which comes into play in the region, where electric field (and hence the electric flux) is changing with time is known as displacement current.

Formulae: i. $I_D = \varepsilon_0 \frac{d\phi_E}{dt}$ where, ε_0 = absolute permittivity of space and $\frac{d\phi_E}{dt}$ = rate of change of electric flux.

ii. $I_D = \frac{CdV}{dt}$ where, C = capacitance and $\frac{dV}{dt}$ = change in potential with respect to time.

Unit: ampere (SI)

Displacement current is zero for steady electric flux linked in a region.

➢ **Conduction current:**

The current in the electric field which arises due to the flow of electrons in the connecting wires of the circuit, in a definite closed path is called conduction current.

i. When a capacitor is connected to the battery, it starts storing charge due to conduction current when the capacitor gets fully charged, the conduction current becomes zero in the circuit.
ii. Conduction current exists even when the electrons flow at uniform rate.
iii. The conduction and displacement currents are individually discontinuous, but the two currents together possess the property of continuity through any closed electric circuit.
iv. Like conduction current, the displacement current is also a source of magnetic field.

➢ **Origin of electromagnetic waves:**

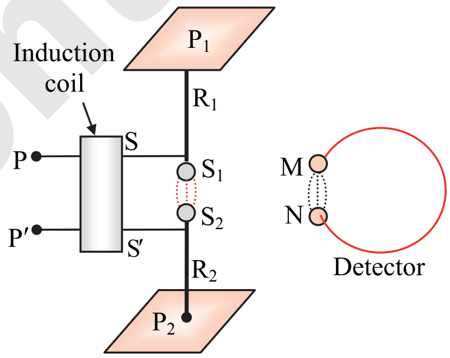
i. In 1865, Maxwell predicted the existence of electromagnetic (em) waves on the basis of mathematical equations, called Maxwell's equation.
ii. According to Maxwell, the time varying magnetic and electric field produced by an accelerated charge are mutually perpendicular and are source of each other. These mutually perpendicular time varying electric and magnetic field constitute electromagnetic waves and propagate in space in a direction perpendicular to both the direction of varying electric and magnetic fields.

➢ **Hertz's experiment:**

i. In 1887, Hertz experimentally demonstrated the production of electromagnetic waves by using a spark oscillator.
ii. Hertz's experimental setup is shown in the figure.
iii. The wavelength of electromagnetic waves produced was found to be,

$$\lambda = \frac{c}{\nu} = \frac{3\times10^8}{5\times10^7} = 6 \text{ m.}$$

iv. Hertz also showed that these electromagnetic waves possessed all the properties of light waves, i.e., reflection, refraction, interference etc.



Hertz's experimental setup

➢ **Speed of electromagnetic waves:**

i. For an electromagnetic wave propagating in the positive X-direction, the values of electric and magnetic fields at a distance x from the origin are represented by the equation,

$$E(y) = E_0 \sin \omega\left(t - \frac{x}{c}\right) \qquad B(z) = B_0 \sin \omega\left(t - \frac{x}{c}\right)$$

Where, c = the velocity of the electromagnetic waves, B_0 and E_0 = amplitude of magnetic and electric field.

ii. The speed of electromagnetic waves in free space is given as,

$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$ where, μ_0 = absolute permeability of free space, ε_0 = absolute permittivity of free space.

iii. For free space,
$\mu_0 = 1.257 \times 10^{-6}$ T m A^{-1} and $\varepsilon_0 = 8.854 \times 10^{-12}$ C^2 N^{-1} m^{-2}

$$\therefore \quad c = \frac{1}{\sqrt{1.257\times10^{-6}\times8.854\times10^{-12}}} = 3\times10^8 \text{ m s}^{-1}$$

Thus, speed of electromagnetic waves in free space is equal to the speed of light in vacuum.

iv. The velocity of electromagnetic wave in a material medium is given by, $v = \frac{1}{\sqrt{\mu\varepsilon}}$

v. The amplitudes (peak values) of the electric and magnetic fields in free space are related to the speed of electromagnetic waves in free space as, $c = \frac{E_0}{B_0}$

vi. The velocity of electromagnetic waves does not depend on amplitude of field vectors.

➢ **Maxwell's equations:** Maxwell's equations predict that the time and space dependant electric and magnetic fields propagate as transverse waves called electromagnetic waves, which possess velocity equal to that of light. The four Maxwell's equations are as given below:

Laws	**Gauss' law in electrostatics (Maxwell's first equation)**	**Gauss' law in magnetism (Maxwell's second equation)**	**Faraday's law of electromagnetic induction (Maxwell's third equation)**	**Ampere-Maxwell's law (Maxwell's fourth equation)**
Statement	The total electric flux through any closed surface is always equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.	The net magnetic flux crossing any closed surface is always zero.	The line integral of electric field along a closed path is equal to time rate of change of magnetic flux through the surface bounded by that closed path.	The line integral of magnetic field along a closed path is equal to μ_0 times the total current (sum of displacement and conduction current) threading the surface bounded by that closed path.
Mathematically	$\oint \vec{E}.\vec{ds} = \frac{q}{\varepsilon_0}$	$\oint \vec{B}.\vec{ds} = 0$	$\oint \vec{E}.\vec{dl} = -\frac{d}{dt}\int_s \vec{B}\cdot\vec{ds}$	$\oint \vec{B}.\vec{dl} = \mu_0\left(I_C + \varepsilon_0\frac{d\phi_E}{dt}\right)$

7.2 Electromagnetic waves and their characteristics

➢ **Electromagnetic waves:**

Electromagnetic waves are transverse waves in which there are time – varying, sinusoidal variations of electric and magnetic fields mutually perpendicular to each other and propagating in space in a direction perpendicular to the direction of wave propagation.

- **Characteristics of electromagnetic waves:**

i. Electromagnetic waves are transverse in nature.

ii. Electromagnetic waves are produced by accelerated electric charges or in a nuclear transition or in the annihilation of an electron and a positron.

iii. Electromagnetic waves do not require any material medium for their propagation. They can travel through vacuum as well as through solids, liquids and gases.

iv. Velocity of EM waves in vacuum / free space (c) = frequency (ν) × wavelength (λ)

v. Electromagnetic waves travel with the speed of light in vacuum.

vi. In a given material medium, the velocity (v_m) of electromagnetic waves is given by, $v_m = \frac{1}{\sqrt{\mu\varepsilon}}$

where, μ = Permeability of the given medium, ε = Permittivity of the given medium.

vii. Thus, refractive index of the medium is given by, $n = \frac{c}{v} = \frac{1}{\sqrt{\mu_0\varepsilon_0}} \times \frac{\sqrt{\mu\varepsilon}}{1} = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}} = \sqrt{\mu_r\varepsilon_r}$

viii. Electromagnetic waves obey the principle of superposition of waves.

ix. The electromagnetic waves possess properties of light, laws of reflection and refraction. They exhibit phenomena of interference, diffraction and polarization.

x. Electric and magnetic fields in electromagnetic waves vibrate in phase.

xi. **Energy density:** The energy of electromagnetic waves is equally distributed among the electric and magnetic field vector. In other words, average electric energy density (u_E) and average magnetic energy density (u_B) of an electromagnetic wave are equal i.e., $u_E = u_B$

In vacuum, due to static electric (E) and magnetic (B) field, $u_E = \frac{1}{2}\varepsilon_0 E_0^2$ and $u_B = \frac{1}{2}\frac{B_0^2}{\mu_0}$.

But in EM waves, as electric and magnetic fields vary with space and time, therefore,

$$u_E = \frac{1}{2}\varepsilon_0\ E_{rms}^2 \text{ and } u_B = \frac{1}{2}\ \frac{B_{rms}^2}{\mu_0}$$

where, $E_{rms} = \frac{E_0}{\sqrt{2}}$ and $B_{rms} = \frac{B_0}{\sqrt{2}}$

The average energy density of electromagnetic waves is therefore, given by $u = u_E + u_B = 2u_E = 2u_B$.

xii. The ratio of the amplitudes of electric and magnetic fields is always constant and it is equal to velocity of the electromagnetic waves, $c = \frac{E_0}{B_0}$.

xiii. The low frequency electromagnetic waves are unaffected by external electric and magnetic fields.

xiv. **Poynting vector:** The energy transported by electromagnetic waves per second per unit area is represented by a vector quantity $\vec{S}$ called Poynting vector. It is given by, $\vec{S} = \vec{E} \times \vec{H} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$.

xv. **Momentum:** The momentum transported by electromagnetic waves is given by, $p = \frac{U}{c} = \frac{S \times A}{c}$.

Where, U = energy transported by electromagnetic waves in a given time,
c = speed of electromagnetic waves in free space and
A = area of cross-section of surface upon which electromagnetic wave is incident.

As a result, when these waves strike a surface, pressure is exerted by them on the surface. This pressure is called as radiation pressure. For visible light it is of the order of 7×10^{-6} N/m^2.

If incident electromagnetic wave is completely reflected then momentum delivered to the surface is $\frac{2U}{c}$ as momentum of electromagnetic wave changes from p to – p.

xvi. The intensity of electromagnetic waves i.e., energy crossing per second per unit area of a surface normally is given by,

$I = u_E c = u_B c$

$\therefore \quad I = \frac{1}{2}\frac{E_0 B_0}{\mu_0} = \frac{1}{2}\frac{B_0^2}{\mu_0}c = \frac{1}{2}\varepsilon_0 E_0^2 c$

xvii. Electromagnetic waves exert pressure upon falling on the objects. It is given by, $P = \frac{I}{c}$

7.3 Transverse nature of electromagnetic waves

i. The electromagnetic waves are produced by accelerated electric charges. An accelerated charge produces a magnetic field in the surrounding region which gives rise to an electric field.

ii. The electric and magnetic fields are mutually perpendicular to each other. If the accelerated charge is oscillating, both the electric and magnetic fields vary with time and they travel outwards from the charge in the form of electromagnetic waves.

iii. If $\vec{E}$ is along the Y-axis and $\vec{B}$ is along the Z-axis, the direction of propagation of wave is along $\vec{E} \times \vec{B}$ i.e., along the X-axis as shown in figure (a).

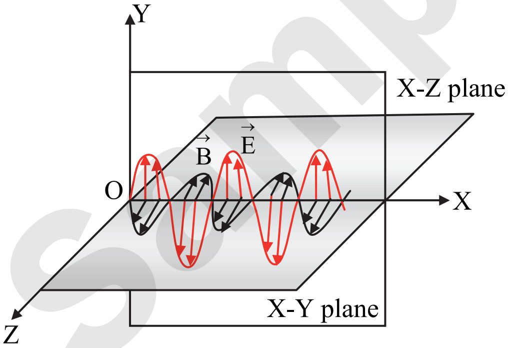


Figure (a) Electromagnetic wave propagating along X axis

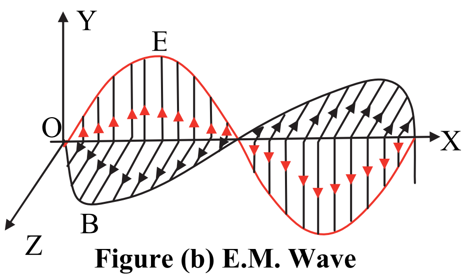


Figure (b) E.M. Wave

iv. A single electromagnetic wave propagating perpendicular to both electric and magnetic field in magnified form is as shown in figure (b).

v. The electric field and magnetic field vary sinusoidally with X and is given by,

$$E_y = E_0 \sin(kx - \omega t) \quad \text{and} \quad B_z = B_0 \sin(kx - \omega t)$$

where, E_0 = amplitude of electric intensity $\vec{E}$, B_0 = amplitude of magnetic induction $\vec{B}$,

$k = \frac{2\pi}{\lambda}$ = Propagation constant, λ = wavelength of oscillations,

$\omega = 2\pi\nu$ = Angular frequency of oscillations.

vi. Both the electric and magnetic fields attain their maximum and minimum values at the same time and at the same point in space i.e., they oscillate in same phase with same frequency.

vii. Energy is equally distributed between electric vector $\vec{E}$ and $\vec{B}$ vibrating in same phase.

viii. From the figures, it is observed that propagation of electromagnetic field is in the direction of $\vec{E}\times\vec{B}$. As the electric and magnetic fields are mutually perpendicular to each other and in the direction of wave propagation, the electromagnetic waves are transverse in nature.

7.4 Electromagnetic spectrum

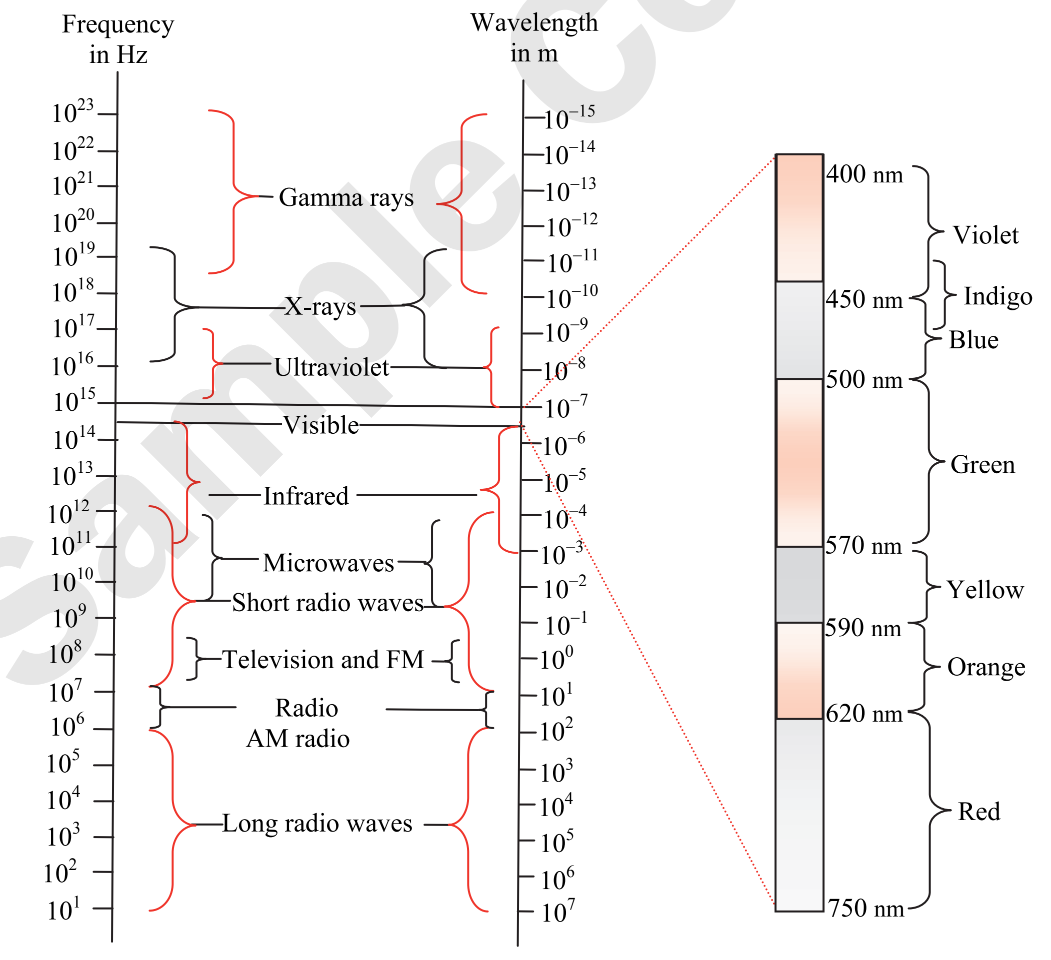
➢ **Electromagnetic spectrum:**

The orderly distribution (i.e., sequential arrangement) of electromagnetic waves according to their wavelengths (or frequencies) in the form of distinct groups having different properties is called the electromagnetic spectrum.

i. The spectrum of electromagnetic radiations has no upper or lower limits i.e., sharp boundaries. All regions overlap.

ii. The known electromagnetic waves have wavelength ranging from 10^{-15} m to more than 10^4 m.

iii. The main parts of an electromagnetic spectrum in the order of increasing wavelength from 10^{-5} Å or 10^{-15} m to 10^6 m are γ – rays, X – rays, ultraviolet rays, visible light, infrared rays, microwaves and radio waves. The different parts of the electromagnetic spectrum differ in their methods of production and detection.



Electromagnetic spectrum

	Gamma rays (γ)	X-rays
Wavelength	< 0.01 nm	0.1 nm to 10 nm
Production	Radioactive decay of nucleus	Stopping fast moving electrons suddenly/Coolidge X-ray tube
Method of detection	Geiger counter, photographic plate, fluorescence.	ionisation chamber, photographic plate, scintillation counters, semi-conductor detector, etc.
Discovered by	Paul Ulrich Villard.	Wilhelm Konrad Rontgen
Properties	i. high penetrating power. ii. moderate ionizing power. iii. produce fluorescence iv. affect a photographic plate. v. no deflection by electric and magnetic fields. vi. knock out electrons from the surface on which they are incident. vii. produce heating effect in the surface exposed to them. viii. cause photoelectric effect, Compton scattering and pair production.	i. No deviation by electric and magnetic fields. ii. affect photographic plates. iii. ionize the gas through which they pass. iv. produce fluorescence. v. travel in straight line and cast the shadows of the objects falling in their path. vi. undergo reflection, refraction, interference, diffraction and polarization. vii. penetrate through thin sheet of metal, wood, flesh, skin, etc., but cannot penetrate denser objects, such as bones, heavy metals, etc. viii. Prolong exposure can have injurious effect on human bodies. ix. cause photoelectric effect.
Applications	i. In radiotherapy for the treatment of cancer and tumour. ii. In food industry to kill micro-organisms. iii. To preserve the food items. iv. To produce nuclear reactions. v. In gamma ray astronomy.	i. In surgery, X-ray photographs are useful to detect bone fracture or the presence of foreign objects like bullets or hidden metal in a human body. ii. For detecting faults, cracks and flaws in metals. iii. To distinguish real diamonds, gems from artificial ones. iv. To detect the structure of crystals, constitution and properties of atoms and molecules in complex substance. v. To cure skin diseases and to destroy tumours in the body of a patient. vi. For detection of explosives, opium etc.

	Ultraviolet rays (UV)	Visible light	Infrared rays (IR)
Wavelength	10 nm to 400 nm	400 nm to 800 nm	800 nm to 1 mm
Production	During transition of inner shells electrons from higher to lower energy levels.	Transition of electrons from higher to lower energy level, heating bodies to glow (e.g.: bulb)	Vibrations of atoms and molecules, hot bodies, solar radiations
Method of detection	Photo cells, photographic film	Eye, photocell, photographic film	Thermopiles, bolometer, infrared photographic film
Discovered by	Johann Wilhelm Ritter	–	Sir Frederick William Hershell
Properties	i. undergo reflection, refraction, interference and polarization. ii. cause photoelectric effect. iii. produce fluorescence in certain materials. iv. cannot pass through glass but can pass through quartz, fluorite, rock salts etc. v. possess the property of synthesizing vitamin D when the skin is exposed to sunlight.	Visible light consists of different wavelengths. Different wavelengths give rise to different colours. Wavelength range of various parts of visible rays are as follows: Violet : 4×10^{-7} to 4.5×10^{-7} m, Blue : 4.5×10^{-7} to 5×10^{-7} m, Green : 5×10^{-7} to 5.7×10^{-7} m, Yellow : 5.7×10^{-7} to 5.9×10^{-7} m, Orange : 5.9×10^{-7} to 6.2×10^{-7} m, Red : 6.2×10^{-7} to 7.5×10^{-7} m.	i. obey laws of reflection and refraction. ii. produce interference and polarization. iii. affect the photographic plates. iv. When fall on the material surface, infrared rays increase temperature of material surface. v. strongly absorbed by glass. vi. penetrate through thick columns of fog and mist.
Applications	i. In checking the mineral samples. ii. UV absorption spectra is used to study molecular structure.	–	i. In taking photographs during conditions of fog, smoke, darkness etc. ii. In diagnosis of superficial tumours and varicose veins.

	iii. To destroy bacteria and hence they are used for sterilizing surgical instrument. iv. In burglar alarms as they can cause photo electric effect. v. In high resolving power microscopes. vi. To distinguish between real and false gems. vii. In the analysis of chemical compounds.		iii. To cure infantile paralysis and to treat sprains, dislocations and fractures. iv. In solar water heaters and solar cookers. v. In medicine. vi. Special infrared photographs of the body, called thermograms, can show up diseased parts because they radiate less heat than the healthy parts, which is sensitive to infrared rays. vii. Infrared rays are reflected by low lying clouds and keep the earth warm hence they show green house effect. viii. To keep green house warm. ix. In remote controls of television, V.C.R etc.

	Microwave	**Radiowaves**
Wavelength	1 mm to 10 m	> 10 m
Production	Klystron valve, magnetron valve, gunn diodes	Oscillating electric LC circuits, rapid acceleration or deceleration of electrons in aerials.
Method of detection	Point contact diodes	Receiver's aerials
Properties	i. obey the laws of reflection and refraction. ii. heat an object on which microwaves are incident.	i. obey laws of reflection and refraction. ii. get diffracted from obstacles coming in their path.
Applications	i. In radar system for the location of distant objects like ships, aeroplanes etc. ii. In long distance telephone communication system. iii. For cooking. iv. In the study of atomic and molecular structure. v. For the transmission of TV signals.	i. For wireless communication purposes. ii. For radio broadcasting and transmission of TV signals. iii. Cellular phones use radio waves to transmit voice communication in the ultra high frequency (UHF) band.

Formulae

1. **Displacement current:** $I_D = \varepsilon_0 \frac{d\phi_E}{dt}$

2. **Ampere's circuital law:** $\oint \vec{B}\cdot\vec{dl} = \mu_0 I$

3. **Modified Ampere's circuital law:**

$$\oint \vec{B}\cdot\vec{dl} = \mu_0\left(I_C + \varepsilon_0 \frac{d\phi E}{dt}\right)$$

4. **Maxwell's equations:**

i. $\oint \vec{E}\cdot\vec{ds} = \frac{q}{\varepsilon_0}$ ii. $\oint \vec{B}\cdot\vec{ds} = 0$

iii. $\oint \vec{E}.\vec{dl} = -\frac{d}{dt}\int_s \vec{B}.\vec{ds}$

iv. $\oint \vec{B}\cdot\vec{dl} = \mu_0\left(I_C + \varepsilon_0 \frac{d\phi B}{dt}\right)$

5. **Electromagnetic wave:**

i. Velocity of electromagnetic waves in free space,

$$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = \frac{E_0}{B_0}$$

ii. Velocity of electromagnetic waves in a material medium, $v_m = \frac{1}{\sqrt{\mu\varepsilon}}$

6. **Refractive index (n) of a material medium:**

$$n = \frac{c}{v} = \frac{1}{\sqrt{\mu_0\varepsilon_0}} \times \frac{\sqrt{\mu\varepsilon}}{1} = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}} = \sqrt{\mu_r\varepsilon_r}$$

Where $\frac{\mu}{\mu_0} = \mu_r$ (relative permeability), $\frac{\varepsilon}{\varepsilon_0} = \varepsilon_r$ (relative permittivity of the material medium).

7. **Average electric energy density:** $u_E = \frac{1}{2}\varepsilon_0 E^2$

8. **Average magnetic energy density:**

$u_B = \frac{1}{2}\frac{B^2}{\mu_0}$

9. **Energy transported by electromagnetic wave per second per unit area:**

$\vec{S} = \vec{E} \times \vec{H} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$

10. **Momentum transported by electromagnetic wave:**

$p = \frac{U}{c}$, where, U is energy transport by electromagnetic wave.

11. **Intensity of electromagnetic waves:**

$I = \frac{1}{2}\frac{E_0 B_0}{\mu_0} = \frac{1}{2}\frac{B_0^2}{\mu_0}c = \frac{1}{2}\varepsilon_0 E_0^2 c$

12. **Pressure exerted by electromagnetic wave:**

$P = \frac{I}{c}$

Concept Building Problems

7.1 Need for Displacement Current and Origin of Electromagnetic Waves

1. A parallel plate capacitor with plates of area A and separation between the plates d, is charged by a constant current I. Consider a plane surface of area A/2 parallel to the plates and drawn symmetrically between the plates. The displacement current through this area will be

(A) I (B) $\frac{I}{2}$
(C) $\frac{I}{4}$ (D) $\frac{I}{6}$

2. The capacity of a parallel plate air capacitor is 20 μF and voltage between the plates is changing at the rate of 2.5 V/s. The displacement current in the capacitor is

(A) 0.2 μA (B) 2.5 μA
(C) 0.5 μA (D) 5 μA

3. A parallel plate capacitor of capacitance 20 μF is being charged by a voltage source whose potential is changing at the rate of 3 V/s. The conduction current through the connecting wires, and the displacement current through the plates of the capacitor, would be, respectively: **[NEET (UG) 2019]**

(A) 60 μA, zero (B) zero, zero
(C) zero, 60 μA (D) 60 μA, 60 μA

7.2 Electromagnetic Waves and Their Characteristics

1. If $\vec{E}$ and $\vec{B}$ represent electric and magnetic field vectors of the electromagnetic wave, the direction of propagation of electromagnetic wave is along **[NCERT Exemplar]**

(A) $\vec{E}$ (B) $\vec{B}$
(C) $\vec{B} \times \vec{E}$ (D) $\vec{E} \times \vec{B}$

2. Consider the following statements about electromagnetic radiations; All of them
i. have energy.
ii. exert pressure on an object.
iii. have the same momentum.
Of these statements
(A) (i), (ii) and (iii) are correct.
(B) (i) and (ii) are correct.
(C) (ii) and (iii) are correct.
(D) (i) and (iii) are correct.

3. A radiation of energy 'E' falls normally on a perfectly reflecting surface. The momentum transferred to the surface is
(c = velocity of light) **[AIPMT 2015]**

(A) $\frac{E}{c}$ (B) $\frac{2E}{c}$
(C) $\frac{2E}{c^2}$ (D) $\frac{E}{c^2}$

4. The ratio of contributions made by the electric field and magnetic field components to the intensity of an EM wave is **[NCERT Exemplar]**

(A) c : 1 (B) c^2 : 1 (C) 1 : 1 (D) $\sqrt{c}$: 1

5. Out of the following options which one can be used to produce a propagating electromagnetic wave **[NEET P-I 2016]**
(A) A chargeless particle
(B) An accelerating charge
(C) A charge moving at constant velocity
(D) A stationary charge

6. In an electromagnetic wave, the amplitude of electric field is 6 V/m. The frequency of wave is 7×10^{14} Hz and is moving along Z-axis. What is the average energy density of electric field?
(A) 4.4×10^{-12} J/m^3
(B) 6.6×10^{-12} J/m^3
(C) 7.96×10^{-11} J/m^3
(D) 8.81×10^{-11} J/m^3

7.3 Transverse Nature of Electromagnetic Waves

1. Which of the following has zero average value in a plane electromagnetic wave?
(A) Kinetic energy. (B) Magnetic field.
(C) Electric field. (D) Both (B) and (C).

2. The electric field for an e.m. wave is $E = E_0 \sin [\pi (18 \times 10^{15} t - 9 \times 10^7 x)]$. What is the speed of the e.m. wave?
(A) 2×10^8 m/s (B) 4×10^7 m/s
(C) 3×10^8 m/s (D) 48×10^8 m/s

3 If the magnetic field in a plane electromagnetic wave is given by
$\vec{B} = 3 \times 10^{-8} \sin(1.6 \times 10^3 x + 48 \times 10^{10} t)\ \hat{j}$ T, then what will be expression of electric field?
[JEE (Main) Jan 2020]
(A) $\vec{E} = \left[60 \sin\left(1.6\times10^3 x + 48\times10^{10} t\right)\hat{k}\ \text{V/m}\right]$
(B) $\vec{E} = \left[3\times10^{-8} \sin\left(1.6\times10^3 x + 48\times10^{10} t\right)\hat{i}\ \text{V/m}\right]$
(C) $\vec{E} = \left[9 \sin\left(1.6\times10^3 x + 48\times10^{10} t\right)\hat{k}\ \text{V/m}\right]$
(D) $\vec{E} = \left[3\times10^{-8} \sin\left(1.6\times10^3 x + 48\times10^{10} t\right)\hat{j}\ \text{V/m}\right]$

4. An em wave is propagating in a medium with a velocity $\vec{v} = v\hat{i}$. The instantaneous oscillating electric field of this em wave is along + y axis. Then the direction of oscillating magnetic field of the em wave will be along
[NEET (UG) 2018]
(A) – z direction (B) + z direction
(C) – y direction (D) – x direction

5. Relative permeability and relative permittivity of a medium are respectively 4 and 9. If the magnetic induction field of the electromagnetic wave travelling in the medium is 8.6×10^{-8} T, then the magnitude of its electric field is
(A) 3.4 Vm^{-1} (B) 4.3×10^{-8} Vm^{-1}
(C) 8.6×10^{-8} Vm^{-1} (D) 4.3 Vm^{-1}

6. An EM wave from air enters a medium. The electric fields are $\vec{E_1} = E_{01}\hat{x} \cos\left[2\pi\nu\left(\frac{z}{c} - t\right)\right]$ in air and $\vec{E_2} = E_{02}\ \hat{x} \cos [k(2z - ct)]$ in medium, where the wave number k and frequency ν refer to their values in air. The medium is non–magnetic. If ε_{r_1} and ε_{r_2} refer to relative permittivities of air and medium respectively, which of the following options is correct?
[JEE (Main) 2018]
(A) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{4}$ (B) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \frac{1}{2}$
(C) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 4$ (D) $\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = 2$

7. In an electromagnetic wave in free space the root mean square value of the electric field is E_{rms} = 6 V/m. The peak value of the magnetic field is: **[NEET (UG) 2017]**
(A) 1.41×10^{-8} T (B) 2.83×10^{-8} T
(C) 0.70×10^{-8} T (D) 4.23×10^{-8} T

7.4 Electromagnetic spectrum

1. All components of the electromagnetic spectrum in vacuum have the same _______.
(A) energy (B) speed
(C) wavelength (D) frequency

2. The penetrating power of X-ray increases with the increase in its _______.
(A) velocity (B) intensity
(C) frequency (D) wavelength

3. Electromagnetic radiation used to sterilize milk is
(A) X – ray (B) γ – ray
(C) UV – ray (D) Radiowaves

4. Arrange the following electromagnetic radiations per quantum in the order of increasing energy: **[JEE (Main) 2016]**
A : Blue light
B : Yellow light
C : X – ray
D : Radiowave
(A) A, B, D, C (B) C, A, B, D
(C) B, A, D, C (D) D, B, A, C

5. Choose the correct sequence of the radiation sources in increasing order of the wavelength of electromagnetic waves produced by them.
(A) X-ray tube, Magnetron valve, Radioactive source, Sodium lamp.
(B) Radioactive source, X-ray tube, Sodium lamp, Magnetron valve.
(C) X-ray tube, Magnetron valve, Sodium lamp, Radioactive source
(D) Magnetron valve, Sodium lamp, X-ray tube, Radioactive source

6. The energy of the e.m. waves is of the order of 15 keV. To which part of the spectrum does it belong? **[AIPMT Re-Test 2015]**
(A) γ-rays (B) X-rays
(C) Infra-red rays (D) Ultraviolet

Miscellaneous

1. The displacement current flows in the dielectric of a capacitor when the potential difference between its plates
(A) is changing with time.
(B) is changing with distance.
(C) has assumed a constant value.
(D) becomes zero.

2. An EM wave radiates outwards from a dipole antenna, with E_0 as the amplitude of its electric field vector. The electric field E_0 which transports significant energy from the source falls off as [NCERT Exemplar]
(A) $\frac{1}{r^3}$ (B) $\frac{1}{r^2}$
(C) $\frac{1}{r}$ (D) remains constant

3. **Assertion:** For a light beam coming from a bulb, its electric field strength equals its magnetic field strength.
Reason: Energy in electric field of beam equals energy in its magnetic field.
(A) Assertion is True, Reason is True; Reason is a correct explanation for Assertion.
(B) Assertion is True, Reason is True; Reason is not a correct explanation for Assertion.
(C) Assertion is True, Reason is False.
(D) Assertion is False, Reason is True.

4. A linearly polarised electromagnetic wave given as $E = E_0 \hat{i} \cos(kz - \omega t)$ is incident normally on a perfectly reflecting infinite wall at z = a. Assuming that the material of the wall is optically inactive, the reflected wave will be given as [NCERT Exemplar]
(A) $E_r = E_0 \hat{i} \sin(kz - \omega t)$
(B) $E_r = E_0 \hat{i} \cos(kz - \omega t)$
(C) $E_r = -E_0 \hat{i} \cos(kz + \omega t)$
(D) $E_r = E_0 \hat{i} \cos(kz + \omega t)$

5. A parallel plate capacitor consists of circular plates each of radius 20 cm separated by a distance of 4 mm. If the charging current is 0.6 A, what is the rate of variation of potential?
(A) $1.44\times10^9 \frac{V}{s}$ (B) $2.16\times10^9 \frac{V}{s}$
(C) $0.72\times10^9 \frac{V}{s}$ (D) $0.36\times10^9 \frac{V}{s}$

6. A metallic ball is charged positively and negatively in a sinusoidal manner at a frequency of 2×10^6 cps. If the maximum charge on the ball is 8 μC, what is the maximum displacement current due to this alternating current?
(A) 6.28 A (B) 100 A
(C) 3.75×10^{-4} A (D) 122.56 A

Mind over Matter

The key to crack this question lies in comprehending that, charge oscillating sinusoidally is given by $Q = q_0 \sin \omega t$ and displacement current can be expressed as $I_D = \frac{dq}{dt}$

7. A 100 Ω resistance and a capacitor of 100 Ω reactance are connected in series across a 220V source. When the capacitor is 50% charged, the peak value of the displacement current is [NEET P-II 2016]
(A) $11\sqrt{2}$A (B) 2.2 A
(C) 11 A (D) 4.4 A

8. The electric field intensity produced by the radiation coming from 100 W bulb at a 3 m distance is E. The electric field intensity produced by the radiations coming from 50 W bulb at the same distance is [NCERT Exemplar]
(A) $\frac{E}{2}$ (B) 2E
(C) $\frac{E}{\sqrt{2}}$ (D) $\sqrt{2}$ E

9. Light with an energy flux of 50×10^4 Wm^{-2} falls on a perfectly reflecting surface at normal incidence. If the surface area is 20 cm^2, the average force exerted on the surface is
(A) 1.25×10^{-6} N (B) 2.50×10^{-6} N
(C) 6.67×10^{-6} N (D) 3.0×10^{-6} N

Mind over Matter

The key to crack this question lies in comprehending that, when wave is totally reflected from a surface, momentum delivered to the surface is twice the momentum delivered by the e.m. wave to the surface when incident upon it.

10. A red LED emits light at 0.1 watt uniformly around it. The amplitude of the electric field of the light at a distance of 1 m from the diode is [JEE (Main) 2015]
(A) 1.73 V/m (B) 2.45 V/m
(C) 5.48 V/m (D) 7.75 V/m

11. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in [NCERT Exemplar]
(A) visible region.
(B) infrared region.
(C) ultraviolet region.
(D) microwave region.

12. Light with an energy flux of 20 W/cm^2 falls on a non-reflecting surface at normal incidence. If the surface has an area of 30 cm^2, the total momentum delivered (for complete absorption) during 30 min is [NCERT Exemplar]
(A) 36×10^{-5} kg-m/s (B) 36×10^{-4} kg-m/s
(C) 108×10^4 kg-m/s (D) 1.08×10^7 kg-m/s

13. If displacement current in a circuit changes according to the relation ($2t^2 + 6$) S.I. units, for t; $2 \text{ s} \le t \le 4$ s then, what will be the net change in flux associated with the circuit during that time interval?

(A) $\frac{\varepsilon_0}{49.34}$ S.I. units (B) $\frac{54.63}{\varepsilon_0}$ S.I. units

(C) $\frac{\varepsilon_0}{54.63}$ S.I. units (D) $\frac{49.34}{\varepsilon_0}$ S.I. units

Practice Problems

7.1 Need for Displacement Current and Origin of Electromagnetic Waves

1. According to Maxwell, in electromagnetic wave, varying electric field gives ________.
   (A) conduction current.
   (B) eddy current.
   (C) displacement current.
   (D) stationary magnetic field.

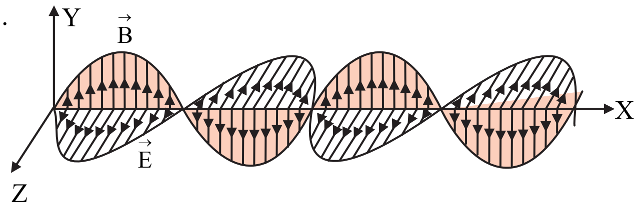
2. Ampere's circuital law fails to explain displacement current because
   (A) the law is applicable only for resistances.
   (B) displacement current is pseudo current.
   (C) the law is time independent.
   (D) the law is applicable only for capacitors.

3. When charge on capacitor connected to a battery is maximum, then
   (A) the conduction current in ideal case through a circuit is unity.
   (B) the displacement current in ideal case through a circuit is zero.
   (C) the conduction current in ideal case through a circuit is zero.
   (D) the displacement current in ideal case through a circuit is unity.

4. Electromagnetic waves travel in a medium which has relative permeability 1.3 and relative permittivity 2.14. Then the speed of the electromagnetic wave in the medium will be
   (A) 4.2×10^6 m/s (B) 1.8×10^6 m/s
   (C) 2.6×10^8 m/s (D) 1.8×10^8 m/s

5. A particle of charge -28 μC moving with velocity 40 ms^{-1} along the X-axis enters a region where an electric field of induction E of magnitude 2×10^4 V/m is along the negative Z-axis. If the charged particle continues moving along the X-axis, the magnitude of B is
   (A) 10^{-3} Wb/m^2 (B) 10^3 Wb/m^2
   (C) 2800 Wb/m^2 (D) 500 Wb/m^2

7.2 Electromagnetic Waves and Their Characteristics

1. 

   The representation describes
   (A) propagation of transverse electromagnetic wave along X-direction.
   (B) propagation of electromagnetic wave along X-direction with time varying electric and magnetic fields in varying planes.
   (C) propagation of electromagnetic wave along X-direction with time independent electric field along Z-direction and magnetic field along Y-direction.
   (D) propagation of linearly polarised electromagnetic wave along X-direction.

Mind over Matter

The key to crack this question lies in comprehending that, e.m. waves have sinusoidally varying electric and magnetic field vectors at right angles to each other and to the direction of propagation.
The given representation has electric and magnetic fields confined to respective specific planes throughout the propagation of wave.

2. Fundamental particle in an electromagnetic wave is _______.
   (A) phonon (B) photon
   (C) proton (D) electron

3. When the sun shines on your hands, your hands get warm because
   (A) e.m. waves transfer large amount of radiation pressure.
   (B) e.m. waves transfer large amount of momentum.
   (C) e.m. waves transfer energy.
   (D) all of the above.

4. A plane electromagnetic wave is incident on a material surface. If the wave delivers momentum p and energy E, then
   (A) $p = 0, E = 0$ (B) $p \ne 0, E \ne 0$
   (C) $p \ne 0, E = 0$ (D) $p = 0, E \ne 0$

5. The electric vector of an e.m. wave is also termed as _______ vector.
   (A) poynting (B) pointing
   (C) light (D) transverse

6. Choose an incorrect statement:
   i. The velocity of light depends on electric and magnetic properties of the medium.
   ii. The velocity of e.m. wave in vacuum is a fundamental constant.
   iii. The velocity of e.m. wave depends on the refractive index of material medium.
   iv. The velocity of e.m. waves is its inherent characteristic.
   (A) i and ii (B) ii and iii
   (C) iii (D) iv

7. Which of the formula/e suggest/s that velocity of light depends on electric properties of medium?
   i. $v = \frac{E(t)}{B(t)}$ [where, E(t), B(t) are amplitudes of electric and magnetic field vectors respectively at a time instant t in a medium.]
   ii. $v = \frac{1}{\sqrt{\mu\varepsilon}}$
   iii. $v = \sqrt{c^2\mu_r\varepsilon_r}$
   iv. $\vec{v} = \vec{E} \times \vec{H}$
   (A) (i) and (ii) (B) (ii) only
   (C) (i), (ii) and (iii) (D) (i), (ii) and (iv)

8. The dielectric constant of air is 1.006. If the speed of electromagnetic wave travelling in air is $n \times 10^8$ ms^{-1} then, what is the value of n?
   (A) 3 (B) 3.88 (C) 2.5 (D) 3.2

9. The rms value of the electric field of the light coming from the sun is 430 N/C. The average total energy density of the electromagnetic wave is
   (A) 1.39×10^{-4} J/m^3 (B) 8.78×10^{-5} J/m^3
   (C) 1.64×10^{-6} J/m^3 (D) 2.14×10^{-7} J/m^3

7.3 Transverse Nature of Electromagnetic Waves

1. EM waves are transverse in nature. This means, ________
   (A) associated electric and magnetic field are in phase with each other.
   (B) associated electric and magnetic field are transverse in nature.
   (C) associated electric and magnetic field are perpendicular to each other and to the direction of propagation of wave.
   (D) all EM waves travel with same speed in vacuum.

2. An electromagnetic wave going through vacuum is described by $E = E_0 \sin(kx - \omega t)$. Which of the following is independent of wavelength?
   (A) k (B) ω (C) $\frac{k}{\omega}$ (D) kω

3. In a plane e.m. wave, the magnetic field oscillates sinusoidally with a frequency of 6×10^{10} Hz and amplitude 140 nT. Then the wavelength of the wave and the amplitude of the oscillating electric field respectively will be,
   (A) 1.8×10^{-6} m; 50 V m^{-1}
   (B) 0.5×10^{-2} m; 28 V m^{-1}
   (C) 0.5×10^{-2} m; 42 V m^{-1}
   (D) 10^{-9} m; 49 V m^{-1}

4. The oscillating magnetic field in a plane electromagnetic wave is given by,
   $B_y = 18 \times 10^{-6} \sin[21 \times 10^{11}\, t + 450\, \pi x]$ (in T)
   then wavelength of the wave
   (A) 6.67×10^{-3} m (B) 4.44×10^{-3} m
   (C) 2.67×10^{-3} m (D) 5.67×10^{-3} m

7.4 Electromagnetic Spectrum

1. A radar sends the waves towards a distant object and receives the signal reflected by object. These waves are ________.
   (A) sound waves (B) light waves
   (C) radiowaves (D) microwaves

2. Infrared radiations are detected by ________.
   (A) spectrometer (B) nanometer
   (C) photometer (D) pyrometer

3. Finger prints on a piece of paper may be detected by sprinkling fluorescent powder on the paper and then looking at it in
   (A) dark light. (B) sun-light.
   (C) infrared light. (D) ultraviolet light.

4. X-rays are not used for radar purposes, because they are not
   (A) reflected by target.
   (B) partly absorbed by target.
   (C) electromagnetic waves.
   (D) completely absorbed by target.

5. If λ_v, λ_x and λ_μ represent the wavelength of visible light, X-rays and microwaves respectively, then
   (A) $\lambda_\mu > \lambda_x > \lambda_v$ (B) $\lambda_\mu > \lambda_v > \lambda_x$
   (C) $\lambda_v > \lambda_\mu > \lambda_x$ (D) $\lambda_v > \lambda_x > \lambda_\mu$

Miscellaneous

1. **Assertion:** The displacement current like conduction current is a source of magnetic field.
   Reason: Ampere's law is logically consistent for every circuit.
   (A) Assertion is True, Reason is True; Reason is a correct explanation for Assertion.
   (B) Assertion is True, Reason is True; Reason is not a correct explanation for Assertion.
   (C) Assertion is True, Reason is False.
   (D) Assertion is False, Reason is True.

2. X-rays and γ-rays of same energies are distinguished by their _______.
(A) frequencies
(B) charges
(C) ionising power
(D) method of production

3. Choose the correct option.
Statement I: The visible spectrum contains all the colours that the human eyes and brain can distinguish.
Statement II: The human eyes and brain can distinguish all the colours contained in the visible spectrum.
(A) Statements (I) and (II), both are correct.
(B) Statement (I) and (II), both are incorrect.
(C) Only statement (I) is correct.
(D) Only statement (II) is correct.

4. The shortest wavelength of X-rays emitted from an X-ray tube depends upon
(A) nature of the gas in the tube.
(B) nature of target of the tube.
(C) voltage applied to tube.
(D) all of the above.

5. **Assertion:** The electrical conductivity of earth's atmosphere increases with altitude.
Reason: The high energy particles (i.e., γ-rays and cosmic rays) coming from outer space and entering our earth's atmosphere cause ionisation of the atoms of the gases present there.
(A) Assertion is True, Reason is True; Reason is a correct explanation for Assertion.
(B) Assertion is True, Reason is True; Reason is not a correct explanation for Assertion.
(C) Assertion is True, Reason is False.
(D) Assertion is False, Reason is False.

6. **Assertion:** Cathode rays are e.m. waves.
Reason: All cosmic rays are e.m. waves.
(A) Assertion is True, Reason is True; Reason is a correct explanation for Assertion.
(B) Assertion is True, Reason is True; Reason is not a correct explanation for Assertion.
(C) Assertion is True, Reason is False.
(D) Assertion is False, Reason is False.

7. **Assertion:** Hydrogen atom does not emit X-rays.
Reason: Hydrogen molecule has five degrees of freedom.
(A) Assertion is True, Reason is True; Reason is a correct explanation for Assertion.
(B) Assertion is True, Reason is True; Reason is not a correct explanation for Assertion.
(C) Assertion is True, Reason is False.
(D) Assertion is False, Reason is True.

8. _______ lamps are used in physical therapy.
(A) X-rays (B) LASIK
(C) Infrared (D) Ultraviolet

9. Electromagnetic waves travel in a medium with a speed of 2×10^8 ms^{-1}. The relative permeability of the medium is 1. Find the relative permittivity.
(A) 1.85 (B) 3.82
(C) 2.25 (D) 6.42

10. If ε_0 and μ_0 are the permittivity and permeability of free space and ε and μ are the corresponding quantities for a medium, then refractive index of the medium is
(A) 1
(B) $\sqrt{\frac{\mu_0\varepsilon_0}{\mu\varepsilon}}$
(C) Insufficient information
(D) $\sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}}$

11. **Assertion:** A portable AM radio set is kept horizontal to receive the signals properly.
Reason: Radio waves are polarised electromagnetic waves.
(A) Assertion is True, Reason is True; Reason is a correct explanation for Assertion.
(B) Assertion is True, Reason is True; Reason is not a correct explanation for Assertion.
(C) Assertion is True, Reason is False.
(D) Assertion is False, Reason is False.

12. If the permeability and permittivity of a material medium is 5×10^{-6} Tm/A and 17.7×10^{-12} C^2/Nm^2, then what will be the difference between frequency of violet light and red light in the medium if wavelength of violet light is 4.5×10^{-7} m and that of red light is 7.0×10^{-7} m?
(A) 0.2×10^{14} Hz (B) 0.42×10^{14} Hz
(C) 0.1×10^{14} Hz (D) 0.84×10^{14} Hz

13. Light with an energy flux of 16 W/cm^2 falls on a perfectly reflecting surface at normal incidence. If the surface has an area of 10 cm^2, what is the average force exerted on the surface during a 50 minute time span?
(A) 0.36×10^{-6} N (B) 0.72×10^{-6} N
(C) 10^{-6} N (D) 2×10^{-6} N

Numerical Value Type Questions

1. The average energy density of an electromagnetic wave with its magnetic field component $B = 2\pi \sin(\omega t - kx)$ will be nearly ________ $\times 10^7$ J/m^3. [Take $\pi = 3.14$]
[Ans: 1.57]

2. The dielectric constant of a medium is 4. If the magnetic permeability of the medium is same as that of free space, the speed of electromagnetic wave travelling in that medium is $a \times 10^{8}$ ms^{-1}. Find the value of a.

[Ans: 1.5]

3. For an e.m. wave propagating along X-axis, E_{max} = 30 V/m. The maximum value of magnetic field is of the order of 10^{n} T. What is the value of n?

[Ans: –7]

4. A small metallic ball is charged positively and negatively in a sinusoidal manner at a frequency of 1000 cps. The maximum charge on the ball is 2 μC. what is the displacement current due to this alternating current in mA? [Take π = 3.14]

[Ans: 12.56]

5. Radiations of intensity 1.8 W/m^{2} are striking a metal plate. The pressure on the plate is ________ $\times 10^{-8}$ N/m^{2}.

[Ans: 0.6]

Answers to MCQs

Concept Building Problems

7.1 :	1. (B)	2. (C)	3. (D)							
7.2 :	1. (D)	2. (B)	3. (B)	4. (C)	5. (B)	6. (C)				
7.3 :	1. (D)	2. (A)	3. (C)	4. (B)	5. (D)	6. (A)	7. (B)			
7.4 :	1. (B)	2. (C)	3. (C)	4. (D)	5. (B)	6. (B)				
Misc.:	1. (A)	2. (C)	3. (D)	4. (D)	5. (B)	6. (B)	7. (B)	8. (A)	9. (C)	10. (B)
	11. (C)	12. (B)	13. (D)							

Practice Problems

7.1 :	1. (C)	2. (C)	3. (C)	4. (D)	5. (D)					
7.2 :	1. (D)	2. (B)	3. (C)	4. (B)	5. (C)	6. (D)	7. (B)	8. (A)	9. (C)	
7.3 :	1. (C)	2. (C)	3. (C)	4. (B)						
7.4 :	1. (D)	2. (D)	3. (D)	4. (A)	5. (B)					
Misc.:	1. (C)	2. (D)	3. (D)	4. (C)	5. (A)	6. (D)	7. (B)	8. (C)	9. (C)	10. (D)
	11. (B)	12. (D)	13. (C)							

Hints to MCQs

Concept Building Problems

7.1 Need for Displacement Current and Origin of Electromagnetic Waves

1. 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 $\phi_E = \frac{Q}{\varepsilon_0 A}\frac{A}{2} = \frac{Q}{2\varepsilon_0}$

∴ The displacement current,

$$I_D = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0\left(\frac{1}{2\varepsilon_0}\right)\frac{dQ}{dt} = \frac{I}{2}.$$

2. $I_D = \frac{CdV}{dt} = 20 \times 10^{-6} \times 2.5 = 5 \times 10^{-5}$ A

$= 0.5$ μA

3. Capacitance of capacitor is,

$C = 20$ μF $= 20 \times 10^{-6}$ F

Rate of charging the capacitor $= \frac{dV}{dt} = 3$ V/s

Displacement current

$I_D = C\frac{dV}{dt} = 20 \times 10^{-6} \times 3 = 60 \times 10^{-6}$ A

$= 60$ μA

As conduction current and displacement current are always equal, $I_C = 60$ μA

7.2 Electromagnetic waves and their characteristics

2. Electromagnetic radiations have energy and exert pressure but different EM radiations have different momenta.

3. When an e.m. wave falls normally on a perfectly reflecting surface, it is reflected completely. Hence, momentum transferred to the surface = 2E/c

5. Electromagnetic waves are produced by accelerated charged particles.

6. The average energy density,

$$u_E = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\varepsilon_0\left(\frac{E_0}{\sqrt{2}}\right)^2$$

$$= \frac{1}{4}\varepsilon_0 E_0^2 = \frac{1}{4}\times 8.85\times10^{-12}\times(6)^2$$

$\therefore$ $u_E = 7.96 \times 10^{-11}$ J/m^3

7.3 Transverse nature of electromagnetic waves

1. In electromagnetic wave, the average value of electric field or magnetic field is zero.

2. Comparing with standard general equation, $E_y = E_0 \sin(kx - \omega t)$
Here, $k = 9 \times 10^7$ rad/m
(sign of k is not considered as speed of e.m. wave is to be determined)
and $\omega = 18 \times 10^{15}$ rad/s

$$v = \frac{\omega}{k} = \frac{18\times10^{15}}{9\times10^7} = 2 \times 10^8 \text{ m/s}$$

3. From given equation for magnetic field,
$B_0 = 3 \times 10^{-8}$ T
$\therefore$ $E_0 = B_0 c = 3 \times 10^{-8} \times 3 \times 10^8 = 9$ V/m
As, $\vec{B}$ and $\vec{E}$ are perpendicular to each other,
$\therefore$ $\vec{E} = \left[9\sin\left(1.6\times10^3 x + 48\times10^{10} t\right)\hat{k} \text{ V/m}\right]$

Thinking Hatke - Q.3

In electromagnetic wave, electric field is always perpendicular to the magnetic field. Therefore, for B_y the electric field will be in Z-direction. Also, $E_0 = cB_0$. Hence, the only correct option is (C).

4. Direction of propagation of an em wave is along $\vec{E}\times\vec{B}$.

Given: Wave velocity $(v\hat{i})$ i.e., $\vec{E}\times\vec{B}$ is along + x-axis, electric field is along + y-axis. This implies according to vector product rules, $\vec{B}$ is along + z-axis.

5. E = Bv

but $v = \dfrac{c}{\sqrt{\mu_r \varepsilon_r}}$

$$\therefore\quad E = \frac{Bc}{\sqrt{\mu_r \varepsilon_r}} = \frac{8.6\times10^{-8}\times3\times10^8}{\sqrt{4\times9}} = 4.3 \text{ V/m}$$

6. $E_1 = E_{01}\,\hat{x}\,\cos\left[2\pi\nu\left(\frac{z}{c}-t\right)\right]$

$E_2 = E_{02}\,\hat{x}\,\cos[k(2z - ct)]$

$= E_{02}\,\hat{x}\,\cos\left[\frac{2\pi}{\lambda}\times c\left(\frac{2z}{c}-t\right)\right] \quad \ldots\left(\because k = \frac{2\pi}{\lambda}\right)$

$= E_{02}\,\hat{x}\cos\,2\pi\nu\left(\frac{2z}{c}-t\right) \quad \ldots\left(\because \frac{c}{\lambda} = \nu\right)$

From above equation, we can say,
The velocity of EM waves in new medium is,

$v = \dfrac{c}{2}$

$\therefore$ $\dfrac{1}{\sqrt{\mu_0\varepsilon_2}} = \dfrac{1}{2}\times\dfrac{1}{\sqrt{\mu_0\varepsilon_1}}$

$\therefore$ $\sqrt{\dfrac{\varepsilon_1}{\varepsilon_2}} = \dfrac{1}{2}$

$\therefore$ $\dfrac{\varepsilon_1}{\varepsilon_2} = \dfrac{1}{4}$

Relative permittivity, $\varepsilon_r = \dfrac{\varepsilon}{\varepsilon_0}$

$\therefore$ $\dfrac{\varepsilon_{r_1}}{\varepsilon_{r_2}} = \dfrac{1}{4}$

7. $E_{rms} = \dfrac{E_0}{\sqrt{2}}$

But $E_0 = cB_0$

$\therefore$ $B_0 = \dfrac{\sqrt{2}E_{rms}}{c} = \dfrac{\sqrt{2}\times6}{3\times10^8} = 2.83 \times 10^{-8}$ T

7.4 Electromagnetic spectrum

1. All components of the electromagnetic spectrum travel in vacuum with velocity 3×10^8 m/s.

2. The penetrating power of X-rays depends upon its energy which in turn depends upon frequency.

4. Energy $\propto \nu$
$\nu_{Radio} < \nu_{yellow} < \nu_{blue} < \nu_{X\text{-rays}}$
$\therefore$ $E_{Radio} < E_{yellow} < E_{blue} < E_{X\text{-rays}}$
Hence, correct increasing order is D, B, A, C.

5.

Sources	Radiation emitted
X-ray tube	X-rays
Magnetron valve	Microwaves
Radioactive source	γ-rays
Sodium lamp	Visible light

As, $\lambda_{\gamma\text{-rays}} < \lambda_{X\text{-rays}} < \lambda_{visible} < \lambda_{microwave}$, the option sequencing radiation sources in increasing order of wavelength of waves produced by them is (B).

6. $\lambda = \frac{hc}{E} = \frac{6.6\times10^{-34}\times3\times10^{8}}{15\times10^{3}\times1.6\times10^{-19}} = 0.825$ Å

$\therefore$ $\lambda \approx 1$Å

This wavelength value belongs to X-ray region of the spectrum.

Miscellaneous

1. The displacement current I_D is given by,

$I_D = \varepsilon_0 \frac{d\phi}{dt}$ Where, ϕ is the electric flux.

For a parallel plate capacitor, $\phi = EA$

Where A is the area of the plate and E is the electric field between the plates. Now, $E = V/d$ where d is the distance between the plates.

Hence, $I_D = \varepsilon_0 \frac{d}{dt}(AE) = \varepsilon_0 A \frac{dE}{dt} = \frac{\varepsilon_0 A}{d}\frac{dV}{dt}$

Thus, I_D exists along as the potential difference V is changing with time t.

2. A dipole antenna radiates EM waves outwards. The amplitude of electric field vector is inversely proportional to distance from antenna (r) i.e., $E_0 \propto \frac{1}{r}$

4. A wave gets reflected from denser medium without any change in its form but with phase change of 180° or π^c. Incident wave is moving at $+\hat{i}$ hence reflected wave will move along $-\hat{i}$ with additional phase difference of π^c.

$\therefore$ Equation of reflected wave

$\vec{E}_r = E_0\left(-\hat{i}\right)\cos[k(-z) - \omega t + \pi]$

$= E_0\left(-\hat{i}\right)\cos\left[\pi - (kz + \omega t)\right]$

$= E_0\left(-\hat{i}\right)\left[-\cos(kz + \omega t)\right]$

$[\because \cos(\pi - \theta) = -\cos\theta]$

$\therefore$ $\vec{E}_r = E_0\,\hat{i}\cos(kz + \omega t)$

5. $I_D = I_C = C\frac{dV}{dt} = \frac{\varepsilon_0 A}{d}\frac{dV}{dt} = \frac{\varepsilon_0}{d}A\frac{dV}{dt}$

Here $A = \pi \times (0.2)^2$ m^2 and $d = 4 \times 10^{-3}$ m

$\frac{dV}{dt} = \frac{4\times10^{-3}\times0.6}{8.85\times10^{-12}\times3.14\times4\times10^{-2}}$

$= 2.16 \times 10^9 \frac{V}{s}$

6. $I_D = \frac{d}{dt}(q_0 \sin \omega t) = q_0\,\omega \cos \omega t$

Maximum displacement current,

$(I_D)_{max} = q_0\,\omega = q_0 \times 2\pi\nu$

$= 8 \times 10^{-6} \times 2 \times 3.14 \times 2 \times 10^6$

≈ 100 A

7. For R-C series circuit,

$Z = \sqrt{R^2 + X_C^2} = \sqrt{(100)^2 + (100)^2} = 100\sqrt{2}\ \Omega$

Peak value of displacement current,

$i_0 = \frac{V_0}{Z} = \frac{V_{rms}\sqrt{2}}{Z} = \frac{220\sqrt{2}}{100\sqrt{2}} = 2.2$ A

8. Field intensity $E = \frac{U}{At} = \frac{Power}{A}$

$\therefore$ $E \propto$ Power (P)

$\therefore$ $\frac{E_2}{E_1} = \frac{P_2}{P_1} = \frac{50}{100}$

$\therefore$ $E_2 = \frac{1}{2}E_1 = \frac{E}{2}$

9. F_{av} = Rate of change of momentum.

Total momentum transferred $= \frac{2U}{c}$

$F_{av} = \frac{2U/c}{t}$

For unit time,

$F_{av} = \frac{2(S\times A)}{c} = \frac{2\times50\times10^4\times20\times10^{-4}}{3\times10^8}$

$= 6.67 \times 10^{-6}$ N

10. Intensity $I = \frac{Power}{Area} = \frac{P}{4\pi r^2}$

Also, $I = U_{av}c$

$\therefore$ $\frac{P}{4\pi r^2} = \frac{1}{2}\varepsilon_0 E_0^2 \times c$

$\therefore$ $E_0 = \sqrt{\frac{2P}{4\pi\varepsilon_0 r^2 c}}$

$= \sqrt{\frac{2\times0.1\times9\times10^9}{1^2\times3\times10^8}}$ .... $\left(\because \frac{1}{4\pi\varepsilon_0} = 9\times10^9 \text{ S.I. units}\right)$

$= \sqrt{6} = 2.45$ V/m

11. $E = h\nu$, $E = 11$eV $= 11 \times 1.6 \times 10^{-19}$ J

$\therefore$ $\nu = \frac{E}{h} = \frac{11\times1.6\times10^{-19}}{6.62\times10^{-34}} = 2.65 \times 10^{15}$ Hz

This frequency value belongs to UV region.

12. Total energy falling on surface $U = \phi At$

Where, energy flux $\phi = 20$ W/cm^2,

area $A = 30$ cm^2, time $t = 30 \times 60$ s

Momentum of incident light

$p_i = \frac{U}{c} = \frac{20\times30\times30\times60}{3\times10^8} = 36 \times 10^{-4}$ kg

The surface is a non reflective surface

$\therefore$ Momentum of reflected light $p_f = 0$

$\therefore$ Momentum delivered to surface

$= p_i - p_f = 36 \times 10^{-4}$ kg m/s

13. $I_D = \varepsilon_0 \dfrac{d\phi}{dt}$

$(2t^2 + 6) = \varepsilon_0 \dfrac{d\phi}{dt}$

$d\phi = \dfrac{1}{\varepsilon_0}(2t^2 + 6)\,dt$

∴ Net changes in flux is given by

$$\int_0^{\phi} d\phi = \frac{1}{\varepsilon_0}\int_2^4 \left(2t^2+6\right)dt$$

$$\phi = \frac{1}{\varepsilon_0}\left(\frac{2t^3}{3}+6t\right)_2^4$$

$$\phi = \frac{1}{\varepsilon_0}\left\{\left[\frac{\left(2\times4^3\right)}{3}+6(4)\right]-\left[\frac{\left(2\times2^3\right)}{3}+6(2)\right]\right\}$$

$$\phi = \frac{1}{\varepsilon_0}(66.67 - 17.33) = \frac{49.34}{\varepsilon_0} \text{ S.I. units}$$

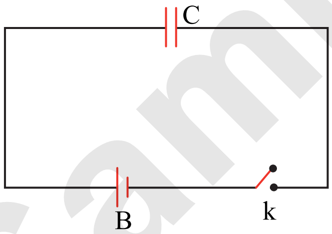
Practice Problems

7.1 Need for Displacement Current and Origin of Electromagnetic Waves

1. In electromagnetic wave, change in electric field gives displacement current.

$I_D = \varepsilon_0 \dfrac{d\phi_E}{dt}$

2. Displacement current arises when electric flux is varying with time. But Ampere's circuital law is time independent and cannot account for displacement current.

3. 

When key is pressed, conduction current (I_C) flows through connecting wires and capacitor starts storing charge.
As the charge on capacitor grows, conduction current in the wires decreases.
When capacitor is charged fully, conduction current between plates of capacitor becomes zero.

4. $v = \dfrac{c}{\sqrt{\mu_r \varepsilon_r}} = \dfrac{3\times10^8}{\sqrt{1.3\times2.14}} \approx 1.8 \times 10^8$ m/s

5. $v = \dfrac{E}{B} \Rightarrow B = \dfrac{2\times10^4}{40} = 500$ Wb/m^2

7.2 Electromagnetic Waves and Their Characteristics

1. The representation describes linearly polarised electromagnetic wave propagating in X-direction with oscillating electric field $\vec{E}$ and magnetic field $\vec{B}$ along Z-direction and Y-direction respectively.

2. Photon is the fundamental particle in an EM wave.

3. Your hand gets warm due to absorption of energy from e.m. waves only. Due to large value of 'c', amount of momentum transfer and radiation pressure transfer is extremely small.

4. EM waves carry momentum and hence can exert pressure on surfaces. They also transfer energy to the surface so, $p \neq 0$ and $E \neq 0$.

5. The electric vector of an e.m. wave is responsible for optical effects. Hence, it is called as light vector.

6. The frequency of e.m. wave is its inherent characteristic.

7. Velocity of e.m. waves does not depend on amplitude of field vectors. Hence, formula (i) is incorrect.

Formula (iii) is incorrect as $v = \dfrac{c}{\sqrt{\mu_r \varepsilon_r}}$

Formula (iv) is incorrect, the correct formula is, $\vec{S} = \vec{E} \times \vec{H}$

Formula (ii) relates velocity to permittivity (ε) and permeability (μ) of medium which are measures of electric and magnetic properties of medium respectively.

8. $c = \dfrac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8$ ms^{-1}

Also,

$v = \dfrac{1}{\sqrt{\mu_0 k \varepsilon_0}} = \dfrac{c}{\sqrt{1.006}} \approx 3 \times 10^8$ ms^{-1}

∴ n = 3

9. Average energy density due to electric field

$u_E = \dfrac{1}{2}\varepsilon_0 E^2$ where, E is rms value

∴ $u_E = \dfrac{1}{2} \times 8.85 \times 10^{-12} \times (430)^2$

$= 8.18 \times 10^{-7}$ J/m^3

Total average energy density is,

$U = 2u_E = 2 \times 8.18 \times 10^{-7} = 1.64 \times 10^{-6}$ J/m^3

7.3 Transverse Nature of Electromagnetic Waves

3. $\lambda = \frac{c}{\nu} = \frac{3\times10^8}{6\times10^{10}} = 0.5 \times 10^{-2}$ m

$E_0 = cB_0 = 3 \times 10^8 \times 140 \times 10^{-9} = 42$ V m^{-1}

Thinking Hatke - Q.3

As, values of amplitude of electric field are different in all the given options, it is sufficient to calculate the amplitude of electric field (E_0) alone to get the final correct answer i.e., (C).

4. Here, $B_y = 18 \times 10^{-6} \sin[21 \times 10^{11}\, t + 450\, \pi x]$

The Y-component of the magnetic field is given by, $B_y = B_0 \sin 2\pi\left(\frac{x}{\lambda}+\frac{t}{T}\right)$

Comparing the given equation with the above equation,

$\frac{2\pi}{\lambda} = 450\,\pi$

$\therefore \quad \lambda = \frac{2}{450} = 4.44 \times 10^{-3}$ m

7.4 Electromagnetic Spectrum

2. Infrared rays produce heat, when they fall on matter and hence they can be detected by a pyrometer.

4. X-rays being of high energy radiations, penetrate the target and hence are not reflected back.

Miscellaneous

1. Ampere's law is logically inconsistent when applied to an electrical circuit containing a capacitor. For such circuits modified Ampere's circuital law is applied.

3. Human eyes and brain can distinguish colours made up of mixing of multiple wavelengths such as pink or magenta (which are absent in visible spectrum). Such colours are called unsaturated colours.

4. $eV = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{eV}$ i.e., $\lambda \propto \frac{1}{V}$

6. Cathode rays are highly energetic beam of electrons while cosmic rays are high energy charged particles. As cathode rays or cosmic rays do not travel with velocity 'c' (3×10^8 m/s) in vacuum, they are not categorised as e.m. waves.

7. Hydrogen atom is monovalent, i.e. it contains only one electron in ground state. For emission of X-rays, electron should jump from higher energy level to lower energy level. Hence, even if hydrogen atom gets exited, it is impossible for it to emit X-rays.

8. Infrared waves are termed as heat waves. After absorption they heat up body tissues causing pain relief.

9. The speed of electromagnetic waves in a medium is given by,

$v = \frac{c}{\sqrt{\mu_r\varepsilon_r}}$

$\therefore \quad \varepsilon_r = \frac{c^2}{v^2\,\mu_r} = \frac{(3\times10^8)^2}{(2\times10^8)^2\times1} = 2.25$

10. We know,

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

$\therefore \quad v = \frac{1}{\sqrt{\mu\varepsilon}}$ where μ and ε are permittivity and permeability of the medium.

Refractive index of medium $\mu_m = \frac{c}{v} = \sqrt{\frac{\mu\varepsilon}{\mu_0\varepsilon_0}}$

11. The radio waves are polarised electromagnetic waves. The antenna of portable AM radio is sensitive to only magnetic components of electromagnetic waves. Hence, the set should be put horizontal and in proper position so that the signals are received properly from radio station.

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

$v = \frac{1}{\sqrt{5\times10^{-6}\times17.7\times10^{-12}}} = 1.06 \times 10^8$ m/s

For violet light,

$v = \nu_v\, \lambda_v$

$\nu_v = \frac{1.06\times10^8}{4.5\times10^{-7}} = 2.35 \times 10^{14}$ Hz

For red light

$v = \nu_r\, \lambda_r$

$\nu_r = \frac{1.06\times10^8}{7\times10^{-7}} = 1.51 \times 10^{14}$ Hz

$\nu_v - \nu_r = (2.35 \times 10^{14}) - (1.51 \times 10^{14})$

$= 0.84 \times 10^{14}$ Hz

13. The total energy falling on the surface is

U = Energy falling per unit area × area × time

$= 16 \times 10 \times (50 \times 60)$

$= 4.8 \times 10^5$ J

Therefore, the total momentum delivered for complete reflection is

$p = \frac{2U}{c} = \frac{2\times4.8\times10^5}{3\times10^8} = 3.2 \times 10^{-3}$ kg m/s

The average force exerted on the surface is

$F = \frac{p}{t} = \frac{3.2\times10^{-3}}{50\times60} = 1.07 \times 10^{-6}$ N

Numerical Value Type Questions

1. Average energy density of e.m wave,

$u_B = \frac{1}{2}\frac{B_0^2}{\mu_0}$

$= \frac{1}{2} \times \frac{(2\pi)^2}{4\pi \times 10^{-7}}$

$= 1.57 \times 10^7$ J/m^3

2. $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8$ m/s

Also,

$v = \frac{1}{\sqrt{\mu_0 k \varepsilon_0}} = \frac{c}{\sqrt{k}} = \frac{3\times10^8}{\sqrt{4}} = 1.5 \times 10^8$ ms^{-1}

$\therefore$ a = 1.5

3. $B_0 = \frac{E_0}{c} = \frac{30}{3\times10^8} = 10^{-7}$ T

4. Charge oscillating sinusoidally is given by

$Q = q_0 \sin \omega t$

Displacement current,

$I_D = \frac{dq}{dt} = q_0\, \omega \cos \omega t$

$(I_D)_{max} = q_0\, \omega = q_0 \times 2\pi\nu$

$= 2 \times 10^{-6} \times 2 \times 3.14 \times 10^3$

$= 12.56$ mA

5. The pressure exerted is given as,

Pressure (P) $= \frac{I}{c} = \frac{1.8}{3\times10^8} = 0.6\times10^{-8}\ \frac{N}{m^2}$

Problems To Ponder

1. Do a comparative study between conduction current and displacement current.

Ans: Total current in a general medium is a result of contribution of conduction current (I_C) and displacement current (I_D).

In a conducting medium, conduction current dominates displacement current, while in an insulating medium displacement current dominates conduction current.

Together they offer continuity of current along any closed path, though individually they may not be continuous.

Both possess same units (ampere) and dimensions [$M^0L^0T^0I^1$]. Both have same physical effects.

Conduction current exists even in uniform electric field while variation in electric flux with respect to time is essential condition for production of displacement current.

The discovery of displacement current indicates a symmetry between laws of electricity and magnetism.

2. Does entire electromagnetic spectrum of waves entering the atmosphere of earth from space, reach the surface of the earth? Comment.

Ans: The earth is enveloped by layer of gases, i.e., atmosphere. The atmosphere absorbs certain wavelengths of electromagnetic spectrum coming from the space.

Most of the UV-rays, X-rays and γ-rays which possess wavelengths shorter than visible light as well as long wavelength radio waves and infrared rays do not reach the surface of the earth.

The portion of e.m. spectrum which is not absorbed by atmosphere mostly consists of visible light, near infrared rays and partially radio waves. These wavelength ranges are called atmospheric windows.

Ground-based astronomical observations require optical and radio telescope that function considering the atmospheric windows.

As atmospheric windows are closed for infrared rays, X-rays and γ-rays, these e.m. waves can be observed with the help of astronomical satellites orbiting outside the earth's atmosphere.

Also, high energy X-rays and γ-rays have potential to damage cellular structure of organisms. By absorbing them, atmosphere protects the life on the earth.

3. Discuss the statement: X-rays cannot be focused on a single point.

Ans: Visible light is focused usually by using glass lenses or mirrors.

As the light passes through glass, light slows down by 1.5 times its speed in vacuum, i.e., glass has a refractive index 1.5 for visible light.

For X-rays, refractive index of all materials is typically 1.000005.

Since it is very close to 1, X-rays tend to initially penetrate and eventually get absorbed in most materials without significant change in their directions.

Hence, X-rays cannot be focused on a single point using lenses.

But using different techniques such as grazing incidence mirrors and collimated apertures X-rays can be redirected.

It should be noted though, this change in direction is of minute nature.

MEMORY MAP

ELECTROMAGNETIC WAVES

*Scan the adjacent **Q.R. Code** for a chapter revision video.*

Important terms

1. **Displacement current:** The current which comes into play in the region, where electric field (and hence the electric flux) is changing with time is known as displacement current.
   i. $I_D = \varepsilon_0 \frac{d\phi_E}{dt}$
   ii. $I_D = \frac{CdV}{dt}$
2. **Conduction current:** The current in the electric field which arises due to the flow of electrons in the connecting wires of the circuit, in a definite closed path.
3. **Ampere-Maxwell's law:** Line integral of magnetic field ($\vec{B}$) over a closed path in vacuum is equal to μ_0 times the sum of the conduction current (I) and displacement current (I_D).
   $\oint \vec{B}\cdot\vec{dl} = \mu_0\left(I + \varepsilon_0 \frac{d\phi_E}{dt}\right)$

Speed of electromagnetic waves

1. **Equation of electromagnetic waves:**
   i. $E(y) = E_0 \sin\omega\left(t - \frac{x}{c}\right)$ ii. $B(z) = B_0 \sin\omega\left(t - \frac{x}{c}\right)$
2. **Speed of electromagnetic waves in free space:**
   $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = \frac{E_0}{B_0}$ where ε_0 = Absolute Permittivity of free space, μ_0 = Absolute Permeability of free space
3. **Velocity of electromagnetic waves in material medium:** $v = \frac{1}{\sqrt{\mu\varepsilon}}$

Maxwell's equations

1. **Maxwell's first equation:** $\oint \vec{E}\cdot\vec{ds} = \frac{q}{\varepsilon_0}$
2. **Maxwell's second equation:** $\oint \vec{B}\cdot\vec{ds} = 0$
3. **Maxwell's third equation:** $\oint \vec{E}\cdot\vec{dl} = -\frac{d}{dt}\int_s \vec{B}\cdot\vec{ds}$
4. **Maxwell's fourth equation:** $\oint \vec{B}\cdot\vec{dl} = \mu_0\left(I_C + \varepsilon_0 \frac{d\phi_E}{dt}\right)$

Characteristics of Electromagnetic waves

1. **Refractive index:** $n = \frac{c}{v} = \sqrt{\mu_r\varepsilon_r}$
2. **Average electric energy density:** $u_E = \frac{1}{2}\varepsilon_0 E_{rms}^2$ (where $E_{rms} = \frac{E_0}{\sqrt{2}}$)
3. **Average magnetic energy density:** $u_B = \frac{1}{2}\frac{B_{rms}^2}{\mu_0}$ (Where $B_{rms} = \frac{B_0}{\sqrt{2}}$)
4. **Energy transported:** $\vec{S} = \vec{E}\times\vec{H} = \frac{1}{\mu_0}\vec{E}\times\vec{B}$
5. **Momentum transported:** $p = \frac{U}{c} = \frac{S\times A}{c}$ (U = Energy transported by electromagnetic waves. A = Area of cross-section of surface)
6. **Intensity:** $I = \frac{1}{2}\varepsilon_0 E_0^2 c = \frac{1}{2}\frac{B_0^2}{\mu_0}c$
7. **Pressure:** $P = \frac{I}{c}$

Transverse nature

1. EM Waves are produced by accelerated electric charges.
2. Both electric and magnetic fields oscillate in same phase with same frequency but are mutually perpendicular
3. Propagation of electromagnetic field is in the direction of $\vec{E}\times\vec{B}$.
4. EM Waves are transverse in nature

Electromagnetic Spectrum

1. **Radio Waves:** i. Wavelength ≈ > 10 m. ii. Produced by accelerated motion of charges in conducting wires. iii. Used in radio and television communication systems.
2. **Microwaves:** i. Wavelength ≈ 1mm to 10m. ii. Produced by special vacuum tubes (called klystrons, magnetrons and Gunn diodes). iii. Used in radar systems in aircraft navigation. iv. In microwave ovens, frequency of microwaves is selected to match resonant frequency of water molecules for efficient energy transfer which raises the temperature of any food containing water.
3. **Infrared waves:** i. Wavelength ≈ 800nm to 1mm. ii. Produced by hot bodies and molecules. iii. Infrared lamps are used in physical therapy. iv. Helps in maintaining earth's average temperature through the greenhouse effect. v. Infrared detectors are used in Earth satellites, both for military purposes and to observe growth of crops. vi. Electronic devices emit infrared and are used in the remote switches of household electronic systems.
4. **Visible Light:** i. Wavelength ≈ 400 nm to 800 nm. ii. Can be detected by the human eye.
5. **Ultraviolet rays:** i. Wavelength ≈ 10 nm to 400 nm. ii. Produced by special lamps and very hot bodies, especially the sun. iii. Exposure induces production of more melanin, causing tanning of the skin. iv. Absorbed by ordinary glass. v. Due to its shorter wavelengths, it can be focused into very narrow beams for high precision applications such as LASIK *eye surgery*. vi. UV lamps are used to kill germs in water purifiers.
6. **X Rays:** i. Wavelength ≈ 0.1 nm to 10 nm. ii. Produced by bombarding a metal target by high energy electrons. iii. Used as a diagnostic tool in medicine and as a treatment for certain forms of cancer. iv. Because X-rays damage or destroy living tissues and organisms, care must be taken to avoid unnecessary or over exposure.
7. **Gamma rays:** i. Wavelength ≈ < 0.01 nm. ii. Produced in nuclear reactions and also emitted by radioactive nuclei. iii. Used in medicine to destroy cancer cells.