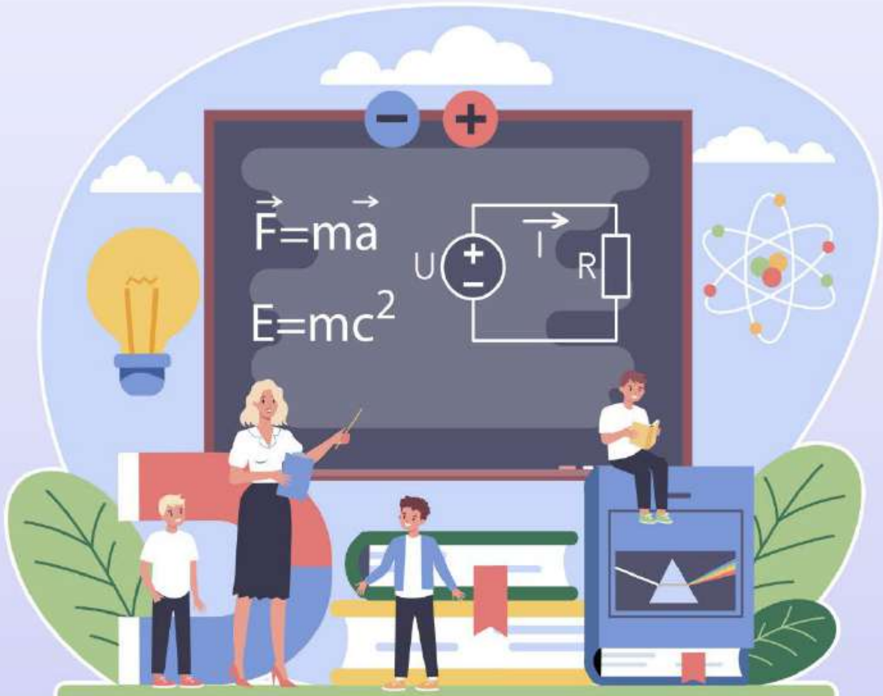
भौतिकी
Physics

कक्षा / Class XII
2026-27

विद्यार्थी सहायक सामग्री
Student Support Material



केन्द्रीय विद्यालय संगठन~Kendriya Vidyalaya Sangathan

विकास गुप्ता, भा.प्र.से.
आयुक्त
Vikas Gupta, IAS
Commissioner

तत् त्वं पूषन् अपावृणु
केन्द्रीय विद्यालय संगठन

केन्द्रीय विद्यालय संगठन
18, संस्थागत क्षेत्र, शहीद जीत सिंह मार्ग, नई दिल्ली-110016
Kendriya Vidyalaya Sangathan
18, Institutional Area, Shaheed Jeet Singh Marg, New Delhi-110016

संदेश

शिक्षा केवल पुस्तकों तक सीमित ज्ञान नहीं है; यह स्वयं को पहचानने, अपने विचारों को विस्तार देने और जीवन की चुनौतियों का आत्मविश्वास से सामना करने की सतत् यात्रा है। केन्द्रीय विद्यालय संगठन का सदैव यह प्रयास रहा है कि प्रत्येक विद्यार्थी के लिए ऐसा शिक्षण वातावरण हो, जहाँ जिज्ञासा को प्रोत्साहन मिले, सीखना आनंददायी बने और प्रत्येक बालक अपनी अंतर्निहित क्षमताओं को पहचानकर उन्हें विकसित कर सके।

राष्ट्रीय शिक्षा नीति 2020 ने शिक्षा को सिर्फ रटने से समझने, सूचना से ज्ञान और ज्ञान से जीवनोपयोगी दक्षताओं की ओर अग्रसर किया है। आज का समय कृत्रिम बुद्धिमत्ता (Artificial Intelligence – AI), डिजिटल नवाचार और निरंतर बदलती तकनीकों का है। ऐसे युग में केवल तथ्यों का ज्ञान पर्याप्त नहीं है; आवश्यक है कि विद्यार्थी मनन- चिंतन करना सीखें, प्रश्न पूछें, समस्याओं का समाधान खोजें और नए विचारों के साथ आगे बढ़ें। यही क्षमताएँ उन्हें भविष्य के लिए तैयार करेंगी।

इन्हीं उद्देश्यों को ध्यान में रखते हुए केन्द्रीय विद्यालय संगठन के पाँचों आंचलिक शिक्षा एवं प्रशिक्षण संस्थानों (ZIETs) के माध्यम से, समर्पित एवं अनुभवी शिक्षकों द्वारा कक्षा 9 से 12 के विद्यार्थियों के लिए यह विद्यार्थी सहायक सामग्री तैयार की गई है। यह केवल परीक्षा की तैयारी की संकलन सामग्री नहीं है, बल्कि विषयों को सरलता से समझने, अवधारणाओं को स्पष्ट करने, नियमित अभ्यास करने और आत्मविश्वास के साथ आगे बढ़ने का एक विश्वसनीय साथी है।

इस सामग्री में विषय-वस्तु को विद्यार्थियों की आवश्यकताओं के अनुरूप सरल, व्यवस्थित एवं दक्षता-आधारित दृष्टिकोण से प्रस्तुत किया गया है। मुझे प्रसन्नता है कि इसे हमारे शिक्षकों के अनुभव, नवाचार और विद्यार्थियों के प्रति उनकी प्रतिबद्धता ने समृद्ध बनाया है। मुझे विश्वास है कि यह सामग्री विद्यार्थियों की सीखने की यात्रा को अधिक सहज, रोचक और प्रभावी बनाएगी तथा उन्हें बोर्ड परीक्षाओं के साथ-साथ जीवन की व्यापक चुनौतियों के लिए भी तैयार करेगी।

मेरा विश्वास है कि जब एक जिज्ञासु विद्यार्थी, प्रेरित शिक्षक और सार्थक शिक्षण संसाधन एक साथ आते हैं, तब शिक्षा केवल उपलब्धि का माध्यम नहीं रहती, बल्कि व्यक्तित्व निर्माण की एक सशक्त प्रक्रिया बन जाती है। यही भावना इस विद्यार्थी सहायक सामग्री के केंद्र में है।

मेरी हार्दिक शुभकामनाएँ हैं कि आप सभी सीखने की इस यात्रा में निरंतर आगे बढ़ें, अपने सपनों को नए आयाम दें और ज्ञान, संवेदनशीलता तथा नवाचार के साथ राष्ट्र निर्माण में अपना महत्वपूर्ण योगदान दें।

शुभकामनाओं सहित।

(विकास गुप्ता)

PATRON
SH. VIKAS GUPTA, IAS
COMMISSIONER, KVS

CO-PATRON
MS. CHANDANA MANDAL
ADDITIONAL COMMISSIONER (ACAD.), KVS (HQ)

COORDINATOR
Ms. P B S USHA
JOINT COMMISSIONER (TRAINING), KVS (HQ)

COVER DESIGN
KVS PUBLICATION SECTION

EDITOR
MR. P I T RAJA
DIRECTOR, ZIET MYSURU

ZIET COORDINATOR
SHRI DINESH KUMAR
TA(PHYSICS)

CONTENT CREATOR

S NO.	NAME OF TEACHER	DESIGNATION	NAME OF KV	REGION
1	MR. LOKESH KURCHANIYA	PGT PHYSICS	PM SHRI KV NO. 3 JHANSI	AGRA
2	MR AZAD SARKAR	PGT PHYSICS	PM SHRI KV IIT INDORE	BHOPAL
3	MR VINKUL PARKASH	PGT PHYSICS	PM SHRI KV ABOHAR	CHANDIGARH
4	MR. NAVEEN PANT	PGT PHYSICS	KENDRIYA VIDYALAYA BHEL HARIDWAR	DEHRADUN
5	MR. VIKAS MONAKAR	PGT PHYSICS	PM SHRI KV IMA DEHRADUN	DEHRADUN
6	MR. SYAM T S	PGT PHYSICS	PM SHRI KV RAMAVARMAPURAM	ERNAKULAM
7	MR SIVADAS	PGT PHYSICS	PM SHRI KV KANJIKODE	ERNAKULAM
8	MR RANDHEER VANNERY	PGT PHYSICS	PMSHRI K V NO.1 PALAKKAD	ERNAKULAM
9	MR. SAJI R	PGT PHYSICS	PM SHRI KV ADOOR (S-1)	ERNAKULAM
10	MR. PRASANTH KUMAR M	PGT PHYSICS	PM SHRI KV PAYYANUR	ERNAKULAM
11	MR KARAN KINDRA	PGT PHYSICS	PM SHRI KV GC CRPF PINJORE	GURUGRAM
12	MS. SUVIDHA	PGT PHYSICS	PM SHRI KV JAKHOO HILLS, SHIMLA	GURUGRAM
13	MR. NARESH KUMAR	PGT PHYSICS	PM SHRI KV WARANGAL	HYDERABAD
14	MS ALIVELUMANGA BAI	PGT PHYSICS	PM SHRI KV NELLORE	HYDERABAD
15	MR. MANTRAVADI SRIRAM	PGT PHYSICS	PM SHRI KV NO. 2 NAUSENABAUGH	HYDERABAD
16	MS. SWEETY UJJAWAL	PGT PHYSICS	PM SHRI KV NO. 1 GCF JABALPUR	JABALPUR
17	MS. MONIKA GAURI	PGT PHYSICS	PM SHRI KV SUNJUWAN	JAMMU
18	MR. RAMESH CHAUDHARY	PGT PHYSICS	KV CURAJ BANDARSINDRI	JAIPUR

About the Student Support Material

The Student Support Material (SSM) for Class XII Physics has been developed for the academic session 2026–27 under the guidance of Kendriya Vidyalaya Sangathan (KVS), Headquarters, New Delhi. The responsibility for preparing this material was entrusted to the KVS Zonal Institute of Education and Training (ZIET), Mysuru.

To ensure quality, accuracy, and student-friendly presentation, ZIET Mysuru collaborated with experienced Physics teachers from various Kendriya Vidyalayas across different regions. Their collective expertise has helped in developing a comprehensive, well-structured, and examination-oriented resource for learners.

The SSM has been prepared in accordance with the latest CBSE curriculum and assessment framework, the National Education Policy (NEP) 2020, Competency-Based Education (CBE) principles, and NCERT learning outcomes. It aims to strengthen conceptual understanding, scientific reasoning, problem-solving skills, and the application of Physics in real-life situations.

The material has been organized systematically to make learning engaging and effective. Each chapter generally includes:

- Infographics
- Important Definitions, Laws, and Formulae
- Solved Numerical Problems
- Multiple Choice Questions (MCQs)
- Assertion-Reason and Case-Based Questions
- Competency-Based Questions
- Short and Long Answer Questions
- Practice Exercises and Revision Material

Special Features

✓ Simple and student-friendly language

✓ Emphasis on conceptual clarity and scientific thinking

✓ Step-by-step solutions to numerical problems

✓ Real-life applications of Physics concepts

✓ Competency-based and examination-oriented questions

✓ Logical and systematic presentation of content

This Student Support Material serves as both a study guide and a learning companion. It encourages inquiry, critical thinking, and independent learning while helping students prepare effectively for classroom assessments and examinations. Regular use of this material will help learners develop confidence, strengthen their conceptual foundations, and achieve academic success in Physics.

We hope that this collaborative effort by KVS ZIET Mysuru and participating Physics teachers will significantly benefit students and contribute to their academic growth and scientific temper.

How to Use this Student Support Material (SSM)

Welcome to the Student Support Material for Class XII Physics. This resource has been carefully designed to help you understand fundamental concepts, strengthen problem-solving skills, and prepare effectively for school examinations and future competitive pursuits.

Best Practices for Effective Learning

To make the most of this material, follow the steps given below:

• **Build Conceptual Understanding**: Begin by reading the concept notes thoroughly and focus on understanding the physical principles rather than memorizing facts and formulae.

• **Learn Key Definitions**, Laws, and Formulae: Familiarize yourself with important terms, laws, principles, and mathematical relationships presented in each chapter.

• **Practice Numerical Problems**: Solve the worked-out examples and numerical questions regularly to develop accuracy, logical thinking, and confidence in problem-solving.

• **Strengthen Analytical Skills**: Attempt competency-based, application-oriented, and case-study questions to connect Physics concepts with real-life situations.

• **Revise Systematically**: Use concept maps, infographics, and chapter summaries for quick revision and reinforcement of learning.

• **Evaluate Your Understanding**: Solve MCQs, short-answer, and long-answer questions to assess your preparation and identify areas requiring further attention.

• **Discuss and Explore:** Engage in discussions with teachers and classmates to clarify doubts and deepen your understanding of concepts.

Versatile Usage

This SSM can be effectively used for:

• Daily Classroom Learning and Homework

• Unit Tests and Periodic Assessments

• Half-Yearly and Annual Examinations

• Revision and Self-Assessment

• Strengthening Foundations for Higher Studies

Regular and sincere use of this material will help you develop conceptual clarity, scientific reasoning, problem-solving abilities, and confidence in Physics. Most importantly, it will encourage you to view Physics not merely as a subject but as a way of understanding the world around you.

Happy Learning and Best Wishes for Your Success!

CHAPTER1:

Electric charge is a fundamental propepty of matter.

ELECTRIC CHARGES AND FIELD

CLASS XII PHYSICS – CONCEPT MAP

CHAPTER AT A GLANCE
- Electric charge
- Coulomb's law
- Electric field
- Electric field lines
- Electric flux & Gauss's law
- Conductors
- Applications

1 NATURE OF ELECTRIC CHARGE

TWO TYPES OF CHARGE

Positive (+) Negative (–)

Like charges repel, unlike charges attract.

ADDITIVITY OF CHARGE

Net charge of a system is the algebraic sum of all individual charges.

CHARGE IS CONSERVED

In an isolated system, total charge remains constant.

CHARGE IS QUANTISED

Charge occurs in integral multiples of e.

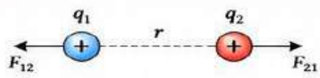
$q = ne$

$e = 1.6 \times 10^{-19}$ C

INVARIANCE OF CHARGE

Charge is invariant under change of frame of reference.

2 COULOMB'S LAW



- The electrostatic force between two point charges is directly proportional to the product of charges and inversely proportional to the square of the distance between them.
- Force acts along the line joining the charges.

$$F_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Where,
ε_0 = 8.854 × 10^{-12} $C^2 N^{-1} m^{-2}$ (Permittivity of free space)
$\hat{r}_{12}$ = unit vector from $q_1 \to q_2$

KEY POINTS
- ✓ $F \propto q_1 q_2$
- ✓ $F \propto \frac{1}{r^2}$
- ✓ Force is equal and opposite on both charges.

3 ELECTRIC FIELD

ELECTRIC FIELD INTENSITY ($\vec{E}$)

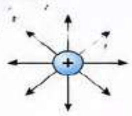
Electric field at a point is the force experienced per unit positive test charge placed at that point.

$$\vec{E} = \frac{\vec{F}}{q_0}$$ SI unit : N/C

FIELD DUE TO A POINT CHARGE

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

(radially outward for +q and inward for –q)



FIELD DUE TO A SYSTEM OF CHARGES

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots$$

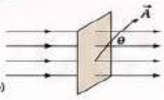
(Principle of superposition)

ELECTRIC FIELD LINES
- Originate from + charge and terminate at – charge (or at infinity).
- Tangent at any point gives direction of $\vec{E}$.
- Do not intersect.
- Closer lines ⇒ stronger field.

4 ELECTRIC FLUX

Electric flux through a surface is the measure of the number of electric field lines passing through it.

$$\Phi_E = \vec{E}\cdot\vec{A} = EA\cos\theta$$



Where,
- $\vec{A}$ = Area vector (perpendicular to surface)
- θ = Angle between $\vec{E}$ and $\vec{A}$

FLUX DEPENDS ON
- ✓ Magnitude of $\vec{E}$
- ✓ Area of surface (A)
- ✓ Orientation (θ)

SPECIAL CASES

$\theta = 0°$ (Maximum flux)	$\theta = 90°$ (Zero flux)	Arbitrary θ
$\Phi_E = EA$	$\Phi_E = 0$	$\Phi_E = EA\cos\theta$

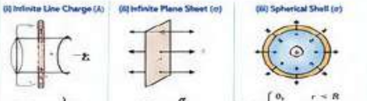
5 GAUSS'S LAW

The total electric flux through any closed surface is equal to $\frac{1}{\varepsilon_0}$ times the total charge enclosed.

$$\oint \vec{E}\cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$$

MEANING
- Electric flux through a closed surface depends only on the charge enclosed, not on the shape or size of the surface.

APPLICATIONS (for symmetric charge distributions)



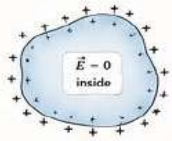
(i) Infinite Line Charge (λ): $E = \frac{\lambda}{2\pi\varepsilon_0 r}$ (radially outward)

(ii) Infinite Plane Sheet (σ): $E = \frac{\sigma}{2\varepsilon_0}$ (perpendicular to sheet)

(iii) Spherical Shell (σ): $E = \begin{cases} 0, & r < R \\ \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}, & r > R \end{cases}$ (R = radius, Q = total charge)

6 CONDUCTORS

IN ELECTROSTATIC EQUILIBRIUM
- ✓ $\vec{E} = 0$ inside the conductor
- ✓ Potential is constant throughout the conductor
- ✓ Excess charge resides on the outer surface
- ✓ Surface of a conductor is an equipotential
- ✓ Electric field just outside surface is perpendicular to the surface



CHARGE RESIDES ON SURFACE

Charge resides on the surface in such a way that there is no electric field inside.

CHARGE DENSITY (σ)

Charge per unit area on the surface.

Higher at sharp points.

7 APPLICATIONS OF ELECTRIC FIELD

Electrostatic Precipitators	Photocopiers	Lightning	Van de Graaff Generator	Deflection in CRT
Remove smoke and dust particles from industrial gases.	Uses electric field to attract toner particles to paper.	Due to large charge separation between clouds and ground.	Builds up very high charge to produce strong electric fields.	Electric field deflects electron beam in TV/monitor screens.

KEY TAKEAWAYS
- ✓ Charge is conserved and quantised.
- ✓ Coulomb's law governs the force between charges.
- ✓ Electric field represents the influence of charge.
- ✓ Field lines visualize the electric field.
- ✓ Gauss's law is a powerful tool for symmetric cases.
- ✓ In conductors, charge resides on the surface and field inside is zero.

Formulae to remember, concepts to conquer!

ELECTRIC CHARGES AND FIELD

CLASS XII PHYSICS – FORMULA SHEET

IMPORTANT CONSTANT

$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2 N^{-1} m^{-2}$
(Permittivity of free space)

1. COULOMB'S LAW

Force between two point charges.

$$F_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

VECTOR FORM

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{12}$$

KEY POINTS
- $F \propto q_1 q_2$
- $F \propto \frac{1}{r^2}$
- Force is along the line joining charges.
- Equal and opposite on both charges.

2. ELECTRIC FIELD

Electric field intensity.

$$\vec{E} = \frac{\vec{F}}{q_0}$$

SI unit : N/C

FIELD DUE TO A POINT CHARGE

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

FIELD DUE TO SYSTEM OF CHARGES

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots$$

PROPERTIES
- Radially outward for + charge
- Radially inward for – charge
- Direction of $\vec{E}$ is the direction of force on +ve test charge.

3. ELECTRIC FLUX

Electric flux through a surface.

$$\Phi_E = \vec{E}\cdot\vec{A} = EA\cos\theta$$

SPECIAL CASES

Condition	Flux (Φ_E)
$\theta = 0°$ ($\vec{E}$ parallel to $\vec{A}$)	EA
$\theta = 90°$ ($\vec{E}$ perpendicular to $\vec{A}$)	0
Arbitrary θ	$EA\cos\theta$

WHERE
$\vec{A}$ = Area vector (perpendicular to surface)
θ = Angle between $\vec{E}$ and $\vec{A}$

4. GAUSS'S LAW

Total electric flux through any closed surface.

$$\oint \vec{E}\cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$$

SYMMETRIC CASES (RESULTS)

(i) Infinite Line Charge (λ)
$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

(ii) Infinite Plane Sheet (σ)
$$E = \frac{\sigma}{2\varepsilon_0}$$

(iii) Spherical Shell (Radius R, Charge Q)
$$E = \begin{cases} 0, & r < R \\ \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}, & r > R \end{cases}$$

5. CONDUCTORS (IN ELECTROSTATIC EQUILIBRIUM)
- $\vec{E} = 0$ inside the conductor
- ✓ Potential is constant throughout
- ✓ Charge resides on the outer surface
- ✓ Surface is an equipotential
- ✓ Electric field just outside the surface is perpendicular to it

JUST OUTSIDE SURFACE

$$E = \frac{\sigma}{\varepsilon_0}$$

WHERE σ – Surface charge density

DIRECTION REMINDER

$\vec{E}$ direction = direction of force on positive test charge.

FIELD LINES SUMMARY
- Originate from + and terminate at – (or infinity).
- Closer lines → stronger field.
- Do not intersect.

REMEMBER
- ✓ Field is a vector quantity.
- ✓ Gauss's law depends only on charge enclosed.
- ✓ Use symmetry to apply Gauss's law easily.

MULTIPLE CHOICE QUESTIONS

For Aspiring DOCTORS

Q1. Two identical charged conducting spheres A and B have their centres separated by a certain distance. Charge on each sphere is q and the force of repulsion between them is F. A third identical uncharged conducting sphere is brought in contact with sphere A first and then with B and finally removed from both. New force of repulsion between spheres A and B (Radii of A and B are negligible compared to the distance of separation so that for calculating force between them they can be considered as point charges) is best given as:
NEET 2025

(a) 3F/ 5 (b) 2 F/3 (c) 2F (d) 3F/8

Q2. A thin spherical shell of radius R has charge Q spread uniformly over its surface. Which of the following graphs most appropriately represents the electric field E(r) produced by the shell in the range $0 \leq r < \infty$, where r is the distance from the centre of the shell?

(a) A graph showing E constant inside the shell.
(b) A graph showing E = 0 for r < R and E decreasing as $1/r^2$ for r > R.
(c) A graph showing E increasing linearly inside.
(d) A graph showing E decreasing linearly outside. NEET 2024

Q3. An electric dipole is placed at an angle of 30° with an electric field of intensity 2×10^5 N C^{-1}. It experiences a torque equal to 4 N m. Calculate the magnitude of charge on the dipole, if the dipole length is 2 cm. NEET 2023

(a) 8 mC (b) 2 mC (c) 5 mC (d) 7 mC

Q4. A spherical conductor of radius 10 cm has a charge of 3.2×10^{-7} C distributed uniformly. What is the magnitude of electric field at a point 15 cm from the centre of the sphere-?

(a) 1.28×10^4 N/C (b) 1.28×10^5 N/C (c) 1.28×10^6 N/C (d) 1.28×10^7 N/C NEET 2020

Q5. Polar molecules are the molecules: NEET 2021

(a) having a permanent electric dipole moment.
(b) having zero dipole moment.
(c) acquire a dipole moment only in the presence of electric field due to displacement of charges.
(d) acquire a dipole moment only when magnetic field is absent.

For Aspiring Engineers

Q6. Given below are two statements:

Statement I: If the net positive charge of a closed surface is zero, then the net electric flux through the surface is zero.

Statement II: If the electric flux through a closed surface is zero, then the net charge inside the surface must be zero.

Choose the correct answer: **JEE Main 2023**

(a) Both Statement I and Statement II are true.
(b) Both Statement I and Statement II are false.
(c) Statement I is true but Statement II is false.

(d) Statement I is false but Statement II is true.

Q7. A point charge of 2 μC is placed at the center of a cubic Gaussian surface of side 10 cm. The net electric flux through the surface is: ($\varepsilon_0 = 8.85 \times 10^{-12}$ $C^2 N^{-1} m^{-2}$)

(a) 2.26×10^5 N m²/C (b) 1.13×10^5 N m²/C

(c) 4.52×10^5 N m²/C (d) 0.56×10^5 N m²/C **JEE Main 2022**

Q8. Three charges +Q, q, +Q are placed respectively at distance 0, d/2 and d from the origin on the x-axis. If the net force on +Q placed at x = 0 is zero, then the value of q is:

JEE Main 2020

(a) +Q/4 (b) -Q/2 (c) -Q/4 (d) +Q/2

Q9. An electric dipole is formed by two charges +q and -q located at (0,0,d) and (0,0,-d) respectively. A third charge +Q is kept at (L,0,0) where L >> d. The force on the charge +Q is proportional to: **JEE Adv 2023**

(a) $1/L^2$ (b) $1/L^3$ (c) $1/L^4$ (d) L

Q10. **(Multi-correct):** A disk of radius R with uniform positive surface charge density σ is placed on the xy-plane with center at origin. The Electric potential V and electric field E at point (0,0,z) are given. If $R \to \infty$, then **JEE Adv 2022**

(a) $E = \sigma / 2\varepsilon_0$ (b) $E = \sigma / \varepsilon_0$

(c) V is proportional to z (d) V is independent of z

For Practice

Q11. Two identical point charges are placed in a laboratory vacuum at a distance r. If a technician moves them closer such that the new distance is exactly half of the original, how does the electrostatic force of interaction change?

(a) It reduces to one-fourth. (b) It reduces to half.

(c) It increases to double. (d) It increases to four times.

Q12. Two charged metallic spheres are suspended in air and experience a force F. If the entire setup is lowered into a tank filled with a special insulating oil having a dielectric constant K = 4, the new force between the spheres will be:

(a) 2F (b) 4F (c) F/2 (d) F/4

Q13. A hollow spherical shell used in a Van de Graaff generator is given a positive charge of 10 μC. A student measures the electric field at the exact geometric center of this 2-meter radius sphere. The reading on the meter will be:

(a) Zero (b) 5×10^3 N/C (c) 20×10^3 N/C (d) 10 N/C

Q14. An electric dipole (like a water molecule model) with charges $\pm 2 \times 10^{-6}$ C separated by 2 cm is placed in a uniform atmospheric electric field of 5×10^5 N/C. The maximum torque experienced by this molecule to align itself with the field is:

(a) 0.01 N·m (b) 0.02 N·m (c) 1×10^{-4} N·m (d) 2×10^{-2} N·m

Q15. For a short electric dipole, the electric field strength at a distant point P on its longitudinal axis varies with the distance r from the center as:

(a) $E \propto r^2$ (b) $E \propto 1/r^2$ (c) $E \propto r^3$ (d) $E \propto 1/r^3$

Q16. If E_axial represents the electric field of a short dipole at a distance d on its axis, and E equatorial represents the field at the same distance on its broadside-on position, the correct relationship is:

(a) E axial = E equatorial (b) E axial = 2 E equatorial
(c) E equatorial = 2 E axial (d) E axial = 1/2 E equatorial

Q17. A tiny dust particle carries a charge q and is trapped exactly at the center of a cubical box. According to Gauss's Theorem, the electric flux passing through only one of the six faces of the cube is:
(a) q/ε_0 (b) $q/6\varepsilon_0$ (c) $6q/\varepsilon_0$ (d) Zero

Q18. Two small identical metallic balls having charges q and – 2q are kept far at a separation r. They are brought in contact and then separated at distance r /2. Compared to the initial force F, they will now : **CBSE 2026**
(a) attract with a force F/2 (b) repel with a force F/ 2
(c) repel with a force F (d) attract with a force F

Q19. In a region of space, electric field lines are observed to be curved and their density varies from point to point. This indicates that the electric field in that region is:
(a) Uniform in magnitude but varying in direction.
(b) Uniform in both magnitude and direction.
(c) Non-uniform in both magnitude and direction.
(d) Zero throughout the region.

Q20. Which of the following is a fundamental property of electrostatic field lines that helps distinguish them from magnetic field lines?
(a) They always form closed continuous loops.
(b) They can cross each other in a strong field.
(c) They start from positive charges and end on negative charges without forming closed loops.
(d) They are always parallel to the surface of a conductor.

Q1. New force = 3F/8. Ans: (d). Q2. Inside shell E = 0; outside $E \propto 1/r^2$. Ans: (b). Q3. q = 2 mC. Ans: (b). Q4. $E = 1.28 \times 10^5$ N/C. Ans: (b). Q5. Polar molecules have permanent dipole moment. Ans: (a). Q6. Both Gauss's Law statements are true. Ans: (a). Q7. Flux = 2.26×10^5 N•m²/C. Ans: (a). Q8. q = −Q/4. Ans: (c). Q9. Force $\propto 1/L^3$. Ans: (b). Q10. E constant, V varies linearly with z. Ans: (a) & (c). Q11. Force becomes 4F. Ans: (d). Q12. New force = F/4. Ans: (d). Q13. Field inside shell = 0. Ans: (a). Q14. Maximum torque = 0.02 N•m. Ans: (d). Q15. $E \propto 1/r^3$. Ans: (d). Q16. E_axial = 2E_equatorial. Ans: (b). Q17. Flux per face = $q/6\epsilon_0$. Ans: (b). Q18. Final force = F/2 and repulsive. Ans: (b). Q19. Non-uniform field in both magnitude and direction. Ans: (c). Q20. Field lines start on positive and end on negative. Ans: (c).

ASSERTION AND REASON QUESTIONS

In the following questions, two statements are given –one labelled Assertion (A) and other labeled Reason (R).
Select the correct answer to these questions from the options as given below.
(a). If both Assertion and Reason are true and Reason is the correct explanation of Assertion.
(b). If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
(c). If Assertion is true but Reason is false.

(d). If both Assertion and Reason are false.

Q1. Assertion: If a point charge is rotated in a circle around a central charge, the work done by the electrostatic force is zero.
Reason: The electrostatic force is a conservative force, and the displacement is always perpendicular to the force in a circular path.

Q2. Assertion: The electric flux through a closed surface depends only on the net charge enclosed, regardless of the shape or size of the surface.
Reason: Gauss's Law is based on the inverse square dependence on distance contained in Coulomb's Law.

Q3. Assertion: It is safer to be inside a car than under a tree during a lightning storm.
Reason: The metallic body of the car acts as a "Faraday Cage," ensuring the electric potential inside remains zero.

Q4. Assertion: An electric dipole placed in a non-uniform electric field always experiences a net force and a net torque.
Reason: In a non-uniform field, the forces on the two charges of the dipole are unequal in magnitude.

Q5. Assertion: The surface charge density at the sharp pointed ends of a conductor is higher than at its flatter portions.
Reason: For a conductor of any shape, the surface charge density is inversely proportional to the radius of curvature at that point.

Q6. ASSERTION: In a non-uniform electric field, a dipole may have translatory motion as well as rotational motion.
REASON: In a non-uniform electric field, a dipole experiences a force as well as torque.

Q6. ASSERTION: Gauss law is applicable only for symmetric charge distribution.
REASON: In gauss law, electric field is due to only those charges which are present inside the closed surface.

Q8. ASSERTION: A point charge q_0 is kept outside a solid metallic sphere, the electric field inside the sphere is zero.
REASON: Induced charge does not contribute to electric field or potential at a given point.

Q9. ASSERTION (A): No torque acts on an electric dipole when its dipole moment is in a direction opposite to the electric field.
REASON (R): An electric dipole is in stable equilibrium when placed in a uniform electric field with its dipole moment opposite to the field.

Q10. ASSERTION (A) : If a point charge q is placed in front of an infinite grounded conducting plane surface, the point charge will experience a force.
REASON (R): This force is due to the induced charge on the conducting surface which is at zero potential.

Answers of Assertion and Reason Questions

1.	2.	3.	4.	5.	6.	7.	8.	9.	10
a	a	c	b	a	a	d	c	c	a

Exercise Assertion and Reason Questions

Q1. Assertion (A): The total amount of charge on a body equal to $4X10^{-19}$ C is not possible.
Reason (R): Experimentally it is established that all free charges are integral multiples of a basic unit of charge denoted by *e*. Thus, charge *q* on a body is always given by *q* = *ne.*

Q2. Assertion (A): The Coulomb force between two points charges depends upon the dielectric constant of the intervening medium.

Reason(R): Coulomb's force varies inversely with the dielectric constant of medium.

Q3. Assertion (A): An electron with velocity 'v' enters a uniform electric field, it tends to move along the direction of electric field.

Reason (R): An electron at rest in a uniform electric field never experiences a force.

Q4. Assertion (A): When a charged comb run through dry hair and taken near a paper, molecules in the paper gets polarized resulting in net force of attraction.

Reason(R): A comb run through one's dry hair attracts small bits of paper.

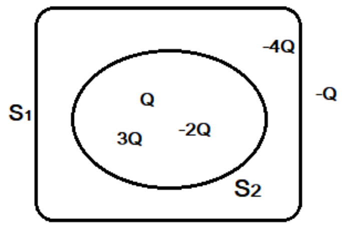
Q5. Assertion (A): Electrostatic force is conservative in nature.

Reason (R): Electric filed lines do not form closed loops

Answers of Exercise Assertion and Reason									
1.	**A**	**2.**	**A**	**3.**	**D**	**4.**	**B**	**5.**	**B**

VERY SHORT ANSWER TYPE QUESTIONS

Q1. A spherical balloon carries a charge that is uniformly distributed over its surface. As the balloon is blown up and increases in size, how does the electric flux come out of the surface change? Give reason.



Q2. Find ratio of electric flux through the surface S_1 and S_2 as shown in figure

Q3. Two small balls, each with a charge Q, hang from the same point by insulating strings of length L from a fixed support. Consider the setup in a region of zero gravity and in equilibrium.

(a) What will be the angle between the two strings?

(b) What will be the tension in each of the strings?

Q4. A thundercloud carries a charge of +50 C at a height of 4000 m and a charge of -50 C at a height of 2000 m from the ground. An airplane crosses through the charged thundercloud at a height of 3000 m from the ground. Find the magnitude and the direction of the electric field acting on the airplane as its crosses through the charged-up thundercloud.

Q5. Two charged conducting spheres of radii a and b are connected to each other by a wire. Find the ratio of the electric fields at their surfaces.

Q6. Why can two electric field lines never cross each other?

Q7. What is the net flux through a closed surface containing an electric dipole?

Q8. How does the force between two point charges change if the dielectric constant of the medium between them increases?

Q9. Define 'quantization of charge'.

Q10. Draw the electric field lines for a system of two equal negative charges.

Very Short Answer Type Questions – Hints and Solutions

Q1. The electric flux remains unchanged. According to Gauss's Law, flux depends only on the net enclosed charge ($\Phi = q/\varepsilon_0$), not the size or radius of the surface.

Q2. The ratio is -1:1 (or -1). Net charge in S_1 = (Q + 3Q − 2Q − 4Q) = -2Q. Net charge in S_2 = (Q + 3Q − 2Q) = 2Q.

Q3. (a) Angle: 180°. In zero gravity, the only force is electrostatic repulsion, pushing the balls as far apart as possible. (b) Tension: $T = (1 / 4\pi\epsilon_0) \times Q^2 / (2L)^2$. The tension balances the repulsive force at a distance of 2L.

Q4. The field magnitude is $E = \sigma/\epsilon_0$ (if treated as plates) or by calculating E_{net} from both layers. The direction is downward (from the +50 C layer at 4000 m toward the −50 C layer at 2000 m).

Q5. The ratio is b: a. When connected, their potentials are equal ($V_a = V_b \Rightarrow kq_a/a = kq_b/b$). Since E = V/r, the surface fields are inversely proportional to the radii ($E_a/E_b = b/a$).

Q6. If they crossed, at the point of intersection, the field would have two different directions, which is physically impossible.

Q7. Zero. According to Gauss's Law, flux depends on the net charge; a dipole's net charge (+q − q) is zero.

Q8. The force decreases. $F_{medium} = F_{vacuum} / K$.

Q9. It is the property by which all free charges are integral multiples of a basic unit of charge (e), expressed as q=ne.

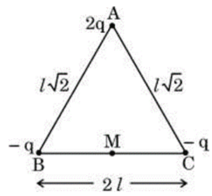
Q10. Sutiable diagram

2 Marks Questions

Q1. An electric dipole of length 10 cm having charges ± 6 x 10^{-3} , placed at 30˚ with respect to a uniform electric field, experiences a torque of $6\sqrt{3}$ Nm. Calculate the magnitude of the electric field

Q2. Two point charges +4Q and -Q are fixed on the x-axis at a distance 'a' apart. Find the distance of point on the line joining them where the net electric field intensity zero?

Q3. The figure shows three point charges kept at the vertices of triangle ABC. Find the net electric field, due to this system of charges, at the midpoint M of base BC. **CBSE 2026**



Q4. A thin rod of length L of the uniform mass density of μ kg/m and linear charge density λ C/m is initially at rest. A uniform electric field E is applied in the direction perpendicular to the length of the rod. The rod begins to move in the direction of the applied electric field. Determine the speed of the rod after it travels through 1 m of distance. Ignore all external forces except the electrostatic forces.

Q5. Plot a graph showing variation of electric field as a function of r > R and r < R (r being the distance from the centre of the shell.

Q6. A point charge +q is placed at a distance d/2 directly above the center of a square of side d. Find the magnitude of the electric flux through the square.

Q7. Five identical charges +Q are placed at five corners of a regular hexagon of side L. Find the magnitude of the electric field at the center of the hexagon.

Q8. Distinguish between a polar and a non-polar molecule with one example each.

Q9. An electrostatic field line is a continuous curve. That is, a field line cannot have sudden breaks. Why not?

Q10. Why must the electric field be normal to the surface of every point of a charged conductor?

2 Marks Questions -Hints and Solutions

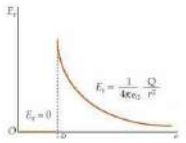
Q1 Formula: $\tau = pE \sin\theta$. $p = q \times 2l = (6 \times 10^{-3}\ C) \times (0.1\ m) = 6 \times 10^{-4}\ C\cdot m$. $E = \tau / (p \sin 30°) = 6\sqrt{3} / (6 \times 10^{-4} \times 0.5) = 2\sqrt{3} \times 10^4\ V/m$.

Q2 For two opposite charges +4Q and −Q, the null point (where $E_{net} = 0$) lies outside the charges, closer to the smaller magnitude charge (−Q). $k(4Q)/(a + x)^2 = kQ/x^2$. $2/(a + x) = 1/x \Rightarrow 2x = a + x \Rightarrow x = a$. The point is at distance a to the right of −Q.

Q3 The fields from charges at B and C (both −q) at the midpoint M are equal and opposite, so they cancel out.Result: The net field at M is due only to the charge +2q at vertex A.$E_{net} = k(2q)/r^2$, where r is the altitude of the triangle AM.

Q4 Force: $F = qE = (\lambda L)E$.Acceleration: $a = F/m = (\lambda LE)/(\mu L) = \lambda E/\mu$. Equation of Motion:$v^2 = u^2 + 2as \Rightarrow v = \sqrt{2 \times (\lambda E/\mu) \times 1} = \sqrt{2\lambda E/\mu}$ m/s.

Q5 Inside (r < R): E = 0.Outside (r > R): $E \propto 1/r^2$.Graph: The graph shows a jump from zero to maximum at the surface (r = R) and then a hyperbolic decay.



Q6 Imagine the square as one face of a cube with side d. By symmetry and Gauss's Law, total flux $\Phi = q/\varepsilon_0$, so flux through one face is $q/6\varepsilon_0$

Q7 A full hexagon with six charges would have zero field at the center. With one missing, the field is equal and opposite to the field that the sixth charge would have produced: $E = kQ/L^2$. for a regular hexagon, the radius of the outer circle (the circumradius) is exactly equal to the length of its side**.**

Q8 Polar molecules have a permanent dipole moment (e.g., H_2O), while non-polar molecules acquire one only in an external field (e.g., O_2)

Q9 Field lines represent the path of a test charge; since force acts continuously in a field, the acceleration and path must be continuous. A break would imply the field suddenly became zero and then reappeared.

Q10 If it weren't normal, there would be a tangential component of the field which would cause surface charges to move (creating a current), contradicting the state of electrostatic equilibrium.

3 MARKS QUESTIONS

Q1. Two point charges $q1 = 2{\cdot}5 \times 10^{-7}$ C and $q2 = -\,2{\cdot}5 \times 10^{-7}$ C are located at points (0, 0, – 15 cm) and (0, 0, 15 cm) respectively. Find : CBSE 2026
(a) The electric dipole moment of the system, and
(b) The magnitude and direction of electric field at the origin (0, 0, 0).

Q2. Two infinitely long straight wires having linear charge densities $-\lambda$ and 3λ are held vertically parallel to each other, distance r apart in free space. Find the nature and magnitude of the force/length exerted by one wire on the other. CBSE 2026

Q3. A small hollow conducting sphere of radius r_1 is given a charge Q. It is surrounded by a concentric conducting spherical shell of inner radius r_2 and outer radius r_3 , having charge − 3q. If a point charge 2q were kept at the centre, find: CBSE 2026
(I) the electric flux through a concentric spherical Gaussian surface of radius x for (1) $x < r_1$, and (2) $r_1 < x < r_2$.
(II) Electric field at a point distant x from the centre for (1) $x > r_3$, and (2) $r_1 < x < r_2$.
(III) Surface charge density on the inner surface of (1) sphere, and (2) shell.

Q4. (a) State Coulomb's Law and express it in vector form.

(b) Consider three charges q_1, q_2, q_3 at the vertices of an equilateral triangle of side L. Derive the expression for the net electrostatic force acting on a charge Q placed at the centroid.

Q5. A point charge q is placed at: (i) the center of a cube, (ii) one corner of the cube, and (iii) the center of one face. Calculate the electric flux through the entire cube and through each face for each case using Gauss's Law and symmetry.

Q6. A uniform electric field $\vec{E} = \overrightarrow{E_0}\hat{\imath}$ exists in a region. Calculate the flux through a cylinder of radius R and length L whose axis is parallel to the field. Show that the net flux is zero.

Q7. Derive the expression for the work done in rotating an electric dipole from an angle θ_1 to θ_2 in a uniform electric field E

Q8. Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and magnitude $17.7 \times 10^{-12} C/m^2$. Calculate the electric field (a) in the outer region of the first plate, and (b) between the plates.

Q9. Using Gauss's Law, show that the electric field due to a uniformly charged infinite plane sheet is independent of the distance from it.

Q10. Two identical small pith balls, each of mass m and charge q, are suspended from a common point by two insulating strings of length l. If the system is in equilibrium and the strings make an angle θ with the vertical, derive the expression for the charge q in terms of m, l, g, and θ.

3 Marks Questions -Hints and Solutions

Q1 a) Dipole Moment: p = q × 2a. Since distance is from −15 cm to +15 cm, 2a = 30 cm = 0.3 m. $p = (2.5 \times 10^{-7}) \times 0.3 = 7.5 \times 10^{-8}$ C·m. The direction is from negative to positive (along the −z axis). (b) Field at Origin: Both charges are equidistant from the origin and have opposite signs. Their fields at the origin point in the same direction. $E_{net} = 2 \times (kq/a^2)$.

Q2 Formula: F = qE where $q= \lambda_1 l$, Use the field of one wire acting on the other: $F = \lambda_1 l E_2 \Rightarrow F/l= \lambda_1(2k\lambda_2/r)$. Magnitude = $(1 / 2\pi\epsilon_0) \times (3\lambda^2/r)$. Since the charges have opposite signs (−λ and 3λ), the force is attractive.

Q3 (I) Flux: For $x < r_1$: $\Phi = q\_enclosed/\epsilon_0 = 2q/\epsilon_0$. For $r_1 < x < r_2$: $\Phi = (2q + Q)/\epsilon_0$. (III) Surface Density (σ): The inner surface of shell (r_2) will have an induced charge of −(2q + Q) to cancel the internal field. σ = Charge / Area = $-(2q + Q) / 4\pi r_2^2$.

Q4 Vector form: $\vec{F}_{21} = (1 / 4\pi\epsilon_0) \times (q_1q_2 / r^2)\, \hat{r}_{12}$. Distance from each vertex to centroid: R = L/√3. Due to symmetry, the net force at centroid is zero.

Q5 Charge at center: Total flux = q/ϵ_0. Flux through each face = $q/6\epsilon_0$. Charge at corner: Flux through one cube = $q/8\epsilon_0$. Flux through each of 3 outer faces = $q/24\epsilon_0$. Charge at face center: Flux through one cube = $q/2\epsilon_0$.

Q6 Left End Cap (Φ_1): The area vector $\vec{A}$ points left (-x), and vector $\vec{E}$ points right (+x). The angle is 180°. =>$(\Phi_1) := E_0 A \cos(180°) = -E_0(\pi R^2)$ .Right End Cap (Φ_2): Both the area vector $\vec{A}$ and $\vec{E}$ point right (+x). The angle is 0°. => $(\Phi_2) := E_0 A \cos(0°) = +E_0(\pi R^2)$. Curved Surface (Φ_3): The area vector is always perpendicular to the cylinder's axis (and the field). The angle is 90°. $(\Phi_3) := E_0 A \cos(90°) = 0$.The total flux is the sum of these parts: $\Phi_{net} = \Phi_1 + \Phi_2 + \Phi_3$

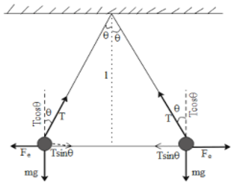
$\Phi_{net} = -E_0(\pi R^2) + +E_0(\pi R^2) + 0$ =>$\Phi_{net} = 0$. Conclusion: The net flux is zero because the number of field lines entering the cylinder equals the number of field lines leaving it, meaning no net charge is enclosed q_{inside}=0

Q7 dW = τ dθ = pE sinθ dθ. Integrating from θ_1 to θ_2: W = pE($\cos\theta_1 - \cos\theta_2$).

Q8 Outer region: E = 0. Between plates: E = σ/ϵ_0 = 2 N/C.

Q9 Using a cylindrical Gaussian surface: 2EA = σ A / ϵ_0 ⇒ E = σ/2ϵ_0. The field is independent of distance.

Q10 Force Analysis: At equilibrium: Balancing Components: Vertical: T cos θ = mg. Horizontal: T sin θ = F_e. Combining Equations: Dividing the two equations gives: tan θ = F_e / mg. Electrostatic Force: $F_e = (1 / 4\pi\epsilon_0) \times (q^2 / r^2)$, where the separation between the balls is: r = 2l sin θ. Result: Substituting F_e and r into the tangent equation and solving for q: $q = \sqrt{(16\pi\epsilon_0 l^2 mg \sin^2\theta \tan\theta)}$



CASE STUDY BASED QUESTION

Q1. When an electric dipole of charges ±q and dipole moment $\vec{p}$ is placed in a uniform electric field electric field $\vec{E}$ making an angle θ with the $\vec{E}$, then two charges experience equal and opposite forces +q $\vec{E}$ and –q $\vec{E}$. These equal and opposite forces cancel each other. As the two forces are not collinear so a torque acts on the dipole. Since the net force acting on the dipole is zero, no work is done in moving the electric dipole in a uniform electric field, but some work will be done in rotating the dipole against the torque acting on it.

i. Two charges +q and –q are located at points (a, 0) and (3a, 0) on x-axis. The dipole moment of the system has magnitude

(A) 2qa and is along +x-axis. (B) 2qa and is along –x-axis.
(C) qa and is along +x-axis. (D) qa and is along –x-axis.

ii. The magnitude of electric field at a certain distance from a dipole on its axis is E_1 and at the same distance on the equatorial plane of the dipole is E_2. (E_1/E_2)is

(A) 1/2 (B) 2 (C) 1/4 (D) 4

iii. The dimensional formula of dipole moment is –

(A) $[L^2T^2A^{-2}]$ (B) $[M^2L^2T^1A^2]$ (C) $[L^1T^1A^2]$ (D) $[L^1T^1A^1]$

iv. An electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$. The torque exerted by the field on the dipole at that instant is –

(A) Parallel to both the $\vec{E}$ and $\vec{p}$. (B) Perpendicular to both $\vec{E}$ and $\vec{p}$.
(C) Parallel to $\vec{E}$ and perpendicular to $\vec{p}$. (D) Perpendicular to $\vec{E}$ and parallel to $\vec{p}$.

Q2. The Millikan's Concept

In 1909, American physicist Robert A. Millikan performed the famous oil drop experiment to determine the nature of electric charge. In the experiment, tiny oil droplets were sprayed between two charged metal plates. By carefully adjusting the electric field, Millikan observed that the charges on the oil drops were always whole-number multiples of a smallest value called the elementary charge.

This proved that electric charge is not continuous but exists in discrete packets. This property is known as **quantization of charge**.

The elementary charge is: e=$1.6 \times 10^{-19} C$

Any charge can therefore be written as: q=ne; where n is an integer (positive or negative).

Millikan's experiment also supported the law of conservation of charge, according to which the total charge of an isolated system always remains constant.

i. Which of the following charges is NOT possible?

A) $1.6 \times 10^{-20} C$ B) $3.2 \times 10^{-16} C$ C) $2.4 \times 10^{-18} C$ D) $4.8 \times 10^{-17} C$

ii. If an object has a net charge of +1 C, it has:

A) Gained 6.25×10^{18} electrons B) Lost 6.25×10^{18} electrons

C) Gained 1 electron D) Lost 1 electron

iii. The total charge of an isolated system remains:

A) Zero B) Variable C) Conserved D) Quantized only during friction

iv. Quantization of charge can be ignored at the macroscopic level because:

A) Charge becomes continuous B) Elementary charge e is extremely small

C) Newton's laws take over D) Gravity cancels the charge

Q3. Dielectric Breakdown and Sharp Points

The electric field near a conductor is given by $E = \sigma/\varepsilon_0$. For a given potential, the surface charge density σ is much higher at sharp points (small radius of curvature) than on flat surfaces. This can lead to "Corona Discharge."

i. Why do lightning conductors have sharp pointed ends?

A) To attract lightning more slowly

B) To create a high electric field that ionizes air and provides a path for discharge

C) To increase the resistance of the building

D) To look aesthetically pleasing

ii. The maximum electric field air can withstand before becoming a conductor is called:

A) Dielectric Constant B) Dielectric Strength C) Permittivity D) Polarization

iii. At a sharp point, the radius of curvature $r \rightarrow 0$. This implies the field E becomes:

A) Zero B) Negligible C) Very high D) Constant

iv. A spark is seen when a person touches a doorknob after walking on a carpet. This is an example of:

A) Magnetic induction B) Electrostatic discharge due to potential difference

C) Current electricity D) Thermionic emission

Case Study – Answer key											
1. i	**1. ii**	**1. iii**	**1. iv**	**2. i**	**2. ii**	**2. iii**	**2. iv**	**3. i**	**3. ii**	**3. iii**	**3. iv**
b	**b**	**d**	**b**	**a**	**b**	**c**	**b**	**b**	**b**	**c**	**b**

5 MARKS QUESTIONS

Q1. (a) Define electric dipole moment. Is it a scalar or a vector?

(b) Derive an expression for the torque acting on an electric dipole placed in a uniform electric field.

(c) At what angle is the torque maximum and minimum? Draw the diagram of orientation of dipole in electric field.

Q2. (a) Derive an expression for the electric field intensity at any point on the axial line of an electric dipole.

(b) How does the field vary with distance r for a short dipole (r >> a)?

(c) Derive the expression for the electric field intensity at a point on the equatorial plane of an electric dipole.

(d) Show that for a short dipole, the field at an axial point is twice the field at an equatorial point at the same distance.

Q3. (a) State Gauss's Law in electrostatics.

(b) Using this law, derive an expression for the electric field due to an infinitely long straight uniformly charged wire.

(c) Plot a graph showing the variation of E with distance r.

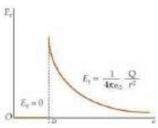
Q4. (a) Define electric flux. Write its SI unit.

(b) Use Gauss's Law to find the electric field intensity due to a uniformly charged infinite plane sheet.

(c) Does this field depend on the distance from the sheet? Explain.

Q5. Using Gauss's Law, derive expressions for the electric field due to a uniformly charged thin spherical shell at a point:

(i) Outside the shell ($r > R$) (ii) On the surface of the shell ($r = R$) (iii) Inside the shell ($r < R$) Include the E vs r graph.

5 Marks Question Derivation Hints	
Q1	Dipole moment ($\vec{p}$) is a vector pointing from $-q$ to $+q$ with magnitude: $p = q \times 2a$. Diagram:Draw two parallel lines for the uniform field $\vec{E}$, an inclined dipole at angle θ, and show forces $+qE$ and $-qE$ acting in opposite directions. Derivation Hint:1. Explain that net force is zero: $+qE - qE = 0$. 2. Calculate Torque (τ) = Force × perpendicular distance between forces. 3. $\tau = (qE) \times (2a \sin\theta) = pE \sin\theta$. Max. and Min. Torque: $\tau = 0$ at 0° and 180° (equilibrium).=> $\tau = pE$ at 90°.
Q2	Axial Line Hint ($E \propto 1/r^3$): Find the fields due to $+q$ and $-q$ at point P on the axis. Subtract the smaller field from the larger one. Result:$E\_axial = 2kp/r^3$ for a short dipole. Equatorial Line Hint: Use vector resolution. The vertical components of the fields ($E \sin\theta$) cancel out, while the horizontal components ($E \cos\theta$) add up. Result: $E_{equatorial} = kp/r^3$. Diagram: For the equatorial line, show the vector addition forming a resultant parallel but opposite to $\vec{p}$.
Q3	Statement: Total flux through a closed surface is $1/\epsilon_0$ times the net charge enclosed. Diagram: Draw an infinitely long wire with linear charge density λ. Draw a cylindrical Gaussian surface around it of radius r and length l. Flux only passes through the curved surface because flux through flat ends is zero ($\vec{E} \perp d\vec{A}$). Total Flux: $\Phi = E \times (2\pi rl)$. Enclosed charge: $q = \lambda l$. Apply Gauss's Law: $E(2\pi rl) = \lambda l / \epsilon_0 \Rightarrow E = \lambda / (2\pi\epsilon_0 r)$.
Q4.	Definition: Electric Flux (Φ) is the total number of electric field lines passing through a surface. SI Unit: $N{\cdot}m^2/C$. Gaussian Surface: A cylinder (pillbox) piercing through the sheet, with cross-sectional area A at both ends. The electric field $\vec{E}$ is perpendicular to the sheet. Flux only passes through the two flat ends of the cylinder: $\Phi = 2EA$. 3. Enclosed charge: $q = \sigma A$, where σ is the surface charge density. According to Gauss's Law: $2EA = \sigma A / \epsilon_0$ => $E = \sigma / 2\epsilon_0$. Distance Factor: The electric field is independent of distance r from the sheet because the field is uniform.
Q5.	Case 1: Outside ($r > R$): Treat the entire charge as concentrated at the center. $E = (1 / 4\pi\epsilon_0) \times (q / r^2)$. Case 2: Inside ($r < R$): A Gaussian surface inside the shell encloses zero charge. Therefore, by Gauss's Law: $E = 0$. Graph: Include the graph showing $E = 0$ until $r = R$ and then a $1/r^2$ decrease. 

Electric charge is a fundamental property of matter.

ELECTRiC CHARGES AND FiELD

CLASS XII PHYSICS – FORMULA SHEET

CHAPTER AT A GLANCE
- Electric charge
- Coulomb's law
- Electric field
- Electric flux & Gauss's law
- Conductors
- Applications

1 ELECTRIC CHARGE

Key Points
- Charge is a fundamental property of matter.
- SI unit : Coulomb (C)
- Two types of charge : Positive (+) and Negative (–)
- Like charges repel, unlike charges attract.
- Charge is conserved.
- Charge is quantised.

Quantisation of Charge

$$q = ne$$

where $n = 0, \pm1, \pm2, \cdots$

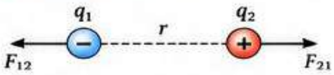
$e = 1.6 \times 10^{-19}$ C

Charge is invariant under change of frame of reference.

Additivity of Charge

$$q_{net} = \sum_i^i q_i$$

2 COULOMB'S LAW



The electrostatic force between two point charges is directly proportional to the product of charges and inversely proportional to the square of the distance between them, acting along the line joining them.

$$F_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Where,

$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$

F_{12} = force on q_1 due to q_2

Key Points
- ✓ $F \propto q_1 q_2$
- ✓ $F \propto \frac{1}{r^2}$
- ✓ Force is equal and opposite on both charges.

3 ELECTRIC FIELD

Electric Field Intensity ($\vec{E}$)

Electric field at a point is the force experienced per unit positive test charge placed at that point.

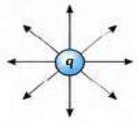
$$\vec{E} = \frac{\vec{F}}{q_0}$$

SI unit : N/C

Field due to a Point Charge

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

(radially outward for +q, inward for –q)



Field due to a System of Charges

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$$

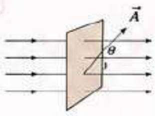
(Principle of superposition)

Electric Field Lines
- Originate from + charge and terminate on – charge (or at infinity).
- Tangent at any point gives direction of $\vec{E}$.
- Do not intersect.
- Closer lines ⇒ stronger field.

4 ELECTRIC FLUX

Electric flux through a surface is the measure of the number of electric field lines passing through it.

$$\Phi_E = \vec{E}\cdot\vec{A} = EA\cos\theta$$



Where,
- $\vec{A}$ = area vector (perpendicular to surface)
- θ = angle between $\vec{E}$ and $\vec{A}$

Flux depends on
- ✓ Magnitude of $\vec{E}$
- ✓ Area of surface (A)
- ✓ Orientation (θ)

Special Cases

$\theta = 0°$ (Maximum flux)	$\Phi_E = EA$
$\theta = 90°$ (Zero flux)	$\Phi_E = 0$
Arbitrary θ	$\Phi_E = EA\cos\theta$

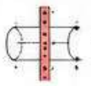
5 GAUSS'S LAW

The total electric flux through any closed surface is equal to $\frac{1}{\varepsilon_0}$ times the total charge enclosed.

$$\oint \vec{E}\cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$$

Applications (for symmetric charge distributions)

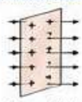
(i) Infinite Line Charge (λ)



$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

(radially outward)

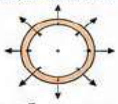
(ii) Infinite Plane Sheet (σ)



$$E = \frac{\sigma}{2\varepsilon_0}$$

(perpendicular to sheet)

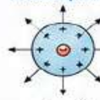
(iii) Spherical Shell (σ)



$E = \frac{\sigma}{\varepsilon_0}$ (outside)

$E = 0$ (inside)

(iv) Solid Sphere (ρ)



$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}, \ r \geq R$

$E = \frac{1}{4\pi\varepsilon_0}\frac{Qr}{R^3}, \ r < R$

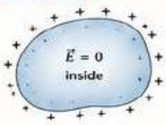
Key Idea

Choose a Gaussian surface that matches the symmetry of the charge distribution to simplify calculations.

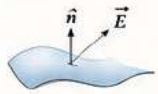
6 CONDUCTORS (IN ELECTROSTATIC EQUILIBRIUM)

Properties
- ✓ $\vec{E} = 0$ inside the conductor
- ✓ Potential is constant throughout
- ✓ Charge resides on the outer surface
- ✓ Surface is an equipotential surface
- ✓ Electric field just outside the surface is perpendicular to it

Excess Charge Resides on Outer Surface



Electric Field Just Outside the Surface



$\vec{E}$ is perpendicular to the surface.

Charge Density (σ)

$$\sigma = \frac{Q}{A}$$

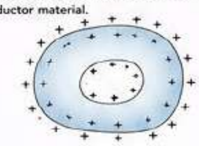
Where, Q = charge on surface
A = surface area

Shape of Conductors

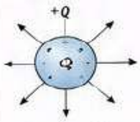
Charge resides on the surface in such a way that there is no electric field inside.

7 CONDUCTORS – IMPORTANT FACTS

- Hollow cavity inside a conductor with no charge ⇒ $\vec{E} = 0$ everywhere inside the cavity.
- If a charge is placed inside the cavity, it induces charges on the inner surface; still $\vec{E} = 0$ in the conductor material.



Electric Field due to a Charged Conducting Sphere



$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}, \ r \geq R$

$E = 0, \ r < R$

8 APPLICATIONS OF ELECTRIC FIELD

Electrostatic Precipitators

Remove smoke and dust particles from industrial gases.

Photocopiers

Uses electric field to attract toner particles to paper.

Lightning

Due to large charge separation between clouds and ground.

Van de Graaff Generator

Builds up very high charge to produce strong electric fields.

Deflection in CRT

Electric field deflects electron beam in TV/monitor screens.

DIRECTION REMINDER

$\vec{E}$ points in the direction of force on a positive test charge.

FIELD LINES SUMMARY
- ✓ Start from + and end on – (or at ∞)
- ✓ Never intersect each other
- ✓ Crowded lines ⇒ stronger field
- ✓ Continuous and closed in conductors

REMEMBER
- ✓ Charge is conserved and quantised.
- ✓ Coulomb's law governs the force.
- ✓ Electric field is a vector quantity.
- ✓ Gauss's law is a powerful tool for symmetric charge distributions.

☆ **EXAM TIP :** Draw clear diagrams, choose proper Gaussian surface, apply symmetry, write units, and state direction!

CHAPTER 2

ELECTROSTATIC POTENTIAL AND CAPACITANCE

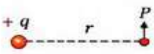
1 ELECTROSTATIC POTENTIAL (V)

Work done in bringing a unit positive charge from infinity to a point (without acceleration).

$$V = -\frac{W_{\infty \to P}}{q_0}$$

1 Due to point charge (q)

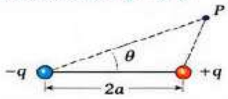
$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$



2 System of charges $q_1, q_2, \cdots, q_n$

$$V = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i}$$

3 Due to electric dipole ($p = 2aq$)



(i) At any point

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}\cdot\hat{r}}{r^2}$$

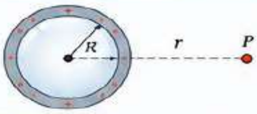
(ii) On dipole axis ($\theta = 0, \pi$)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^2}$$

(iii) In equatorial plane ($\theta = \frac{\pi}{2}$)

$$V = 0$$

2 UNIFORMLY CHARGED SPHERICAL SHELL (Q, R)



(i) Outside ($r > R$)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

(ii) On surface ($r = R$)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$$

(iii) Inside ($r < R$)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$$

CONDUCTORS & INSULATORS

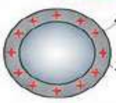
Conductors

- Have free charges which can move freely.
- Electric field inside a conductor is zero in electrostatic equilibrium.

Insulators

- Charges are bound to atoms and cannot move freely.
- Act as barriers to the flow of charge.

FREE CHARGES & BOUND CHARGES INSIDE A CONDUCTOR



- Free charges reside on the surface.
- Inside the conductor, $E = 0$ and $V =$ constant.

3 POTENTIAL DIFFERENCE (ΔV)

Work done against electric field in moving a unit positive charge from one point to another.

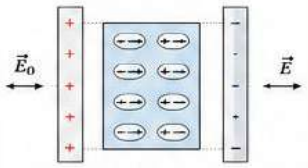
$$V_2 - V_1 = -\frac{W_{12}}{q_0}$$

If W_{12} is work done in moving a charge q from one point to another point then

$$V_2 - V_1 = \frac{W_{12}}{q}$$

$$W_{12} = q\,(V_2 - V_1)$$

4 DIEEECTRICS & ELECTRIC POLARIZATION



When a dielectric is placed in an electric field, its molecules get polarized.

Electric dipole moment of molecules induced in the direction of $\vec{E}$.

$\vec{p} =$ Electric dipole moment of molecule

4 CAPACITORS & CAPACITANCE

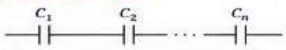
A capacitor consists of two conductors separated by an insulator (dielectric). Capacitance (C) is the ability of a capacitor to store charge.

$$C = \frac{Q}{V} \quad \text{(Farad)}$$

where $Q =$ charge, $V =$ potential difference

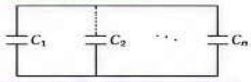
Combination of Capacitors

(i) Series Combination



$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

(ii) Parallel Combination



$$C_{eq} = C_1 + C_2 + \cdots + C_n$$

Parallel Plate Capacitor

(i) Without dielectric

$$C = \frac{\varepsilon_0 A}{d}$$

(ii) With dielectric (constant K)

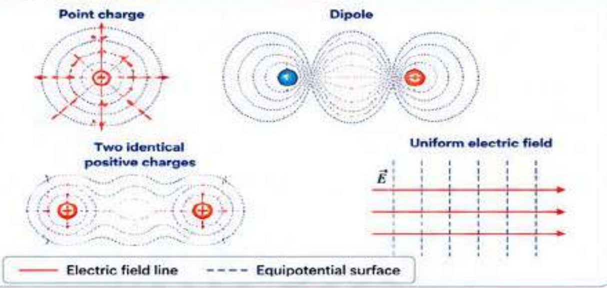
$$C = \frac{K\varepsilon_0 A}{d}$$

Energy stored in a capacitor

$$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$$

EQUIPOTENTIAL SURFACES

1. Electric potential is same at all points on the surface.
2. Electric field lines are always perpendicular to equipotential surfaces.
3. Two equipotential surfaces cannot intersect.
4. No work is required to move a charge along an equipotential surface.
5. No work is required to move a charge along an equipotential surface ($\Delta V = 0$).
6. Shapes of Equipotential Surfaces

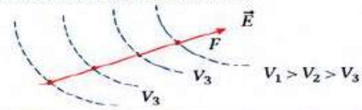


RELATION BETWEEN FIELD & POTENTIAL

$$\vec{E} = -\nabla V$$

(i) Electric field is in the direction in which the potential decreases steepest.

(ii) Its magnitude is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface.

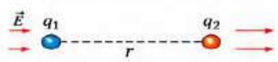


ELECTRIC POTENTIAL ENERGY (U)

(i) For two point charges q_1 and q_2

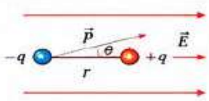
$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

(ii) Two charges in an external field



$$U = q_1 V_1 + q_2 V_2 + \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

(iii) Dipole in an external field



Potential Energy $U = -\vec{p}\cdot\vec{E} = -pE\cos\theta$

Equilibrium of a Dipole

Stable equilibrium	$\theta = 0°$ ($\vec{p} \parallel \vec{E}$)	☺
Unstable equilibrium	$\theta = 180°$ ($\vec{p}$ anti-parallel to $\vec{E}$)	☹

EFFECT OF DIELECTRIC (CONSTANT K) ON A CAPACITOR

Condition / Quantity	Battery Connected (V = Constant)			Battery Disconnected (Q = Constant)		
	Without Dielectric ($K = 1$)	With Dielectric (K)	Change (in terms of K)	Without Dielectric ($K = 1$)	With Dielectric (K)	Change (in terms of K)
Capacitance (C)	C_0	KC_0	$\times K$	C_0	KC_0	$\times K$
Charge (Q)	C_0V	KC_0V	$\times K$	Q_0	Q_0	No change
Potential Difference (V)	V	V	No change	$\frac{Q_0}{C_0} = V_0$	$\frac{Q_0}{KC_0} = \frac{V_0}{K}$	$\div K$
Energy Stored (U)	$\frac{1}{2}C_0V^2$	$\frac{1}{2}KC_0V^2$	$\times K$	$\frac{Q_0^2}{2C_0}$	$\frac{Q_0^2}{2KC_0} = \frac{1}{K}\left(\frac{Q_0^2}{2C_0}\right)$	$\div K$

DIELECTRIC IN A CAPACITOR

Dielectric polarizes and reduces the effective electric field between plates, thus increasing capacitance.

APPLICATIONS IN DAILY LIFE

1. **Power Distribution** – Voltage drives current to deliver power to devices.
2. **Electronic Devices** – Controls the movement of charges in devices like TV screens, electron microscopes.
3. **Lightning Rods** – Facilitates the transfer of charge and prevents damage.
4. **High-Voltage Lines** – Smooth surfaces prevent charge leakage.
5. **Audio Equipment** – Capacitors filter noise and stabilize signals for clear sound.
6. **Camera Flashes** – Capacitors store energy to provide high-power flashes.
8. **Automotive Systems** – Used in hybrid & electric vehicles for energy recuperation.
9. **Medical Devices** – Capacitors in defibrillators deliver a burst of energy.

SIMULATION LINK FOR CAPACITOR

Explore interactive learning for capacitors at:
https://phet.colorado.edu/en/simulations/capacitor-lab-basics

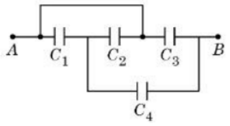
MULTIPLE CHOICE QUESTIONS

Q1 In a region electric field is given by $\vec{E}$= 4x$\hat{\imath}$ N/C. The potential difference between points A(x=1m) and B (x=3m), V_A-V_B is given by: **CBSE 2026 55/1/2**

(a) -16V (b) 16V (c) -8V (d) 8V

Q2 From the figure given below calculate the capacitance of the given combination of capacitors between points A and B (C_1= C_2 =C_3 =1 μF , C_4 =2μF) **JEE MAINS 2026**

(a) 2 (b) 7/2 (c) 7/3 (d) 5/2



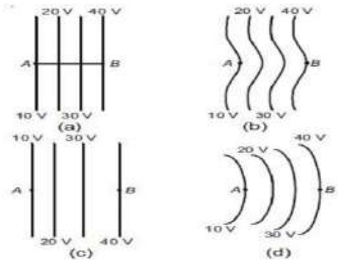
Q3 A point charge lies at a distance x from the midpoint of an electric dipole on its axis. The electric potential at a point P is proportional to:

(a)$1/x^3$ (b) $1/x^2$ (c) $1/x^4$ (d) $1/x^{1/2}$

Q4 Ten capacitors, each of capacitance 1 μF, are connected in parallel to a source of 100 V. The total energy stored in the system is equal to:

(a) 10^{-2} J (b) 10^{-3} J (c) 0.5 x 10^{-3} J (d) 5.0 x 10^{-2} J

Q5 The diagrams below show the regions of equipotential.



A positive charge is moved from A to B in each diagram then:

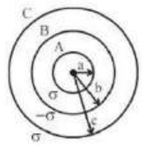
(a) Maximum work is required to move q in figure (c).

(b) In all the four cases the work done is the same.

(c)Minimum work is required to move q in figure (a).

(d) Maximum work is required to move q in figure (b)

Q6 As shown in figure, A, B and C are concentric shells of radius a, b and c respectively (a < b < c). Their surface charge densities are , σ, -σ and σ respectively. What is the electric potential on the surface of shell A ?



(a) $\frac{-\sigma}{\varepsilon_0}$(a+b+c) (b) $\frac{\sigma}{\varepsilon_0}$(a+b+c) (c) $\frac{\sigma}{\varepsilon_0}$(b-a-c) (d) $\frac{\sigma}{\varepsilon_0}$(a-b+c)

Q7: Four charges 10^{-8} C ,-2x10^{-8} C; +3x10^{-8} C and 2x10^{-8} C are placed at the four corners of a square of side 1m the potential at the center of the square is :

(a) zero (b) 360 volt (c) 360√2 volt (d) 180V

Q8: The electrostatic force between the metal plates of an isolated parallel plate capacitor C having a charge Q and area A, is:

(a) Independent of the distance between the plates (b) Linearly proportional to the distance between the plates (c) Proportional to the square root of the distance between the plates

(d) Inversely proportional to the distance between the plates

Q9: A capacitor is charged by a battery. The battery is removed and another identical uncharged capacitor is connected in parallel. The total electrostatic energy of resulting system

(a) Increases by a factor of 4 (b) Decreases by a factor of 2

(c) Remains the same (d) Increases by a factor of 2

Q10: A capacitor works as the charge storing device in

(a)AC circuits (b)DC circuits (c) Both (1) & (2) (d)Neither (1) nor (2)

Q11. A uniform electric field pointing in positive x-direction exists in a region. Let A be the origin, B be the point on the x-axis at x = + 1 cm and C be the point on the y-axis at y = + 1 cm. Then, the potentials at the points A, B and C satisfy

(a) $V_A < V_B$ (b) $V_A > V_B$ (c) $V_A < V_C$ (d) $V_A > V_C$

Q12. Which statement is not correct for an equipotential surface?

(a) Electric field intensity is always perpendicular to the equipotential surface.

(b) Potential difference between any two points on it is zero.

(c) Equipotential surfaces are spherical in shape.

(d) No work is required to move a charge on an equipotential surface

Q13. An electron mass m and charge e travels from rest through a potential difference of V. What will be the final velocity of electron?

(a) eV (b) $\frac{2eV}{m}$ (c) $\sqrt{\frac{2eV}{m}}$ (d) $\sqrt{\frac{2mV}{e}}$

Q14. Four point charges –Q, -q, 2q and 2Q are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square zero, is

(a) Q = -q (b) $Q = \frac{-1}{q}$ (c) Q = q (d) $Q = \frac{1}{q}$

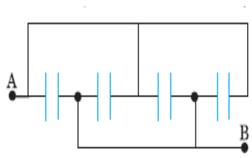
Q15. A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 80 V. The ratio of potential at a distance 5cm from the centre of the sphere to the potential at the surface of sphere is

(a) 1:2 (b) 2:1 (c) 1:1 (d) 1:4

Q16. There is one charged isolated air capacitor and *U* is the energy stored in it. Separation between the plates of the capacitor is increased to double of the initial value. Energy stored becomes

(a) U/2 (b) 2U (c) U/3 (d) 3U

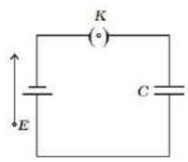
Q17. Four condensers are joined as shown in the figure and the capacity of each condenser is 8 μF. The equivalent capacity between the points A and B will be:



(*a*) 16 μF (*b*) 8 μF

(*c*) 32 μF (*d*) 2 μF

Q18. A parallel plate capacitor is connected to a battery as shown in Fig. Consider two situations: A: Key K is kept closed and plates of capacitors are moved apart using insulating handle. B: Key K is opened and plates of capacitors are moved apart using insulating handle. Choose the correct option(s).



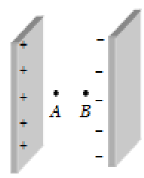
(a) In A : Q remains same but C changes.

(b) In B : V remains same but C changes.

(c) In A : V remains same and hence Q changes.

(d) In B : C remains same and hence V changes.

Q19. Two protons *A* and *B* are placed in space between plates of a parallel plate capacitor charged up to V volts (See fig.) Forces on protons are F_A and F_B , then



(a) $F_A > F_B$ (b) $F_A < F_B$

(c) $F_A = F_B$ (d) none of the above

Q20. *n* small droplets of same size are charged to a same potential *V*. If all of them combine to form a single drop then potential of the single drop will be

(a) n V (b) V/n (c) $n^{2/3}V$ (d) $n^{1/3}V$

ANSWERS

Q1 (a)V_A-V_B= $-\int E.dx$ so potential difference= -2x^2 = -2(3^2-1^2) = -16V

Q2 (a) C_1 & C_2 are parallel so 2μF .. This 2μF is in series with C_4. So 1 μF.now this is in parallel with C_3 so final equivalent resistance is 1 μF+C_3=2 μF

Q3 (b)For an electric dipole, the electric potential at a point on its axial line is given by V=kp/x^2 where distance between the charges is much smaller than the distance at which potential is to be calculated.

Q4 (d) Net capacitance = 10x 1 μF=10^{-5}F connected to 100V so total energy is U=1/2 $C_{eq}V^2$ so we get 5x10^{-2}J

Q5 (b)Work done w = qΔV, ΔV is same in all the cases so work is done will be same in all the cases.

Q6(d) Electric charge on shell A is q_A=4πa^2σ ; Electric charge on shell A is q_B=-4πb^2σ
Electric charge on shell A is q_C=4πc^2σ
Shell A is inside the shell B and C. so V_A=$\frac{1}{4\pi\varepsilon_0}$ (q_A+ q_B+ q_C)

Q7 (c) Potential at the centre is : V=kq/r : V=$\frac{1}{4\pi\varepsilon_0}$ ($q_1/r_1 + q_2/r_2 + q_3/r_3+ q_4/r_4$) = 360√2 V

Q8 (a)For isolated capacitor Q = Constant : F_{avg}=$\frac{Q^2}{2A\varepsilon_0}$: F is independent of the distance between plates

Q9 (b) Common potential = V/2 ; Initial energy U_i=1/2 CV^2 final energy U_f= ¼ CV^2 so loss of energy = ½ CV^2- ¼ CV^2 = ¼ CV^2 decreases by a factor of 2

Q10 b)DC circuits

Q11. (b) E = - $\frac{dV}{dr}$, Direction of electric field must be in the direction of the decreasing order of electric potential.

Q12. (c) Shape of equipotential surface depends on charge or distribution of charges

Q13. (c) eV = $\frac{1}{2}mv^2$ so $v = \sqrt{\frac{2eV}{m}}$

Q14. (a) $\frac{1}{4\pi\varepsilon_0}\frac{-Q}{R}+\frac{1}{4\pi\varepsilon_0}\frac{-q}{R}+\frac{1}{4\pi\varepsilon_0}\frac{2Q}{R}+\frac{1}{4\pi\varepsilon_0}\frac{2q}{R}=0$ Q = -q

Q15. (c) Value of potential inside and on the surface of a charged spherical shell is same

Q16.(b) As capacitor is isolated so charge on capacitor remains same
New capacitance $C'=\frac{C}{2}$ and V'= 2V
Hence, new energy U' = 2U

Q17.(c) All capacitors are connected in parallel so $C_{eq}= C_1+C_2+C_3+C_4$ so C_{eq} = 32 μF

Q18.(c) As it is connected to battery so V remains same but as capacitance changes so charge changes

Q19.(c) As F = qE and value of electric field is uniform in the space between the plates
So $F_A = F_B$

Q20.(c) total charge Q = nq and R= $n^{1/3}$r, So V = $n^{2/3}$V

PRACTICE QUESTIONS

1. If a charged spherical conductor of radius 10 cm has potential *V* at a point 5 cm distant from its center, then the potential at a point 15 cm distant from the center will be:

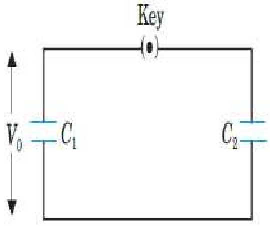
(a) 3V (b) $\frac{3}{2}V$ (c) $\frac{2}{3}V$ (d) $\frac{1}{3}V$

2. A parallel plate air capacitor has capacitance 18 μF. If the distance between the plates is made thrice and a dielectric medium is introduced, the capacitance becomes 72μF. The dielectric constant of the medium is:

(a) 4 (b) 9 (c) 12 (d) 2

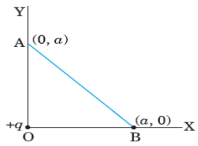
3. Select the incorrect statement.
   (a) Electric potential decreases inside electric field if one goes in a direction making an angle less than 90° with the direction of electric field intensity.
   (b) Electric potential increases at the fastest rate if one goes in the direction of electric field intensity.
   (c) Electric potential decreases at the fastest rate if one goes in the direction of electric field.
   (d) Electric potential increases at the fastest rate if one goes in the direction opposite to that of electric field.

4. A capacitor C_1 is charged by a potential difference V_0 as shown in the figure. This charging battery is then removed and the capacitor is connected to an uncharged capacitor C_2. The final potential difference V across the combination is:



(a) $V_0\left(\frac{C_1-C_2}{C_1}\right)$ (b) $V_0\left(\frac{C_1}{C_1-C_2}\right)$ (c) $V_0\left(\frac{C_1}{C_1+C_2}\right)$ (d) $V_0\left(\frac{C_1+C_2}{C_1}\right)$

5. As per this diagram, a point charge $+q$ is placed at the origin O. Work done in taking another point charge $-Q$ from the point A [co-ordinates $(0, a)$] to another point B [co-ordinates $(a, 0)$] along the straight path AB is:



(a) Zero (b) $\left(\frac{-qQ}{4\pi\varepsilon_0 a^2}\right)\sqrt{2}a$ (c) $\left(\frac{qQ}{4\pi\varepsilon_0 a^2}\right)\frac{a}{\sqrt{2}}$ (d) $\left(\frac{-qQ}{4\pi\varepsilon_0 a^2}\right)\sqrt{2}a$

ANSWERS

1.C 2.C 3.B 4.C 5.D

ASSERTION-REASON QUESTIONS

Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below:

(a) Both assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(b) Both assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).

(c) Assertion (A) is true and Reason (R) is false.

(d) Assertion (A) is false and Reason (R) is also false.

1. **Assertion (A):** Electric field is always normal to equipotential surfaces and along the direction of decreasing order of potential.
Reason (R): electric field is defined as negative gradient of electric potential.

2. **Assertion (A):** Electric field inside a hollow conducting sphere is zero.
Reason (R): Charge is present only on the outer surface of conductor.

3. **Assertion (A):** Work done in moving a charge between any two points in a uniform electric field is independent of the path followed by the charge between these two points.
Reason (R): Electrostatic forces are non-conservative.

4. **Assertion (A):** Electrostatic potential and electric potential energy are two different quantities.
Reason (R): For a test charge Q and a point charge Q, the electric potential energy becomes equal to the potential.

5. **Assertion (A):** When the distance between the parallel plates of a parallel plate capacitor is halved and the dielectric constant of the dielectric used is made three times, then the capacitance becomes three times.

Reason (R): Capacitance does not depend upon the external battery connected.

6. **Assertion (A):** Circuit containing capacitors should be handled very carefully even when the power is off.

Reason (R): The capacitors may break down at any time.

7. **Assertion (A):** Capacity of a conductor is independent on the amount of charge on it.

Reason (R): Capacitance depends on the dielectric constant of surrounding medium, shape and size of the conductor.

8. **Assertion (A):** Two parallel metal plates having charge +Q and –Q are facing at a distance between them. The plates are now immersed in kerosene oil and the electric potential between the plates decreases.

Reason (R): Dielectric constant of kerosene oil is less than 1.

9. **Assertion (A):** Two adjacent conductors of unequal dimensions, carrying the same positive charge have a potential difference between them.

Reason (R): The potential of a conductor does not depend upon the charge given to it.

10. **Assertion (A):** Polar molecules do not have permanent dipole moment.

Reason (R): In polar molecules, the centers of positive and negative charges coincide even when there is no external field.

ANSWERS

1. Option (A) is correct **:** E = - $\frac{dV}{dr}$. So, the electric field is always perpendicular to equipotential surface. Negative gradient of electric potential is electric field. So, direction of electric field must be in the direction of the decreasing order of electric potential.

2. Option (A) is correct**:** Since no charge resides in the surface of a hollow sphere, the electric field also zero inside. For hollow conducting sphere, the charged reside on the surface only.

3. Option (C) is correct. Work done in moving a charge between any two points in a uniform electric field = charge × potential difference. So, it is independent of the path followed by the charge. Electrostatic forces are conservative type.

4. Option (C) is correct. Electric potential and electric potential energy are two different quantities. Electric potential is defined as the potential energy per unit charge. Hence V = P.E./q.

5. Option (B) is correct. Initial capacitance $C_1 = C = \frac{K\varepsilon_0 A}{d}$, $C_2 = \frac{3K\varepsilon_0 A}{d/2}$ So $C_2 = 6C_1$**,**

6. Option (C) is correct. Even when power is off capacitor may have stored charge which may discharge through human body and thus one may get a shock. Breakdown of capacitors requires high voltage.

7. Option (A) is correct. C = $\frac{\varepsilon_0 A}{d}$. In the expression, there is no involvement of charge. So, capacitance is independent of charge. It depends on permittivity of the surrounding medium and the area of the plate.

8. Option (C) is correct. Electric field for parallel plate capacitor in vacuum $E = \frac{\sigma}{\varepsilon_0}$. Electric field in dielectric $E' = \frac{\sigma}{K\varepsilon_0}$. Since the value of K for Kerosene oil is greater than 1, then E'< E. Dielectric constant of Kerosene oil is greater than 1.

9. Option (C) is correct**.** Potential of a conductor depends upon charge and size of the body so potential of both will not be same.

10. Option (D) is correct. In polar molecules centre of positive charge does not coincide with centre of negative charge so they have net dipole moment.

PRACTICE QUESTIONS

1. **Assertion (A):** A metal plate is introduced between the plates of a charged parallel plate capacitor, its capacitance increased.

Reason(R): A metal plate is introduced between the plates of a charged parallel plate capacitor, the effective separation between the plates is decreased.

2. **Assertion (A):** Sensitive instruments can protect from outside electrical influence by enclosing them in a hollow conductor.

Reason(R): Potential inside the cavity is zero.

3. **Assertion (A):** The field intensity in between such sheets having equal and opposite uniform surface densities of charge become constant.

Reason(R): The field intensity does not depend upon the distance between the thin sheets.

4. **Assertion (A):** The electrostatic force between the plates of a charged isolated capacitor decreases when dielectric fills whole space between plates.

Reason(R): The electric field between the plates of a charged isolated capacitance increases when dielectric fills whole space between plates.

5. **Assertion (A):** Electric field inside a conductor is zero.

Reason(R): The potential at all the points inside a conductor is same.

Answers

1. A 2.C 3.A 4.D 5.B

VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

Q1 Two points R and S are equidistant from two charges +Q and -2Q. Calculate the amount of work done in moving a charge –Q from point R to S. **CBSE 2026 (55/5/3)**

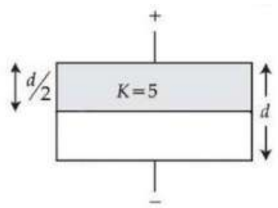
Q2 Two pint charges - 2 μC and 5 μC are placed at (-30cm,0) and (30cm,0) respectively in an external electric field $\vec{E} = \frac{A}{x^2}\,\hat{\imath}$ where A=9x10^5 Nm^2C^{-1}. Find the electrostatic potential energy of the configuration. **CBSE 2026 (55/3/2)**

Q3 A parallel plate capacitor of plate area A and plate separation d is completely filled with two dielectric slabs of dielectric constant K_1 and K_2 each of area A/2. Find the effective capacitance of the capacitor. **55B CBSE 2026**

Q4: (a) Draw electric field lines and equipotential surfaces for a system of two equal positive charges separated by some distance. (b) Using the drawings in (a) above, explain that electric field need not be a constant over each point of an equipotential surface. **CBSE 55/2/3**

Q5 Two air filled capacitors C_1 and C_2 are connected in parallel with a dc battery. After the capacitors are fully charged, a slab of dielectric constant K is inserted between the plates of each capacitor. How will the i) charge on each capacitor and ii) energy stored in the capacitor affected after the slab is introduced. **CBSE 55/2/3**

Q6 A parallel plate capacitor has a capacitance C. When it is half filled with a material of dielectric constant K=5 as shown in the figure, then calculate the percentage increase in the capacitance of the capacitor. **IIT JEE MAINS 2026**



Q7 A parallel plate air capacitor is connected to a battery. The plates are pulled apart at a uniform speed v. If x is the separation between the plates at any instant of the capacitor is then the time rate change of the electrostatic energy of the capacitor is proportional to x^{α}. Calculate the value of α. **IIT JEE 2026**

Q8: Obtain an expression for electrostatic potential energy of a system of three charges q, 2q and 3q placed at the vertices of an equilateral triangle of side a.

Q9 Two small conducting balls A and B of radius r_1 and r_2 have charges q_1 and q_2 respectively. They are connected by a wire. Obtain the expression for charges on A and B, in equilibrium.

Q10. Draw an equipotential surface for a system consisting of two charges Q, –Q separated by a distance r in air. Locate the points where the potential due to the dipole is zero.

SOLUTIONS

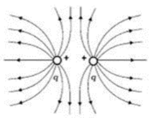
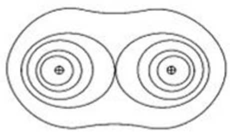
1: work $W=q(V_S-V_R)$; $V_R=\frac{1}{4\pi\varepsilon_0}(\frac{Q}{r_1}+\frac{(-2Q)}{r_2})$; $V_R=V_S$ so potential difference is zero and hence work done is also zero.

2: $V(r)=-\int E.dx=-\int\frac{A}{x^2}.dx=\frac{A}{x}$; $U=q_1 V(x_1)+q_2V(x_2)+\frac{q_1q_2}{4\pi\varepsilon_0x_{12}}=q_1A/x_1+q_2A/x_2+\frac{q_1q_2}{4\pi\varepsilon_0x_{12}}$

$x_1=x_2=30$cm , and $x_{12}=60$cm

So after substituting all the values we get U=8.85J

3 : Sol $C_1=\frac{K_1\varepsilon_0A/2}{d}$ and $C_2=\frac{K_2\varepsilon_0A/2}{d}$ so $C_{eq}=C_1+C_2=\frac{K_1\varepsilon_0A}{2d}+\frac{K_2\varepsilon_0A}{2d}=\frac{\varepsilon_0A}{2d}(K_1+K_2)$

4 (a)  

(b) Different points on an equipotential surface might be at different distances from the source charge,so the electric field will not be constant at all points as shown in the diagram

5: In parallel combination the potential difference is same across the capacitors. On inserting dielectric slab capacitance become K times, so charge becomes K times.

Energy stored by a capacitor $U=1/2\ CV^2$. As capacitance becomes K times energy stored by each capacitor also increases by a factor of K(dielectric constant)

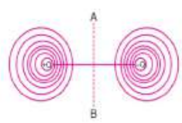
6 Initial capacitance: C= $C=\varepsilon_0A/d$ New capacitance = C/2 (1+K) ; K=5(given) so $C_{new}=3C$ change in capacitance = 2C so change in %=200%

7**:** $C=\frac{\varepsilon_0A}{x}$ $U=1/2\ CV^2$, $U=1/2\frac{\varepsilon_0A}{x}V^2$ so U α 1/x , Now dU/dt = dU/dx × dx/dt dx/dt = velocity

Since U α 1/x so dU/dx α x^{-2} hence alpha is proportional to x^{-2}

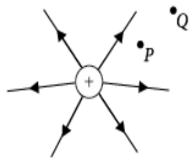
8**:** potential energy of the system is $U=\frac{1}{4\pi\varepsilon_o}\frac{q_1q_2}{r}$ so $U=\frac{1}{4\pi\varepsilon_o}\frac{(-7q^2)}{a}$

9**:**According to law of conservation of charge ; $q_i=q_f$: $q_1+q_2=q_1+q_2=Q$, i f When two balls are connected with wire : $V_1=V_2$: $q_1=\frac{Qr_1}{r_1+r_2}$ and $q_2=\frac{Qr_2}{r_1+r_2}$ and $Q=q_1+q_2$



10: The equipotential surface for the system is as shown. Electric potential is zero at all points in the plane passing through the dipole equator AB.

PRACTICE QUESTIONS



Q1. Figure shows the field lines on a positive charge. Is the work done by the field in moving a small positive charge from Q to P positive or negative? Give reason.

Q2. What is the amount of work done in moving a point charge Q around a circular arc of radius 'r' at the centre of which another point charge 'q' is located?

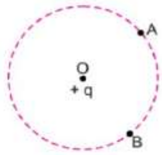
Q3. What should be the charge on a sphere of radius 4 cm, so that when it is brought in contact with another sphere of radius 2 cm carrying charge of 10 μC, there is no transfer of charge from one sphere to other?

Q4. A parallel plate is charged by a battery. When the battery remains connected, a dielectric slab is inserted in the space between the plates. Explain what changes if any, occur in the values of (i) Potential difference between the plates (ii) Capacitance (iii) Charge on the plates (iv) Energy stored in the capacitor?

Q5. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor.

ANSWERS

1. The work done by the field is negative. This is because the charge is moved against the force exerted by the field.



2. The potential of points A and B are same being equal to $V_A = V_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$,Where R is the radius of the circle. Work done W= q ($V_B - V_A$) = q ($V_A - V_A$) = 0

3. $V_A = V_B$, Hence Q = 20μC

4. (i) When battery remains connected, the potential difference remains the same.
   (ii) The capacitance of capacitor increases as K > 1. (iii) The charge Q = CV, V = same, C = increases; there, charge on plates increases (iv) Energy stored by capacitor increases.
   (v) Electric field strength remains same.

5. $U_f : U_i = 1:2$

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

Q1 Two parallel plate capacitors X and Y are connected in series to a 6 V battery. They have the same plate area and same plate separation but capacitor X has air between its plates, whereas capacitor Y contains a material of dielectric constant 4.

(a) Calculate the capacitances of X and Y, if the equivalent capacitance of the combination of X and Y is 4 μF.

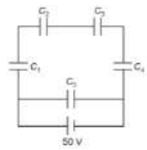
(b) Calculate the potential difference across the plates of X and Y. **(CBSE 2026 55/5/1)**

Q2 A 12 μF capacitor is charged to a potential difference of 150V. The terminals of the charged capacitor are then connected to those of an uncharged 6μF capacitor. Calculate the potential difference and charge on each capacitor.

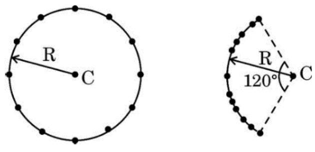
Q3 A three coulomb charge moves from a point (0,-2,-5) to another point (5, 1, 2) in an electric field given by E= $2x\hat{\imath} + 3y^2\hat{\jmath} + 4\hat{k}$ N/C. Calculate the work done in moving the charge in this distance. **JEE Mains 2026**

Q4 A metal sphere of capacitance 100pF is charged to a potential of 100V. Another identical metal uncharged sphere is brought in contact with the charged sphere. Calculate the change in energy stored in the capacitors when they touch each other. ($5/2 \times 10^{-7}$J)

Q5 Five capacitors of capacitances $C_1 = C_2 = C_3 = C_4 = 10\ \mu F$ and $C_5 = 2.5\ \mu F$ are connected as shown, along with a battery of 50 V. Find the equivalent capacitance and the charges on each capacitor



Q6 a) Twelve negative charges of same magnitude are equally spaced and fixed on the circumference of a circle of radius R as shown in Fig. (i). Relative to potential being zero at infinity, find the electric potential and electric field at the center C of the circle.
b) If the charges are unequally spaced and fixed on an arc of 120^0 of radius R as shown in Fig. (ii), find electric potential at the center C. **CBSE 55/1/1**



(i) (ii)

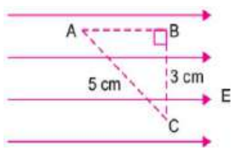
Q7 A parallel plate capacitor (A) of capacitance C is charged by a battery to voltage V. The battery is disconnected and an uncharged capacitor (B) of capacitance 2C is connected across A. Find the ratio of:

(a) Final charges on A and B
(b) Total electrostatic energy stored in A and B initially and energy stored in A initially

Q8 Two point charges + q and q are located at points (3a, 0) and (0, 4a) respectively in x-y plane. A third charge Q is kept at the origin. Find the value of Q, in terms of q and a, so that the electrostatic potential energy of the system is zero.

Q9 Two isolated metallic spheres S_1 and S_2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density ($2/\pi \times 10^{-9}$ C/m^2). They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S_2.

Q10. Three points A, B and C lie in a uniform electric field (E) of 5×10^3 NC^{-1} as shown in the figure. Find the potential difference between (i)A and B, and (ii) A and C.



SOLUTIONS

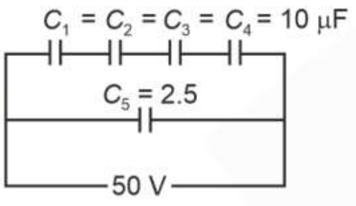
1**:** $1/C_{eq}=1/C_1+1/C_2$ given that $C_{eq}=4$, and $C_x=C$, $C_Y=4C$ so C=5μF and $C_Y=4C=20\mu F$. Total charge q= $C_{eq}V=24 \times 10^{-6}$C , $V_X=q/C_x=4.8$ V & $V_Y=q/C_Y=1.2$V

2: Common potential across both the capacitors = $\frac{C_1V_1+C_2V_2}{C_1+C_2}$, $V_2=0$ so V_c=100V ,

Charge on C_1 , $q_1=C_1V_c$=12 μFx100V=1200 μC and $q_2=C_2V_c$=600 μC

3**:** W=$\int E.dr = \int 2x\hat{\imath} + 3y^2\,\hat{\jmath} + 4\hat{k}\,.(dxi + dyj + dzk)$, W=x^2+y^3+4z evaluate this from (0,-2,-5) to another point (5,1,2) & we get W=186J.

4: Ans: common potential = V_c=50V, U_i=1/2 CV^2 = 5x10^{-7}J and U_f = 2.5 x 10^{-7}J. Change in the energy = 2.5 x 10^{-7}J



5**:** Ceq = 2.5 + 2.5 = 5 μF, $q_1 = q_2 = q_3 = q_4$ = 2.5 × 50 = 125 μC, q_5 = 2.5 × 50 = 125 μC

6**:** a) Electric potential due to point charge V= kq/R Value of each charge = -q, Total charge = -12q Total potential V=k (-12q)/R = -12q/4πε_0R . By symmetry the resultant of all electric field vectors becomes zero. So electric field is zero. (b) Electric potential is a scalar quantity and does not depend on placement of charges .Therefore V= 12kq/R, V=-12q/4πε_0R

7: a) Initially Q= CV Finally $q_A=C_AV_1$ and $q_B=C_BV_1$; $q_A/q_B=C_A/C_B$ =1/2

(b) q_A+q_B=Q , q_A=Q/3 & q_B=2Q/3 so U_A+U_B/U_{Ai} = 1/3

8: Potential energy of the system = $k(\frac{Q(-q)}{4a}+\frac{qQ}{3a}-\frac{q^2}{5a})$; Potential energy of the system = 0. So $K\ (\frac{Q(-q)}{4a}+\frac{qQ}{3a}-\frac{q^2}{5a})$ = 0; Q=12q/5

9: Charge on sphere S_1 : Q1 = surface charge density x surface Area =8 x 10^{-13} C. Charge on sphere S_2 : 72 x 10^{-13} C : When connected by a thin wire they acquire a common potential V and the charge remains conserved. $Q_1+Q_2= Q'_1+Q'_2$ on solving Q'_1= 2x10^{-12}C

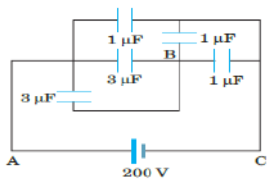
10: (i) Potential difference between A and B = E × (AB) = 5 × 10^3 × (4 × 10^{-2}) = 200 volt

(ii) The line joining B to C is perpendicular to electric field, so potential of B = potential of C i.e., $V_B = V_C$ Distance AB =4 cm

Potential difference between A and C = E × (AB) = 5 × 10^3 × (4 × 10–2) = 200 volt

PRACTICE QUESTIONS

Q1. A charged particle of mass *m* and charge *q* is kept initially at rest on a frictionless surface. Another charged particle of mass 4*m* and charge 2*q* starts moving with velocity *v* towards it. Calculate the distance of the closest approach for both the charged particles.



Q2. (a) Four identical metallic balls were placed diametrically opposite on the circumference of an imaginary circle of radius 10m. The first three balls were charged with 30mC, 40mC and -70mC charge. Evaluate the value of charge(q) given to the fourth ball so that the net potential at the centre of the circle becomes zero .

Q3. A capacitor of 200 pF is charged by a 300 V battery. The battery is then disconnected and the charged capacitor is connected to another uncharged capacitor of 100 pF. Calculate the difference between the final energy stored in the combined system and the initial energy stored in the single capacitor.

Q4. A parallel plate capacitor is charged by a battery. After sometime the battery is disconnected and a dielectric slab with its thickness equal to the plate separation is inserted between the plates. How will (i) the capacitance of the capacitor, (ii) potential difference between the plates and (iii) the energy stored in the capacitor be affected? Justify your answer in each case.

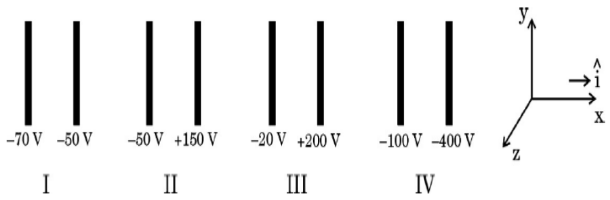
Q5. Find the ratio of the potential difference that must be applied across the parallel and the series combination of two identical capacitors so that the energy stored in the two cases, becomes the same.

ANSWERS

1. $\frac{1}{4\pi\varepsilon_0}\frac{5q^2}{mv^2}$ 2. q=0 3. $3X10^{-6}$ J 4. $C = KC_0$, $V=\frac{1}{K}V0$, $E=\frac{1}{K}E_0$ 5. $V_P : V_S = 1:2$

CASE STUDY TYPE QUESTIONS

1. The above figure shows four pairs of parallel identical conducting plates, separated by the same distance 2.0 cm and arranged perpendicular to x-axis. The electric potential of each plate is mentioned. The electric field between a pair of plates is uniform and normal to the plates. (i) For which pair of the plates is the electric field E along $\hat{\imath}$?



(A) I (B) II (C) III (D) IV

(ii) An electron is released midway between the plates of pair IV. It will:

(A) Move along $\hat{\imath}$ at constant speed (B) move along -$\hat{\imath}$ at constant speed

(C) Accelerate along $\hat{\imath}$ (D) accelerate along -$\hat{\imath}$

(iii) Let E_1, E_2, E_3 and E_4 be the magnitudes of the electric field between the pairs of plates, I, II, III and IV respectively, then:

(A) $E_1 > E_2 > E_3 > E_4$ (B) $E_3 > E_4 > E_1 > E_2$

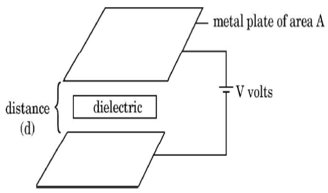
(C) $E_4 > E_3 > E_2 > E_1$ (D) $E_2 > E_3 > E_4 > E_1$

(iv) An electron is projected from the right plate of set I directly towards its left plate. It just comes to rest at the plate. The speed with which it was projected is about:

(Take (e/m) =$1.76 X 10^{11}$ C/kg)

(A) $1.3 X 10^5$ m/s (B) $2.6 X 10^6$ m/s (C) $6.5 X 10^5$ m/s (D) $5.2 X 10^7$ m/s

2. A parallel plate capacitor is an arrangement of two identical metal plates kept parallel, a small distance apart. The capacitance of a capacitor depends on the size and separation of the two plates and also on the dielectric constant of the medium between the plates. Like resistors, capacitors can also be arranged in series or parallel or a combination of both. By virtue of electric field between the plates, charged capacitors store energy.



(a) The capacitance of a parallel plate capacitor increases from 10μF to 80μF on introducing a dielectric medium between the plates. Find the dielectric constant of the medium.

(b) n capacitors, each of capacitance C, are connected in series. Find the equivalent capacitance of the combination.

(c) A capacitor is charged to a potential (V) by connecting it to a battery. After some time, the battery is disconnected and a dielectric is introduced between the plates. How will the potential difference between the plates, and the energy stored in it be affected? Justify your answer.

ANSWERS

Ans.1. (i) (D) IV (ii) (D) accelerate along -$\hat{\imath}$ (iii) (C) $E_4 > E_3 > E_2 > E_1$ (iv) (B) $2.6 X 10^6$ m/s

Ans.2 (a) K=8 (b) $C_s= \frac{C}{n}$ (c) Potential difference decreases by a factor 1/K, Energy reduces by a factor 1/K

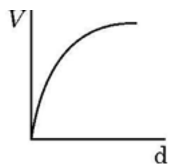
PRACTICE QUESTIONS

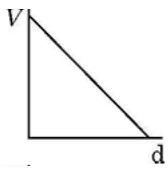
Q1 .A parallel plate capacitor has two parallel plates which are separated by an insulating medium like air, mica etc. When the plate are connected to the terminals of a battery they get equal and opposite charges and an electric field is set up in between them. The electric field between the two plates depends upon the potential difference applied, the separation of the plates and nature of the medium between the plates.

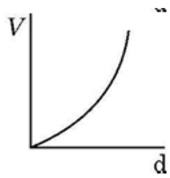
(i) The electric field between the plates of a parallel plate capacitor is E. Now the separation between the plates is doubled and simultaneously the applied potential difference between the plates is reduced to half of its initial value The new value value of the electric field between the plates will be :

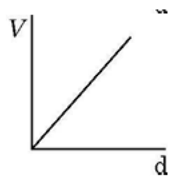
(a) E (b) 2E (c) E/4 (d) E/2

(ii) A constant electric field is to be maintained between the two plates of a capacitor whose separation d changes with time. Which of the graphs correctly depict the potential difference (V) between the plates as a function of separation between the plates to maintain the constant electric field.

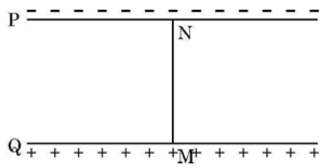
(a) 

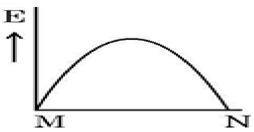
(b) 

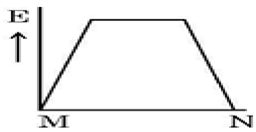
(c) 

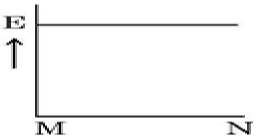
(d) 

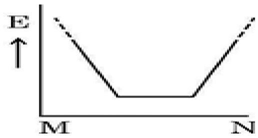
(iii) In the above figure P,Q are the two parallel plates of a capacitor. Plate Q is at positive potential with respect to plate P. MN is an imaginary line drawn perpendicular to the plates. Which of the graphs shown correctly the variation of the magnitude of electric field strength E along the line MN?



(A) 

(B) 

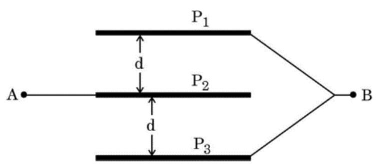
(C) 

(D) 

(iv) Three parallel plates are placed above each other with equal displacement d between the neighboring plates. The electric field between the first pair of the plates is E_1 and electric field between the second pair of the plate is E_2. The potential difference between the third and first plate is?

(a) $(\overrightarrow{E_1}+\overrightarrow{E_2}).\vec{d}$ (b) $(\overrightarrow{E_1}-\overrightarrow{E_2}).\vec{d}$ (c) $(\overrightarrow{E_2}-\overrightarrow{E_1}).\vec{d}$ (d) $d(E_1+E_2)/2$

2. A parallel plate capacitor consists of two conducting plates kept generally parallel to each other at a distance. When the capacitor is charged, the charge resides on the inner surfaces of the plates and an electric field is set up between them. Thus, electrostatic energy is stored in the capacitor. The figure shows three large square metallic plates, each of edge length 'L' held parallel and equidistant from each other. The space



between P_1 and P_2 and P_2 and P_3 is completely filled with mica sheets of dielectric constant K. The plate P_2 is connected to point A and other plates P_1 and P_3 are connected to point B. Point A is maintained at a positive potential with respect to point B and the potential difference between A and B is V. **2025 CBSE**

(i) The capacitance of the system between A and B will be:

(a) $\frac{\varepsilon_0 KL^2}{d}$ (b) $\frac{\varepsilon_0 KL^2}{2d}$ (c) $\frac{2\varepsilon_0 KL^2}{d}$ (d) $\frac{2\varepsilon_0 Kd}{L^2}$

(ii) The charge on plate P_1 is:

(a) $\frac{\varepsilon_0 VKL^2}{2d}$ (b) $\frac{\varepsilon_0 VKL^2}{d}$ (c) $\frac{2\varepsilon_0 VKL^2}{d}$ (d) $\frac{\varepsilon_0 VKL^2}{4d}$

(iii) The electric field in the region between P_1 and P_2 is:

(a) V/d (b) 2V/d (c) V/2d (d) d/V

(iv) The separation between the plates of same area L^2 of a parallel plate air capacitor having capacitance equal to that of this system, will be :

(a) d/K (b) 2d/K (c) d/2K (d) d /4K

ANSWERS PRACTICE QUESTIONS

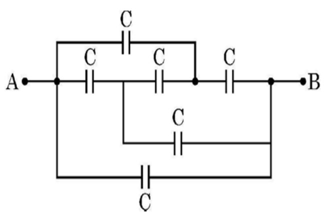
Ans.1 (i) (c) E/4. (ii) (d) (iii)(c) (iv) (a) $(\vec{E_1}+\vec{E_2}).\vec{d}$

Ans 2: (i) (c) $\frac{2\varepsilon_0 KL^2}{d}$ (ii) (b) $\frac{\varepsilon_0 VKL^2}{d}$ (iii) (a)V/d (iv) (c) d/2K

LONG ANSWER TYPE QUESTIONS

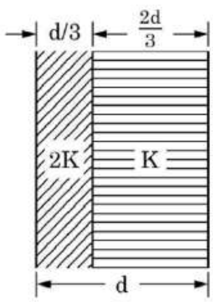
Q1 (i)Find the equivalent capacitance between A and B in the given figure.

(ii) A dielectric slab is inserted between the plates of a capacitor. The electric between the plates decreases. Explain.



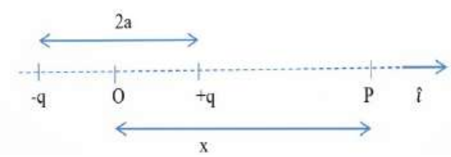
(iii) A capacitor A of capacitance C , having a charge Q is connected across another uncharged capacitor B of capacitance 2C find an expression for (a) potential difference across the combination and (b) Charge lost by capacitor A

(iv) Two slabs of dielectric constant 2K and K fill the space between plates of a parallel plate capacitor of plate area A and plate separation d as shown in the figure. Find the equivalent capacitance of the system



Q2. (i) An electric dipole (dipole moment $\vec{p} = p\hat{\imath}$), consisting of charges - q and q, separated by distance 2a, is placed along the x-axis, with its centre at the origin. Show that the potential V, due to this dipole, at a point x, (x >> a) is equal to $\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2}$

(ii) Two isolated metallic spheres S_1 and S_2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density $\left(\frac{2}{\pi} X\ 10^{-9}\right)$C/m^2.. They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S_1.



Q3 (i) Derive an expression for potential energy of an electric dipole p in an external uniform electric field E . When is the potential energy of the dipole (1) maximum, and (2) minimum?

(ii) Three point charges q, 2q and nq are placed at the vertices of an equilateral triangle. If the potential energy of the system is zero, find the value of n.

ANSWERS

1: (i) C_{net}= C+C = 2C, (ii) Within the dielectric slab, induced electric field due to polarization, Decreases the electric field. $E=E_o/K$ (iii) (a)$V' = Q_{total} / C_{eq} = Q/3C = V/3$ (b) charge lost by capacitor = Q-Q/3 = 2Q/3 (iv) $C_1=6K\varepsilon_0 A/d$, $C_2=3K\varepsilon_0 A/2d$, $1/C_{eq}=1/C_1+1/C_2$; $C_{eq} = 6K\varepsilon_0 A/5d$

2 : (i) Derive expression of potential at P, $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{x^2-a^2}$ As p is along x-axis so, $V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2-a^2}$ If x>>a, $V= \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2}$ (ii) Charge on $S_1 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} X\ 10^{-9}\right) \times 4\pi\ (1X\ 10^{-2})^2 = 8 X 10^{-13}$ C, Charge on $S_2 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} X\ 10^{-9}\right) \times 4\pi\ (3X\ 10^{-2})^2 = 72 X 10^{-13}$ C When connected by thin wire they acquire common potential V and charge remains conserved $Q_1 + Q_2 = Q_1' + Q_2'$ and $\frac{Q_1'}{Q_2'} = \frac{r_2}{r_1}$, On solving $Q_1' = 2 X 10^{-12}$ C

3: (i) Derivation of expression of potential Energy, $U(\theta) = -p\ E\ cos\ cos\ \theta\ = \vec{p}.\vec{E}$

(1) Potential energy is maximum $\theta = 180^0$, (2) Potential energy is minimum $\theta = 0^0$

(ii) Consider an equilateral triangle of side a, Potential energy $U= \frac{kq_1q_2}{a} + \frac{kq_2q_3}{a} + \frac{kq_1q_3}{a}$

$U= \frac{k\ q\ .2q}{a} + \frac{k\ 2q\ .nq}{a} + \frac{k\ q\ .nq}{a}$, According to question U=0, So $\frac{k\ q\ .2q}{a} + \frac{k\ 2q\ .nq}{a} + \frac{k\ q\ .nq}{a} = 0$, After solving $n = -\frac{2}{3}$

PRACTICE QUESTIONS

1. (i) Draw equipotential surfaces of an electric dipole.

(ii) Two point charges q_1 and q_2 are located at $\vec{r_1}$ and $\vec{r_2}$ respectively in an external field $\vec{E}$. Obtain an expression for potential energy of the system

(iii) The dipole moment of a molecule is 10^{-30} Cm. It is placed in an electric field $\vec{E}$ of 10^5 V/m such that its axis is along the electric field. The direction of $\vec{E}$ is suddenly changed by 60° at an instant. Find the change in the potential energy of the dipole, at that instant.

2. (i) A dielectric slab of dielectric constant 'K' and thickness 't' is inserted between plates of a parallel plate capacitor of plate separation d and plate area A. Obtain an expression for its capacitance.(ii) Two capacitors of different capacitances are connected first (1) in series and then (2) in parallel across a dc source of 100 V. If the total energy stored in the combination in the two cases are 40 mJ and 250 mJ respectively, find the capacitance of the capacitors.

3.(a) Derive an expression for potential energy of a dipole in an external field.

(b) Draw equipotential surfaces due to an isolated point charge (+ q) and depict the electric field lines.

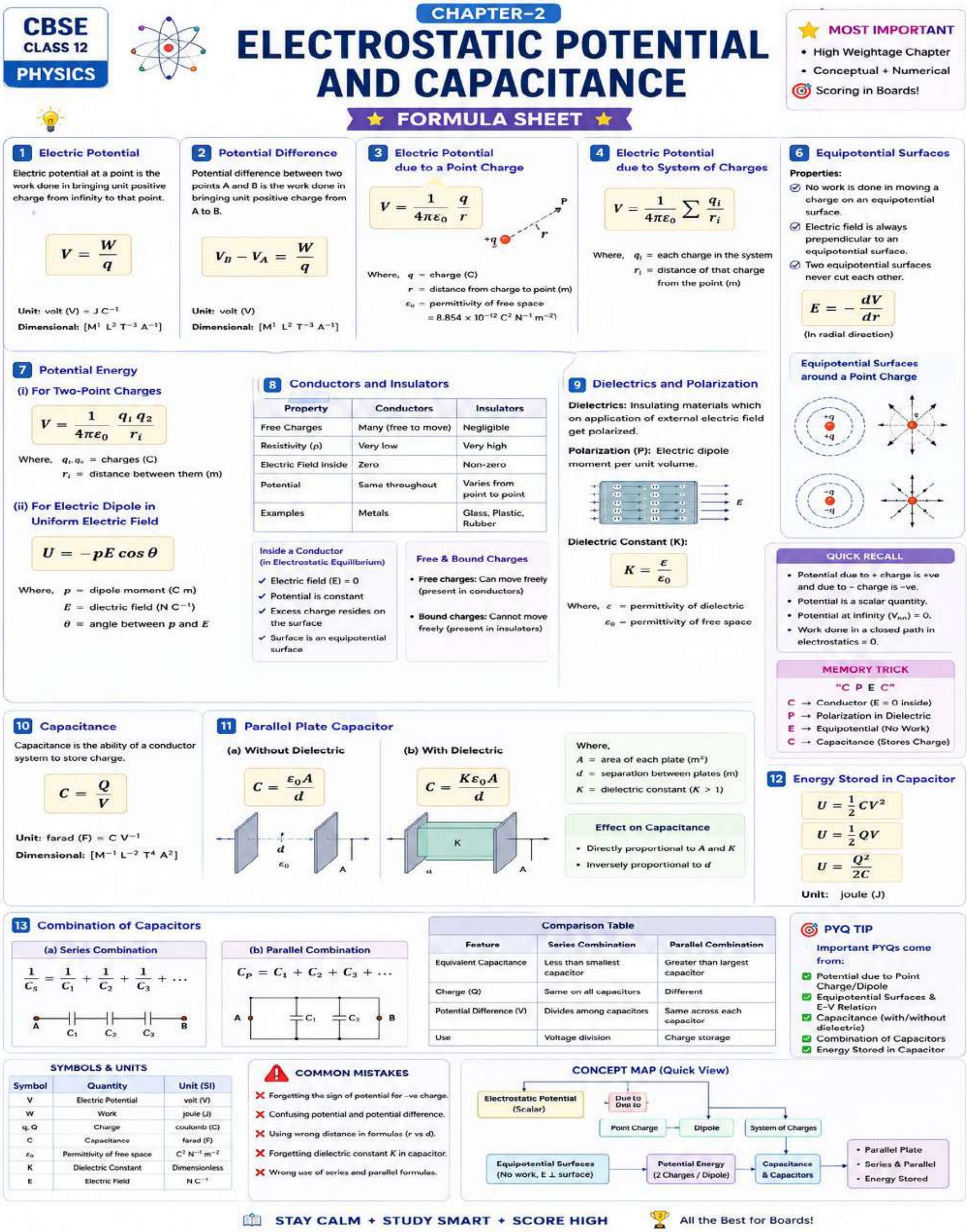
(c) Three point charges + 1 µC, – 1 µC and + 2 µC are initially infinite distance apart. Calculate the work done in assembling these charges at the vertices of an equilateral triangle of side 10 cm.

ANSWERS

1. (i) Suitable Diagram, (ii) potential energy of the system = q_1 V $(\vec{r_1})$ + q_2 V $(\vec{r_2})$ + $\frac{1}{4\pi\varepsilon_0}\ \frac{q_1q_2}{r_{12}}$, (iii) $5 X 10^{-26}$J

2. (i) Derivation of correct expression. $C = \frac{K\varepsilon_0\ A}{d-t+\frac{t}{k}}$. (ii) $C_1 = 40\mu f$ and $C_2 = 10\mu f$

3. (a) Correct derivation U= - pE$\cos \cos \theta$. (b) Suitable Diagram (c) W = -0.09 J



CBSE CLASS 12 PHYSICS

CHAPTER–2

ELECTROSTATIC POTENTIAL AND CAPACITANCE

★ FORMULA SHEET ★

MOST IMPORTANT
- High Weightage Chapter
- Conceptual + Numerical
- Scoring in Boards!

1 Electric Potential

Electric potential at a point is the work done in bringing unit positive charge from infinity to that point.

$$V = \frac{W}{q}$$

Unit: volt (V) = J C^{-1}

Dimensional: [M^1 L^2 T^{-3} A^{-1}]

2 Potential Difference

Potential difference between two points A and B is the work done in bringing unit positive charge from A to B.

$$V_B - V_A = \frac{W}{q}$$

Unit: volt (V)

Dimensional: [M^1 L^2 T^{-3} A^{-1}]

3 Electric Potential due to a Point Charge

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

Where, q = charge (C)

r = distance from charge to point (m)

ε_0 = permittivity of free space = 8.854 × 10^{-12} C^2 N^{-1} m^{-2}

4 Electric Potential due to System of Charges

$$V = \frac{1}{4\pi\varepsilon_0}\sum \frac{q_i}{r_i}$$

Where, q_i = each charge in the system

r_i = distance of that charge from the point (m)

6 Equipotential Surfaces

Properties:
- No work is done in moving a charge on an equipotential surface.
- Electric field is always perpendicular to an equipotential surface.
- Two equipotential surfaces never cut each other.

$$E = -\frac{dV}{dr}$$

(In radial direction)

Equipotential Surfaces around a Point Charge

7 Potential Energy

(i) For Two-Point Charges

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_i}$$

Where, q_1, q_2 = charges (C)

r_i = distance between them (m)

(ii) For Electric Dipole in Uniform Electric Field

$$U = -pE\cos\theta$$

Where, p = dipole moment (C m)

E = directric field (N C^{-1})

θ = angle between p and E

8 Conductors and Insulators

Property	Conductors	Insulators
Free Charges	Many (free to move)	Negligible
Resistivity (ρ)	Very low	Very high
Electric Field inside	Zero	Non-zero
Potential	Same throughout	Varies from point to point
Examples	Metals	Glass, Plastic, Rubber

Inside a Conductor (in Electrostatic Equilibrium)
- ✓ Electric field (E) = 0
- ✓ Potential is constant
- ✓ Excess charge resides on the surface
- ✓ Surface is an equipotential surface

Free & Bound Charges
- Free charges: Can move freely (present in conductors)
- Bound charges: Cannot move freely (present in insulators)

9 Dielectrics and Polarization

Dielectrics: Insulating materials which on application of external electric field get polarized.

Polarization (P): Electric dipole moment per unit volume.

Dielectric Constant (K):

$$K = \frac{\varepsilon}{\varepsilon_0}$$

Where, ε = permittivity of dielectric

ε_0 = permittivity of free space

QUICK RECALL
- Potential due to + charge is +ve and due to − charge is −ve.
- Potential is a scalar quantity.
- Potential at infinity (V_∞) = 0.
- Work done in a closed path in electrostatics = 0.

MEMORY TRICK

"C P E C"

C → Conductor (E = 0 inside)

P → Polarization in Dielectric

E → Equipotential (No Work)

C → Capacitance (Stores Charge)

10 Capacitance

Capacitance is the ability of a conductor system to store charge.

$$C = \frac{Q}{V}$$

Unit: farad (F) = C V^{-1}

Dimensional: [M^{-1} L^{-2} T^4 A^2]

11 Parallel Plate Capacitor

(a) Without Dielectric

$$C = \frac{\varepsilon_0 A}{d}$$

(b) With Dielectric

$$C = \frac{K\varepsilon_0 A}{d}$$

Where,

A = area of each plate (m^2)

d = separation between plates (m)

K = dielectric constant (K > 1)

Effect on Capacitance
- Directly proportional to A and K
- Inversely proportional to d

12 Energy Stored in Capacitor

$$U = \frac{1}{2}CV^2$$

$$U = \frac{1}{2}QV$$

$$U = \frac{Q^2}{2C}$$

Unit: joule (J)

13 Combination of Capacitors

(a) Series Combination

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

(b) Parallel Combination

$$C_P = C_1 + C_2 + C_3 + \ldots$$

Comparison Table

Feature	Series Combination	Parallel Combination
Equivalent Capacitance	Less than smallest capacitor	Greater than largest capacitor
Charge (Q)	Same on all capacitors	Different
Potential Difference (V)	Divides among capacitors	Same across each capacitor
Use	Voltage division	Charge storage

PYQ TIP

Important PYQs come from:
- Potential due to Point Charge/Dipole
- Equipotential Surfaces & E–V Relation
- Capacitance (with/without dielectric)
- Combination of Capacitors
- Energy Stored in Capacitor

SYMBOLS & UNITS

Symbol	Quantity	Unit (SI)
V	Electric Potential	volt (V)
W	Work	joule (J)
q, Q	Charge	coulomb (C)
C	Capacitance	farad (F)
ε_0	Permittivity of free space	C^2 N^{-1} m^{-2}
K	Dielectric Constant	Dimensionless
E	Electric Field	N C^{-1}

COMMON MISTAKES
- ✗ Forgetting the sign of potential for –ve charge.
- ✗ Confusing potential and potential difference.
- ✗ Using wrong distance in formulas (r vs d).
- ✗ Forgetting dielectric constant K in capacitor.
- ✗ Wrong use of series and parallel formulas.

CONCEPT MAP (Quick View)

Electrostatic Potential (Scalar) → Due to → Point Charge, Dipole, System of Charges

Equipotential Surfaces (No work, E ⊥ surface) → Potential Energy (2 Charges / Dipole) → Capacitance & Capacitors → Parallel Plate, Series & Parallel, Energy Stored

STAY CALM + STUDY SMART + SCORE HIGH

All the Best for Boards!

CHAPTER 03

CURRENT ELECTRICITY

1. ELECTRIC CURRENT

Electric current is the rate of flow of electric charge.

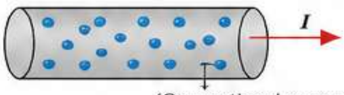
$$\boxed{I = \frac{dQ}{dt}}$$ (Unit: ampere, A)

$1\ \text{A} = 1\ \text{C s}^{-1}$

Conventional current flows from higher potential to lower potential.

2. FLOW OF ELECTRIC CHARGES IN A METALLIC CONDUCTOR

In a metal, current is due to the flow of free electrons.



Electrons drift opposite to the conventional current.

3. DRIFT VELOCITY

Average velocity acquired by free electrons in a conductor due to the applied electric field.

$$\boxed{v_d = \frac{I}{nAe}}$$

where, n = number density of free electrons
A = cross-sectional area
e = charge of electron (1.6×10^{-19} C)

Direction of v_d is opposite to I.

4. MOBILITY AND ITS RELATION WITH CURRENT

Mobility (μ) is the drift velocity acquired per unit electric field.

$$\boxed{\mu = \frac{v_d}{E}}$$ (Unit: $\text{m}^2\ \text{V}^{-1}\ \text{s}^{-1}$)

Since $E = \frac{V}{\ell}$ and $I = nAev_d$

$$\boxed{I = nAe\mu E = \frac{nAe\mu}{\ell} V}$$

Current is directly proportional to potential difference (V) for a given conductor (Ohm's law).

Where,
n = number density
A = cross-sectional area
e = charge of electron
μ = mobility
ℓ = length of conductor
E = electric field
V = potential difference

5. OHM'S LAW

At constant temperature, current through a conductor is directly proportional to the potential difference across it.

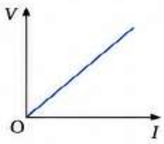
$$\boxed{V = IR}$$

where, R = resistance (ohm, Ω)

$$R = \frac{V}{I}$$

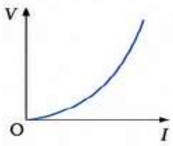
6. V–I CHARACTERISTICS

(a) Linear (Ohmic Conductor)



Straight line
(R = constant)

(b) Non-linear (Non-ohmic Conductor)



Curve
($R \neq$ constant)

7. ELECTRICAL ENERGY AND POWER

Electrical Energy (W)

Work done in time t:

$$\boxed{W = VIt = I^2Rt = \frac{V^2}{R}t}$$

Unit: joule (J) or watt-hour (Wh)

Electrical Power (P)

Rate of doing work:

$$\boxed{P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}}$$

Unit: watt (W)

8. RESISTIVITY AND CONDUCTIVITY

Resistivity (ρ)

$$\boxed{R = \rho\frac{\ell}{A}}$$

Unit: Ω m

(Depends on material and temperature)

Conductivity (σ)

$$\boxed{\sigma = \frac{1}{\rho}}$$

Unit: S m^{-1}

(Siemens per meter)

Good conductors: high σ (low ρ)

9. TEMPERATURE DEPENDENCE OF RESISTANCE

For metals (approx.)

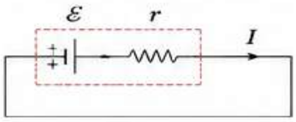
$$\boxed{R_T = R_0[1 + \alpha(T - T_0)]}$$

where,
R_T = resistance at temperature T
R_0 = resistance at reference temperature T_0
α = temperature coefficient of resistance (K^{-1})

For semiconductors: Resistance decreases with increase in temperature.

10. INTERNAL RESISTANCE OF A CELL

A real cell has some resistance (r) inside it.



Terminal potential difference across R:

$$V = IR = \mathcal{E} - Ir$$

11. POTENTIAL DIFFERENCE AND EMF OF A CELL

Potential Difference (V)

Energy spent per unit charge between two points.

$$\boxed{V = \frac{W}{q}}$$

EMF ($\mathcal{E}$)

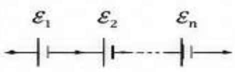
Energy supplied per unit charge by the cell (open circuit).

$$\boxed{\mathcal{E} = \frac{W}{q}}$$

For a cell delivering current: $\mathcal{E} = V + Ir$

12. COMBINATION OF CELLS

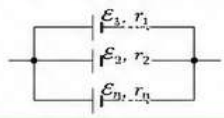
(a) Series Combination



$$\mathcal{E}_{eq} = \mathcal{E}_1 + \mathcal{E}_2 + \cdots + \mathcal{E}_n$$

$$r_{eq} = r_1 + r_2 + \cdots + r_n$$

(b) Parallel Combination



$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \cdots + \frac{1}{r_n}$$

(If cells are identical: $\mathcal{E}_{eq} = \mathcal{E}$, $r_{eq} = \frac{r}{n}$)

13. KIRCHHOFF'S RULES

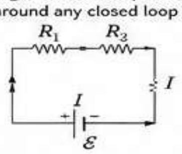
(a) Junction Rule (KCL)

Algebraic sum of currents at a junction is zero.

$$\boxed{I_1 + I_2 = I_3 + I_4 \quad (\text{or } \textstyle\sum I = 0)}$$

(b) Loop Rule (KVL)

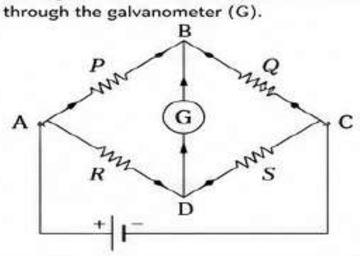
Algebraic sum of potential differences around any closed loop is zero.



$$\boxed{\textstyle\sum(\pm IR) + \sum(\pm\mathcal{E}) = 0 \quad (\text{or } \sum V = 0)}$$

14. WHEATSTONE BRIDGE

A bridge is balanced when no current flows through the galvanometer (G).



Balance condition:

$$\frac{P}{Q} = \frac{R}{S} \quad \text{or} \quad PS = QR$$

Symbols Used

I : Current (A)
V : Potential difference (V)
R : Resistance (Ω)
r : Internal resistance (Ω)
$\mathcal{E}$: EMF (V)
ρ : Resistivity (Ω m)
σ : Conductivity (S m^{-1})
μ : Mobility ($\text{m}^2\ \text{V}^{-1}\ \text{s}^{-1}$)
v_d : Drift velocity (m s^{-1})
A : Area (m^2)
n : Number density (m^{-3})
e : Charge of electron (C)
ℓ : Length (m)
T : Temperature (K)

Key Units

Current : ampere (A)
Charge : coulomb (C)
Potential : volt (V)
Resistance : ohm (Ω)
Energy : joule (J)
Power : watt (W)
Resistivity : Ω m
Conductivity : S m^{-1}

Note

All relations are for steady current and uniform conductors unless stated.

MULTIPLE CHOICE QUESTIONS

For Aspiring DOCTORS

1. In a metallic conductor, if the length is doubled keeping the cross-section and applied voltage constant, the drift velocity: [NEET 2025]

(a) Doubles (b) Halves (c) Remains same (d) Becomes four times

2. A wire obeys Ohm's law. If the current through it is tripled, the resistance: [AIIMS 2024]

(a) Triples (b) Reduces to one-third (c) Remains the same (d) Increases nine times

3. The resistivity of silver at 20°C is 1.6×10^{-8} Ω•m. A silver wire of length 2 m and radius 1 mm has resistance approximately: [NEET 2025]

(a) 0.010 Ω (b) 0.020 Ω (c) 0.032 Ω (d) 0.064 Ω

4. When n identical resistors of resistance R are connected in series and then separately in parallel, the ratio of power consumed (series: parallel) for the same supply voltage is: [AIIMS]

(a) 1: n^2 (b) n^2: 1 (c) 1: n (d) n: 1

5. In a meter bridge, if P and Q (the ratio arms) are interchanged and the null point shifts from 40 cm to 60 cm. This confirms: [NEET 2023]

(a) P = Q (b) P = 3Q/2 (c) P/Q = 2/3 (d) The bridge is faulty

For Aspiring ENGINEERS

6. The drift velocity of electrons for a conductor connected to a battery is v. If the radius and length of the conductor are both doubled, keeping the voltage constant, the new drift velocity will be: [JEE Main 2023]

(a) v/2 (b) v (c) 2v (d) v/4

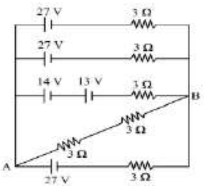
7. A copper wire has a resistance of 10 Ω at 0°C. If the temperature coefficient of resistance is 4×10^{-3} /°C, its resistance at 100°C will be: [JEE Main 2022]

(a) 12 Ω (b) 14 Ω (c) 16 Ω (d) 20 Ω

8. Two cells of emf 2V and 4V and internal resistance 1Ω and 2Ω respectively are connected in parallel. The equivalent emf is: [JEE Main 2024]

(a) 3V (b) 2.67V (c) 2.5V (d) 2V

9. The voltage and current between points A and B shown in the circuit are [JEE Main 2026]



(a) 24V, 12A (b) 24V, 4A (c) 18V, 12A (d) 27V, 4A

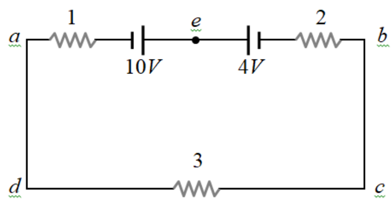
10. Two cells of emfs 1V and 2V and internal resistance 2 Ω and 1Ω, respectively connected in parallel, gave current of 1A through an external resistance. If the polarity of one cell is reversed, then value of current through the external resistance will be $\frac{\alpha}{5}$ A. The value of α is [JEE Main 2026]

(a) 3 (b) 2 (c) 1 (d) 4

11. Figure shows a current carrying conductor of non-uniform cross section. Current I is flowing from left to right as shown. Which of the following relation is correct? (Symbols have usual meaning)

(a) $\sigma_A = \sigma_B$ (b) $E_A < E_B$ (c) $v_{d_A} < v_{d_B}$ (d) All of these

12. The magnitude and direction of the current in the circuit shown will be



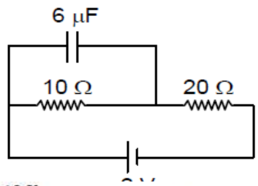
(a) $\frac{7}{3}A$ from a to b through e (b) $\frac{7}{3}A$ from b to a through e

(c) 1 A from b to a through e (d) 1 A from a to b through e

13. Two identical cells send the same current in 2 ohm resistance, whether connected in series or in parallel. The internal resistance of the cell should be

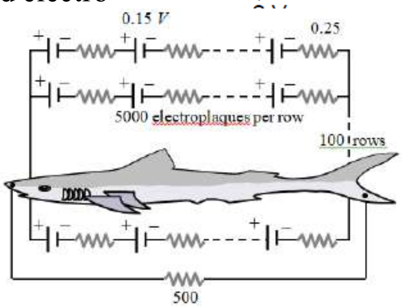
(a) 0 (b) 0.5Ω (c) 1.5Ω (d) 2Ω

14. The charge on the shown capacitor in steady state is



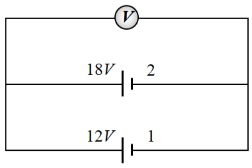
(a) 4 μC (b) 8 μC (c) 12 μC (d) Zero

15. Cells are able to generate current with biological cells called electro plaques. The electro plaques in an eel are arranged in 100 rows, each row stretching horizontally along the body of the fish containing 5000 electro plaques. The arrangement is suggestively shown below. Each electro plaques has an emf of 0.15 V and internal resistance of 0.25 Ω. The water surrounding the eel completes a circuit between the head and its tail. If the water surrounding it has a resistance of 500 Ω, the current an eel can produce in water is about



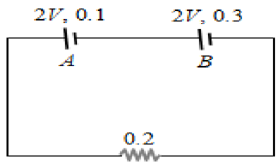
(a) 1.5 A (b) 3.0 A (c) 15 A (d) 30 A

16. Two batteries, one of emf 18 *volts* and internal resistance 2Ω and the other of emf 12 *volt* and internal resistance1Ω, are connected as shown. The voltmeter V will record a reading of



(a) 15 *volt* (b) 30 *volt* (c)14 *volt* (d) 18 *volt*

17. The internal resistances of two cells shown are 0.1Ω and 0.3Ω. If $R = 0.2\Omega$, he potential difference across the cell



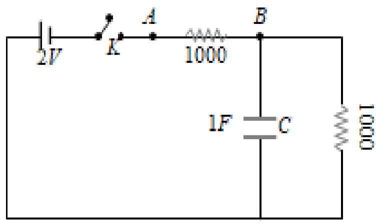
(a) B will be zero (b) A will be zero

(c) A and B will be $2V$ (d) A will be $> 2V$ and B will be $< 2V$

18. In Wheatstone's bridge $P = 9\Omega$, $Q = 11\Omega$, $R = 4\Omega$ and $S = 6\Omega$. How much resistance must be put in parallel to the resistance S to balance the bridge

(a) 24 Ω (b) $\frac{44}{9}$ Ω (c) 26.4 Ω (d) 18.7 Ω

19. When the key K is pressed at time $t = 0$, which of the following statements about the current I in the resistor AB of the given circuit is true



(a) $I = 2\ mA$ at all t (b) I oscillates between 1 mA and 2mA

(c) $I = 1\ mA$ at all t

(d) At $t = 0$, $I = 2\ mA$ and with time it goes to 1 mA

20. Masses of 3 wires of same metal are in the ratio 1: 2: 3 and their lengths are in the ratio 3 : 2 : 1.The electrical resistances are in ratio

(a) 1 : 4 : 9 (b) 9 : 4 : 1 (c) 1 : 2 : 3 (d) 27 : 6 : 1

ANSWERS (MULTIPLE CHOICE QUESTIONS)

1. (b) E = V/L. Doubling L halves E. $v_d = eE\tau/m \propto E \rightarrow v_d$ halves.
2. (c) For an ohmic wire, R = V/I is constant (independent of I or V). Resistance doesn't change.
3. (a) $R_T = 10(1 + 4\times10^{-3} \times 75) = 10(1 + 0.3) = 10 \times 1.3 = 13\ \Omega$.
4. (a) $P_{series} = V^2/(nR)$; $P_{parallel} = V^2/(R/n) = nV^2/R$. Ratio = $(V^2/nR)/(nV^2/R) = 1/n^2$.
5. (c) Initially l=40cm: P/Q = 40/60 = 2/3. After swap l=60cm: Q/P = 60/40 → P/Q still 2/3.

6. (a) v/2, $v_d = eE\tau/m = eV\tau/(mL)$. Since L is doubled (2L), v_d becomes v/2. Radius change doesn't affect v_d if V and L are considered, though it affects current.

7. (b) 14 Ω, Explanation: $R = R_0(1 + \alpha\Delta T) = 10(1 + 4 \times 10^{-3} \times 100) = 10(1 + 0.4) = 14\ \Omega$.

8. (b) 2.67V, $\varepsilon_{eq} = (\varepsilon 1/r1 + \varepsilon 2/r2) / (1/r1 + 1/r2) = (2/1 + 4/2) / (1/1 + 1/2) = (2+2)/(1.5) = 4/1.5 = 8/3 = 2.67V$.

9. (b) 24V, E_{eq} = 27V and $R_{eq} = 3/4\Omega$, $I_{AB} = \frac{27}{6+3/4}$ A, V_{AB} = 4 x 6 =24V

10. (a) 3

11. (d) All of these

12. (d) Applying Kirchoff's voltage law

$-1 \times i + 10 - 4 - 2 \times i - 3i = 0 \Rightarrow i = 1A(a\ to\ b\ via\ e)$.∴Current $= \frac{V}{R} = \frac{10-4}{6} = 1.0A$

13. (d) In series , $i_1 = \frac{2E}{2+2r}$

In parallel, $I_2 = \frac{E}{2+\frac{r}{2}} = \frac{2E}{4+r}$, Since $i_1 = i_2 \Rightarrow \frac{2E}{4+r} = \frac{2E}{2+2r} \Rightarrow r = 2\Omega$

14. (a) Potential Difference across capacitor =2/3 V, Q = CV so Q = 4 μC

15 (a) given problem is the case of mixed grouping of cells $I = \frac{nE}{R+\frac{nr}{m}}$, so total current produced.

Here m=100, n=5000,R=500Ω . E=0.15 V and r =0.25 Ω, $i = \frac{5000\ X\ 0.15}{500 + \frac{5000\ X 0.25}{100}}$ = 1.5A

16 (c) Reading of voltmeter, $E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$ =(18*1+12*2)/ (1+2) = 14 V

17 (a) Applying Kirchhoff law, $(2 + 2) = (0.1 + 0.3 + 0.2)i \Rightarrow i = \frac{20}{3}A$, Hence potential difference across $A = 2 - 0.1 \times \frac{20}{3} = \frac{4}{3}V$ (less than $2V$), Potential difference across $B = 0$

18 (c) $\frac{P}{Q} = \frac{R}{S'}$ (For balancing bridge $\Rightarrow S' = \frac{4\times 11}{9} = \frac{44}{9} \Rightarrow \frac{1}{S'} = \frac{1}{r} + \frac{1}{6} \Rightarrow \frac{9}{44} - \frac{1}{6} = \frac{1}{r} \Rightarrow r = 26.4\Omega$

19 (d) At time $t = 0$ *i.e.* when capacitor is charging, current $i = \frac{2}{1000} = 2mA$

When capacitor is full charged, no current will pass through it, hence the current through the circuit $i = \frac{2}{2000} = 1mA$

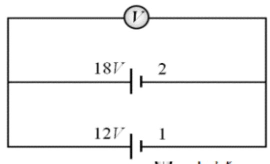
20 (d) 27:6:1 as R α $\frac{l^2}{m}$

EXERCISE QUESTIONS

1. A 50V battery is connected across a 10 Ω resistor. The current is 4.5 A. The internal resistance of the battery is

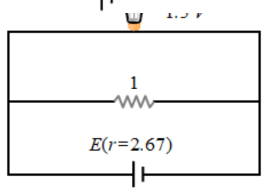
(a) Zero (b) 0.5 Ω (c) 1.1 Ω (d) 5.0 Ω

2. Two batteries, one of emf 18 *volts* and internal resistance 2 Ω and the other of emf 12 *volt* and internal resistance 1 Ω are connected as shown. The voltmeter V will record a reading of



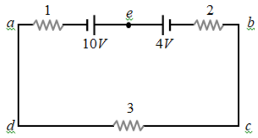
(a) 15 *volt* (b) 30 *volt* (c) 14 *volt* (d)18 *volt*

3. The magnitude and direction of the current in the circuit shown will be



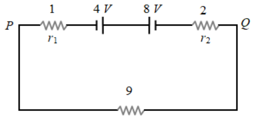
(a) $\frac{7}{3}$A from a to b through e (b) $\frac{7}{3}$A from b to a through e

(c) 1 A from b to a through e (d) 1 A from a to b through e



4. A torch bulb rated as 4.5 W, 1.5 V is connected as shown in the figure. The *e.m.f.* of the cell needed to make the bulb glow at full intensity is

(a) 4.5 V (b) 1.5 V (c)2.67 V (d) 13.5 V



5. Two batteries of e.m.f. 4V and 8 V with internal resistances 1 Ω and 2 Ω are connected in a circuit with a resistance of 9 Ω as shown in figure. The current and potential difference between the points P and Q are

(a) $\frac{1}{3}A, 3V$ (b) $\frac{1}{6}A. 4V$ (c) $\frac{1}{9}A, 9V$ (d) $\frac{1}{2}A, 12V$

ANSWERS (EXERCISE QUESTIONS)

1. (c) 2. (c) 3. (d) 4. (d) 5. (d)

ASSERTION & REASON QUESTIONS

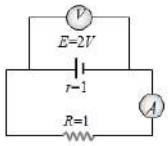
Read the assertion and reason carefully to mark the correct option given below

(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 the assertion and reason both are false.

1. Assertion (A): Drift velocity of electrons in a conductor increases when the temperature of the conductor is increased, keeping the potential difference constant.
Reason (R): At higher temperatures, the relaxation time of electrons decreases due to increased lattice vibrations. [NEET 2017]

2. Assertion (A): The current density J in a conductor depends on both the magnitude and direction of the electric field E.
Reason (R): Current density is a vector quantity defined as J = σE, where σ is the electrical conductivity. [AIIMS 2020]

3. Assertion: The temperature coefficient of resistance is positive for metals and negative for semiconductor.
Reason: The effective charge carriers in metals are negatively charged whereas in semiconductor they are positively charged.



4. Assertion: In the following circuit emf is 2V and internal resistance of the cell is 1 Ω and R = 1Ω, then reading of the voltmeter is 1V.
Reason:$V = E - ir$ where E = 2V, $i = \frac{2}{2} = 1A$ and R = 1 Ω

5. Assertion (A): The resistivity of all materials is temperature-independent. [AIIMS 2020]
Reason (R): Resistivity depends only on the type of material, not on its dimensions.

6. Assertion: Electric appliances with metallic body have three connections, whereas an electric bulb has a two pin connection.
Reason: Three pin connections reduce heating of connecting wires.

7. Assertion: The drift velocity of electrons in a metallic wire will decrease, if the temperature of the wire is increased.
Reason: On increasing temperature, conductivity of metallic wire decreases.

8. Assertion (A): When a wire of resistance R is cut into n equal pieces and all are connected in parallel, the new resistance is R/n².
Reason (R): Each piece has resistance R/n. When n such pieces are in parallel, equivalent resistance = (R/n)/n = R/n². [NEET 2023]

Assertion: The electric bulbs glows immediately when switch is on.
Reason: The drift velocity of electrons in a metallic wire is very high.
9. Assertion: Bending a wire does not affect electrical resistance.
Reason: Resistance of wire is proportional to resistivity of material.
10. Assertion: In meter bridge experiment, a high resistance is always connected in series with a galvanometer. **Reason:** As resistance increases current through the circuit increases.

ANSWERS (ASSERTION & REASON QUESTIONS)

1. (d)Explanation: Assertion is WRONG: drift velocity decreases at higher T because v_d = eEτ/m and τ decreases.
2. (a) Explanation: Both statements are correct. J = σE is a vector relation — J is in the direction of E (for isotropic conductors), and σ is the proportionality constant.
3. (b) The temperature co-efficient of resistance for metal is positive and that for semiconductor is negative. In metals free electrons (negative charge) are charge carriers while in P-type semiconductors, holes (positive charge) are majority charge carriers.
4. (a) Here, $E = 2V, 1 = \frac{2}{2} = 1A$ and $r = 1\Omega$ **.** Therefore, $V = E - ir = 2 - 1 \times 1 = 1V$
5. (d) (6) (c) (7) (b) (8) (a) (9) (a) (10) (c)

EXCERCISE-- ASSERTION & REASON

1. **Assertion:** Voltameter measures current more accurately than ammeter.
   Reason: Relative error will be small if measured from voltameter.
2. **Assertion :** Electric field outside the conducting wire which carries a constant current is zero.
   Reason: Net charge on conducting wire is zero.
3. **Assertion:** The resistance of super-conductor is zero.
   Reason: The super-conductors are used for the transmission of electric power.
4. **Assertion:** Each bulb in a frill of 20 bulbs in series when connected to supply voltage will emit more light than each bulb in frill of 19 bulbs in series when connected to same supply voltage.
   Reason: Each bulb in a frill of 20 bulbs in series will get less voltage than that in frill of 19 bulbs.
5. **Assertion :** Kirchhoff's voltage law indicates that electro static field is conservative.
   Reason: Potential difference between two points in a circuit does not depend on path.

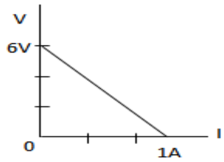
ANSWERS (EXCERCISE-- ASSERTION & REASON)

1. (a) 2. (a) 3. (b) 4. (d) 5. (a)

VERY SHORT ANSWER TYPE QUESTIONS

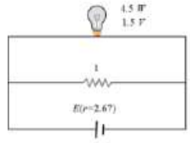
1. Plot a graph showing variation of current versus voltage for the material GaAs.
2. Two materials Si and Cu, are cooled from 300 K to 60 K. What will be the effect on their resistivity?
3. A cell of emf (E) and internal resistance (r) is connected across a variable external resistance (R). Plot graphs to show variation of (i) E with R, (ii) Terminal p.d. of the cell (V) with R.
4. A p.d. of V volts is applied to a conductor of length L and diameter D. How will the drift velocity of e's and the resistance of the conductor change when (i) V is doubled (ii) L is halved and (iii) D is halved, where is each case, the other two factors remain same. Give reason.
5. Two wires, one of copper and the other of manganin, have same resistance and equal thickness. Which wire is longer? Justify your answer.

6. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is as shown below. What is the emf of each cell?



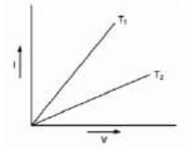
7. Why are alloys used for making standard resistance coils?

8. A torch bulb rated as 4.5 W, 1.5 V is connected as shown in the figure. The *e.m.f.* of the cell needed to make the bulb glow at full intensity?



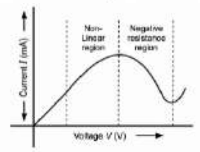
9. The amount of electric charge passing through a cross-section of wire in time t is Q (t) = At^2 + Bt + C. Where A, B and C are constants having values 5, 4 and 1 respectively. Calculate the electric current at t = 4s.

10. I – V graph for a metallic wire at two different temperatures, T_1 and T_2 is as shown in the figure. Which of the two temperatures is lower and why?

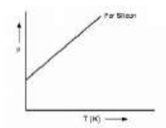


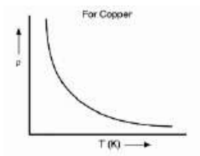
ANSWERS (VERY SHORT ANSWER TYPE QUESTIONS)

1. The variation of electric current with applied voltage for GaAs is as

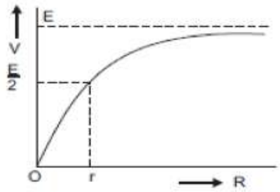


2. In silicon, the resistivity increases In copper, the resistivity decreases





3. (i) The emf E of a cell is independent of external resistance (R). (ii) The terminal p.d. $V = IR = \frac{E}{r+R}R = \frac{E}{1+\frac{r}{R}}$. On increasing R, V increases. When R = 0, V→ 0. When R = r, $V = \frac{E}{2}$, When R → ∞, V = E.



4. $V_d = \frac{eE}{m}\tau = \frac{eV}{ml}\tau$ and $R = \rho\frac{l}{A} = \rho\frac{l}{\pi D^2}$

(i) When V is doubled, V_d becomes double and R remains unchanged.

(ii) When l is halved, V_d becomes double and R becomes halved

(iii) When D is halved, V_d remains unchanged and R becomes 4R.

5. Copper, $R = \frac{\rho l}{A}$, $\rho l = Const.$

6. Let E be emf of each cell and r be the total internal resistance of circuit. The equation of terminal potential difference $V = 3E - Ir$............(1)

At V = 6V, I = 0. Therefore from eq (1), $6 = 3E - 0 \Rightarrow E = 2V$

7. Alloys like Manganin and Constantan are used to make standard resistance coils because of their high resistivity and low temperature coefficient of resistance. This makes their resistance relatively stable and predictable over a range of temperatures, which is crucial for accurate measurements. Additionally, alloys are generally less susceptible to corrosion than pure metals, ensuring the longevity of the resistance coils.

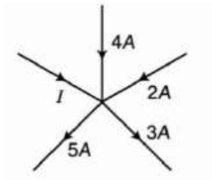
8. Current in the bulb $= \frac{P}{V} = \frac{4.5}{1.5} = 3A$, Current in 1 Ω resistance $= \frac{1.5}{1} = 1.5A$,Hence total current from the cell $i = 3 + 1.5 = 4.5A$,By using $E = V + ir \Rightarrow E = 1.5 + 4.5 \times (2.67) = 13.5V$

9. $I = \frac{dQ}{dt}$, I = 2At + B, I = 44 A

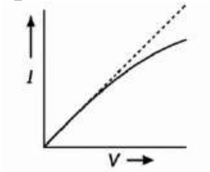
10. If a constant current I flows through the conductor, resistance at temperature T_1 and T_2 is $R_2 > R_1$

EXERCISE QUESTIONS

1. Current of 4.8 amperes is flowing through a conductor. Find the number of electrons per second.
2. When the current i is flowing through a conductor, the drift velocity is v. If $2i$ current is flowed through the same metal but having double the area of cross-section, then find the drift velocity.

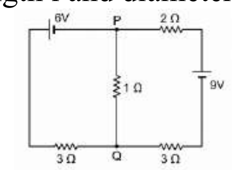


3. What is the value of I in the given current distribution?
4. Current is allowed to flow in a metallic wire at a constant potential difference. When the wire becomes hot, cold water is poured on half of its portion. By doing so, its other half portion becomes still more hot. Explain its reason.
5. The I-V characteristics of a resistor are observed to deviate from a straight line for higher values of current as shown in the adjoining figure why?



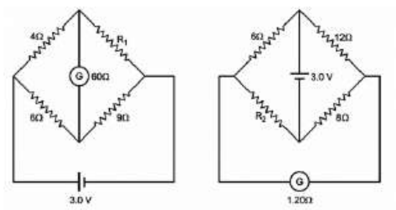
SHORT ANSWER TYPE QUESTIONS

1. A potential difference V is applied across the ends of copper wire of length l and diameter D. What is the effect on drift velocity of electrons if (i) V is halved (ii) l is doubled (iii) D is halved

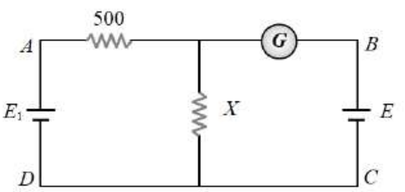


2. Find the magnitude and direction of current in 1Ω resistor in the given circuit.

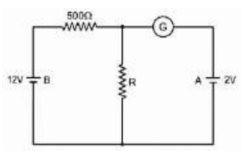
3. Figure shows two circuits each having a galvanometer and a battery of 3V. When the galvanometers in each arrangement do not show any deflection, obtain the ratio R_1/R_2 ?



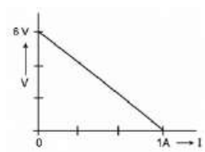
4. In the adjoining circuit, the battery E_1 has an $e.m.f.$ of $12volt$ and zero internal resistance while the battery E has an $e.m.f.$ of $2volt$. If the galvanometer G reads zero, then find the value of the resistance X in ohm ?



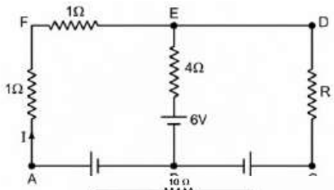
5. Plot a graph showing temperature dependence of resistivity for a typical semiconductor. How is this behavior explained?
6. Answer the following:
 (i) Why are the connections between the resistors in a meter bridge made of thick copper strips?
(ii) Why is it generally preferred to obtain the balance point in the middle of the meter bridge wire?
(iii) Which material is used for the meter bridge wire and why?



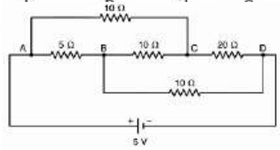
7. In the circuit shown in the figure, the galvanometer 'G' gives zero deflection. If the batteries A and B have negligible internal resistance, find the value of the resistor R?
8. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is shown alongside. What is the emf and internal resistance of each cell?



9. Using Kirchoff's rules determine the value of unknown resistance R in the circuit so that no current flows through 4Ω resistance. Also find the potential difference between A and D?



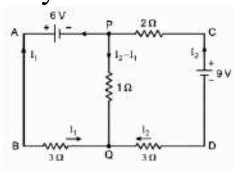
10. Calculate the value of the current drawn from a 5 V battery in the circuit as shown.



ANSWERS (SHORT ANSWER TYPE QUESTIONS)

1. $v_d = \frac{I}{neA} = \frac{V/R}{neA} = \frac{V}{neA(\frac{\rho L}{A})}$

(i) V is halved then drift velocity is halved (ii) l is doubled then drift velocity is halved
(iii) Drift velocity is independent of D

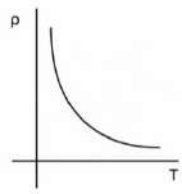


2. Use Kirchhoff's laws to make equations, After solving the equations
I_1 = -1.2A

3. Sol. For balanced Wheatstone bridge, if no current flows through the galvanometer

$\frac{4}{6} = \frac{R_1}{9}$ So, R_1 = 6Ω and $\frac{6}{R_2} = \frac{12}{8}$ so R_2 =4Ω, Hence R_1/R_2 =6/4=3/2

4. For no current through galvanometer, we have , $\left(\frac{E_1}{500+X}\right)X = E \Rightarrow \left(\frac{12}{500+X}\right)X = 2 \Rightarrow X = 100$ Ω



5. The resistivity of a typical semiconductor (carbon) decreases with increase of temperature. The graph is shown in figure.

Explanation: In semiconductor the number density of free electrons (n) increases with increase in temperature (T) and consequently the relaxation period decreases. But the effect of increase in n has higher impact than decrease of τ. So, resistivity decreases with increase in temperature.

6. (i) A thick copper strip offers a negligible resistance, so does not alter the value of resistances used in the meter bridge.

(ii) If the balance point is taken in the middle, it is done to minimise the percentage error in calculating the value of unknown resistance.

(iii) Generally alloys magnin/constantan/nichrome are used in Meter Bridge, because these materials have low temperature coefficient of resistivity.

7. If galvanometer G gives zero deflection, than current of source of 12 V flows through R, and voltage across R becomes 2 V. Current in the circuit is

$$I = \frac{12}{500 + R}$$

And V=IR, $\left(\frac{12}{500+R}\right)$ R = 2 Solving R=100Ω

8. We know that for a circuit

V = E_{eq} - I R_{eq}

From graph, when I=0 A, then V=6 V and I=1 A, then V=0 V. Putting in equation and solving E_{eq}= 6 V and R_{eq}= 2 Ω, Hence emf of each cell = 2V. Resistance of each cell = 2 Ω

9. Applying Kirchhoff's loop rule for loop ABEFA, –9 + 6 + 4 × 0 + 2I = 0, I = 1.5 A ...(i)

For loop BCDEB, 3 + IR + 4 × 0 – 6 = 0, ∴ IR = 3

Putting the value of I from (i) we have

$$1.5 \times R = 3 \text{ so } R = 2\ \Omega$$

Potential diff. between A and D through path ABCD

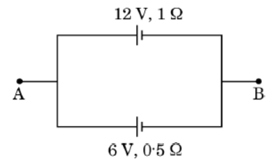
$9 - 3 - IR = V_{AD}$ $\quad$ $9 - 3 - 1.5 \times 2 = V_{AD}$ so $V_{AD} = 3V$

10. it is a balanced wheatstone bridge

Find equivalent resistance and hence find current I = 0.5 A

LONG ANSWER TYPE QUESTIONS

1. (i) Answer the following giving reason: [CBSE 2026]



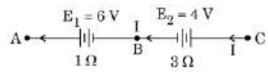
(I) The electron drift speed is estimated to be only a few mm/s for currents in the range of a few amperes. How, then, is the current established almost the instant a circuit is closed?

(II) A large volage supply from which one needs high currents must have very low internal resistance. Why?

(III) The assertion that V =IR is a statement of Ohm's Law is not true. Why?

(ii) Two cells of emf 12 V and 6 V are connected in parallel as shown in figure. Their internal ressitance are 1 Ω and 0.5 Ωrespectively. Calculate the emf and internal resistance of the equivalent cell between points A and B

2. (a) In the given figure, a steady current I flows through the circuit when points A and C are connected by a wire of negligible resistance. Find the potential difference between B and C. [CBSE 2026]



(b) A battery of emf 21 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 3 A, find:

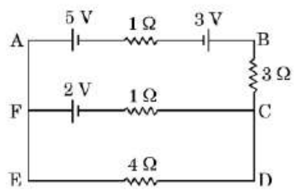
(i) Resistance of the resistor. (ii) The terminal voltage of the battery.

3. (a) An electric field E is established across the ends of a cylindrical conductor of length L and area of cross section A. Discuss how electrons attain the average velocity, independent of time. Hence, obtain a relation between current in the conductor and this 'average velocity' of electrons.

(b) (i) The electron drift speed is estimated to be only a few mm/s for currents in the range of a few amperes. How, then, is the current established almost the instant a circuit is closed?

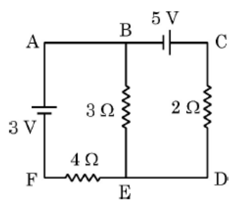
(ii) Two copper wires having their radii in the ratio of 3:2 are connected in series across a battery. Find the ratio of the drift velocities of the electrons in the wire.

4. (a) State Kirchhoff's rules. Using these rules, find the current flowing through branch FC in the given circuit [CBSE 2026]



(b) Establish the relation between drift velocity of the electrons (v_d) and electric current (I) in the conductor.

5. (i) (a) Explain the statement: "Current is a scalar although we represent current with an arrow".



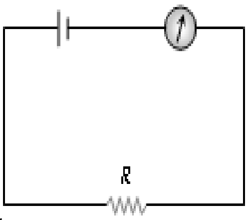
(b) Use Kirchhoff's rules to find the current flowing through 3 Ω resistor in the circuit shown in the figure.

(ii) How is v_d affected when the length of the conductor is doubled, keeping the voltage applied across the conductor constant?

CASE STUDY BASED QUESTIONS

1. Read the following paragraphs and answer the questions that follow.

. Whenever an electric current is passed through a conductor, it becomes hot after some time. The Phenomenon of the production of heat in a resistor by the flow of an electric current through it is called heating effect of current or Joule heating. Thus, the electrical energy supplied by the source of emf is converted into heat. In purely resistive circuit the energy expended by the source entirely appears as heat. But if the circuit has an active element like a motor, then a part of the energy supplied by the source goes to do useful work and the rest appears as heat. Joule's law of heating form the basis of various electrical appliances such as electric bulb, electric furnace, electric press etc



I. Alloys used for making standard resistance coils as alloys
   (a) have more conductivity (b) less conductivity
   (c) less temperature coefficient of resistivity (d) more temperature coefficient of resistivity
II. Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through them. Wire which gets heated up more is
   (a) Nichrome (b) copper
   (c) both gets heated up to same values (d) can't say
III. A 25 W and 100 W are joined in series and connected to the mains. The bulb which will glow brighter is
   (a) 25W as it has high resistance (b) 100 W as it has high resistance
   (c) 25W as it has low resistance (d) 100 W as it has low resistance
IV. The heat emitted by an iron of 100 W in 1 minute is
   (a) 600J (b) 6000J (c) 60J (d)60000J

2. When electric field is applied across a conductor then the electrons move in the direction opposite to the electric field due to electric force on them. The average velocity with which free electrons get drifted in the direction opposite to the applied electric field inside a conductor is called drift velocity. This motion of the electrons in the direction opposite to the electric field is superimposed on their random motion. Drift velocity depends on electric field applied, the nature of material and temperature. On increasing the temperature, relaxation time decreases. Hence decrease in relaxation time, due to increase in temperature, will reduce the drift speed.

I. When a potential difference V be applied across a cylindrical conductor of length L and radius R, is doubled then the drift velocity of electrons gets:
   (a) doubled (b) four times (c) remain same (d) halved
II. Two wires made of same material but of different diameters are connected in series in a circuit. The current flows in the combination of wires. When the current flows from the wire with larger diameter to the one with smaller diameter then drift velocity of electrons:
   (a) will decrease (b) will increase
   (c) remains same (d) first will increase and after some time decrease
III. Two wires each of radius of cross section r but of different materials are connected together end to end (in series). If the densities of charge carriers in the two wires are in the ratio 1:4, the drift velocity of electrons in the two wires will be in the ratio:
   (a) 1 : 2 (b) 2 : 1 (c) 4 :1 (d) 1 : 4

IV. A current I flows through a uniform wire of diameter d when the electron drift velocity is v.The same current will flow through a wire of diameter d/2 made of the same material if the drift velocity of the electrons is

(a)v/4 (b) v/2 (c) 2v (d) 4v

3. When the electric cell (source of EMF) is in a closed circuit, the current flows through the circuit. There is a fall of potential across the the internal resistance of the cell. The terminal potential difference between the two electrodes of the cell becomes less than the EMF of the cell by an amount equal to to potential drop across the internal resistance of the cell. Thus, in a closed circuit The terminal potential difference of a cell is always less than the the EMF of the cell.

I. EMF of a cell is independent of:

(a) size of the electrodes (b) quantity of electrolyte present in the cell

(c) distance between the electrodes (d) all of these

II. Three cells of EMF, 2.0 V,2.5 V and 3.0 V are connected in series. Their internal resistances are 0.20 Ω, 0.20Ω and 0.15Ω respectively. The battery is connected to an external resistor of 6.5 Ω wire a very low resistance ammeter, what would be the reading of ammeter?

(a) 1.1Ω (b) 1Ω (c) 2 Ω (d) 2.1 Ω

III. A cell of emf E and internal resistance r is connected in series with an external resistance 'nr'. Then ratio of terminal potential difference to emf is:

(a)1/n (b) 1/(n+1) (c) n/(n+1) (d) (n+1)/n

IV. In an experiment a student measures terminal potential difference (TPD) of a cell. When the same cell is connected to an external resistance of 5 Ω then the TPD is 2 V and when the same is repeated for an external resistance of 10 Ω then the TPD is 2.4 V. What is the EMF and internal resistance of cell?

(a)2.5 V,3Ω (b) 3 V,3.5Ω (c) 3 V,2.5Ω (d) 2.5 V,3

ANSWERS (CASE STUDY BASED QUESTIONS)

1	(i)c	(ii) a	(iii) a	(iv) b
2	(i)a	(ii) b	(iii) c	(iv) d
3	(i)d	(ii) a	(iii) c	(iv) c

EXERCISE QUESTIONS

1. In a metallic conductor, an electron, moving due to thermal motion, suffers collisions with the heavy fixed ions but after collision, it will emerge out with the same speed but in random directions. If we consider all the electrons, their average velocity will be zero. When an electric field is applied, electrons move with an average velocity, known as drift velocity (V_d). The average time between successive collisions is known as relaxation time (τ). The magnitude of drift velocity per unit electric field is called mobility (μ). An expression for current through the conductor can be obtained in terms of drift velocity, number of electrons per unit volume (n), electronic charge (-e), and the cross-sectional area (A) of the conductor. This expression leads to an expression between current density (J) and the electric field (E). Hence, an expression for resistivity (ρ) of a metal is obtained. This expression helps us to understand increase in resistivity of a metal with increase in its temperature, in terms of change in the relaxation time (τ) and change in the number density of electrons (n).

(i) Consider the contribution of the following two factors I and II in resistivity of a metal

I. Relaxation time of electrons

II. Number of electrons per unit volume The resistivity of a metal increases with increase in its temperature because :

(A) I decreases and II increases. (B) I increases and II is almost constant.
(C) Both I and II increase. (D) I decreases and II is almost constant.

(ii) A steady current flows in a copper wire of non-uniform cross-section. Consider the following three physical quantities :

I. Electric field II. Current density III. Drift speed Then at the different points along the wire:

(A) II and III change, but I is constant. (B) I and II change, but III is constant.
(C) I and III change, but II is constant. (D) All I, II and III change.

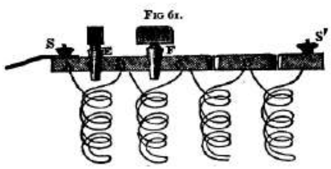
(iii) The resistivity of iron is$1 \times 10^{-7} ohm - m$. The resistance of a iron wire of particular length and thickness is 1 *ohm*. If the length and the diameter of wire both are doubled, then the resistivity in $ohm - m$ will be

(a) 1×10^{-7} (b) 2×10^{-7} (c) 4×10^{-7} (d) 8×10^{-7}

(iv) The temperature coefficient of resistance for a wire is $0.00125/°C$. At $300K$ its resistance is 1 *ohm*. The temperature at which the resistance becomes 2 *ohm* is

(a) 1154 K (b) 1100 K (c) 1400 K (d) 1127 K

2. The box which contains the resistors of different values for estimating and comparing the resistance is known as the resistance box. The accuracy of the resistance box is very high. The main advantage of the resistance box is that the variable resistances are available at one point



Resistance values are adjusted by removing the brass pegs. The box is constructed with the pegs in parallel with precision wound resistance coils-with the peg in place the current flows through the peg (approx. 0 ohms), when removed the current flows through the resistor.

If the length of material is small then surely, resistance will be low and current flows through that material will be high. and if the cross- section area of material is small then; resistance will be low and current flows thought material will be high.

(i) The resistances in a resistance box are arranged in-

(a) Series Combination (b) Parallel combination
(c) Mixed grouped (d) None of the above.

(ii) How can the values of resistors apply to a circuit be changed in a resistance box?

(a) By inserting the keys (b) By removing the keys
(c) By changing the connections. (d) By changing the coils inside the resistance box.

(iii) Which statement is correct-

(a) Resistance box is used to apply variable resistance and Rheostat is used to apply constant resistance

(b) Rheostat is used to apply variable resistance and the Resistance box is used to apply constant resistance.

(c) In resistance box, the value of applied resistance is known.

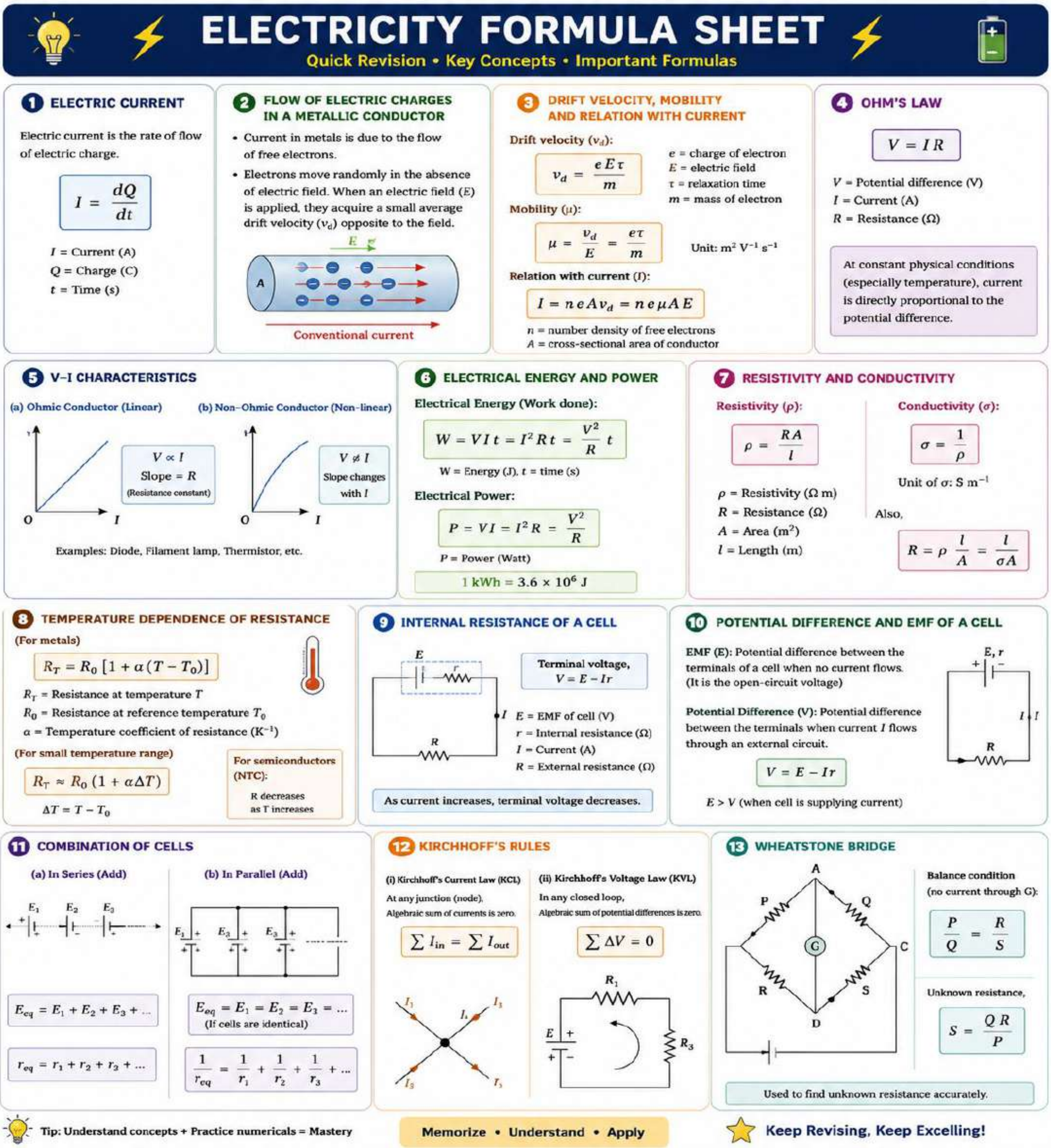
(d) In rheostat, the value of applied resistance is known.

(iv) Why wire is double folded in resistance box?

(a) to nullify the inductance effect. (b) to increase the resistance
(b) for space arrangement (d) to increase the inductance effect.

ANSWERS (EXERCISE QUESTIONS)

1 (i) d (ii) a (iii) a (iv) d
2 (i) a (ii) b (iii) b (iv) a



CHAPTER 04

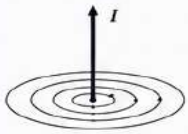
MOVING CHARGES AND MAGNETISM

CBSE CLASS 12 PHYSICS – QUICK REVISION SHEET

1. KEY LAWS & PRINCIPLES

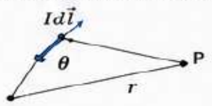
OERSTED'S OBSERVATION

A current-carrying conductor produces a magnetic field around it.



BIOT–SAVART LAW

Magnetic field $d\vec{B}$ at a point due to current element $Id\vec{l}$.



$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2}$$

$\hat{r}$: unit vector from element to point

AMPERE'S CIRCUITAL LAW

Line integral of $\vec{B}$ around any closed path is μ_0 times the current enclosed.

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{encl}$$

LORENTZ FORCE

Force on a charge q moving with velocity $\vec{v}$ in magnetic field $\vec{B}$.

$$\vec{F} = q(\vec{v}\times\vec{B})$$

$$F = |q|\,vB\sin\theta$$

(θ = angle between $\vec{v}$ and $\vec{B}$)

TORQUE ON CURRENT LOOP

A current loop in magnetic field experiences a torque.

$$\vec{\tau} = \vec{\mu}\times\vec{B}$$

$$|\tau| = \mu B\sin\theta$$

$$\vec{\mu} = NIA\,\hat{n}$$

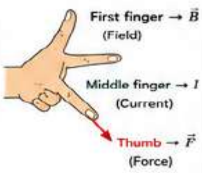
($\hat{n}$: normal to the plane)

2. DIRECTION RULES TOOLKIT

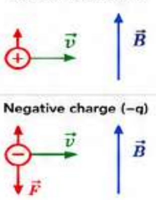
RIGHT HAND THUMB RULE (Magnetic field around a current)

- Thumb → Current
- Curled fingers → $\vec{B}$

FLEMING'S LEFT HAND RULE (Force on conductor)



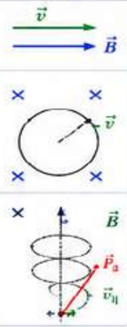
FORCE DIRECTION FOR CHARGES



Use $\vec{F} = q(\vec{v}\times\vec{B})$.
For $-q$, force is opposite.

3. MOTION OF CHARGED PARTICLE IN UNIFORM MAGNETIC FIELD

Case	Condition	Path	Key Formulae	Diagram
1.	$\vec{v} \parallel \vec{B}$	Straight line (No deflection)	$F = 0$	
2.	$\vec{v} \perp \vec{B}$	Circular path	$F = qvB$ (centripetal); $r = \frac{mv}{\lvert q\rvert B}$; $T = \frac{2\pi m}{\lvert q\rvert B}$	
3.	$\vec{v}$ at angle θ to $\vec{B}$	Helical path	$v_\perp = v\sin\theta$; $v_\parallel = v\cos\theta$; $r = \frac{mv_\perp}{\lvert q\rvert B}$; Pitch $p = v_\parallel T$	



4. APPLICATION BOX – GALVANOMETER & CONVERSIONS

MOVING COIL GALVANOMETER (MCG)

Torque: $\tau = NBAI$

Restoring torque: $\tau_r = k\theta$

At equilibrium: $NBAI = k\theta$

$$\Rightarrow I = \frac{k}{NBA}\theta$$

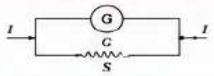
Current sensitivity, $S_I = \frac{\theta}{I} = \frac{NBA}{k}$

Voltage sensitivity, $S_V = \frac{\theta}{V} = \frac{NBA}{kG}$

(Figure of merit $K = \frac{\theta}{I} = \frac{k}{NBA}$)

Purpose: Detects small currents / measures current.

CONVERSION TO AMMETER



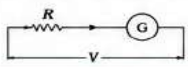
At full scale deflection (I_g):

$$I_g G = (I - I_g)S$$

$$\Rightarrow S = \frac{I_g G}{I - I_g}$$

Purpose: Measure current in a circuit.

CONVERSION TO VOLTMETER



At full scale deflection (V):

$$V = I_g(R + G)$$

$$\Rightarrow R = \frac{V}{I_g} - G$$

Purpose: Measure potential difference.

5. MOST COMMON STUDENT MISTAKES (TOP 6)

1. Magnetic force changes the speed of a charged particle. (False: It only changes direction) ×
2. Currents in the same direction in parallel wires repel. (False: They attract) ×
3. Magnetic field is maximum at the centre of a current loop. (False: It is maximum on the axis at the centre, but not at edges) ×
4. An ammeter is connected in parallel in a circuit. (False: Ammeter is in series) ×
5. Magnetic field lines intersect each other. (False: they never intersect) ×
6. Increasing the number of turns always increases voltage sensitivity. (Depends also on resistance) ×

6. QUICK COMPARISON TABLES

ELECTRIC FORCE vs MAGNETIC FORCE

Aspect	Electric Force	Magnetic Force
Acts on	Charge (q)	Moving charge (q) or current (I)
Expression	$\vec{F}_E = q\vec{E}$	$\vec{F}_B = q(\vec{v}\times\vec{B})$ or $\vec{F} = I(\vec{l}\times\vec{B})$
Magnitude	$F_E = \lvert q\rvert E$	$F_B = \lvert q\rvert vB\sin\theta$ or $F = IlB\sin\theta$
Direction	Along $\vec{E}$ for +q (opposite for −q)	Perpendicular to both $\vec{v}$ and $\vec{B}$ (or $\vec{l}$ and $\vec{B}$)
Work Done	Can do work	Does no work (on charge)
Effect on speed	Can change speed	Does not change speed (only direction)

AMMETER vs VOLTMETER vs GALVANOMETER

Feature	Ammeter	Voltmeter	Galvanometer
Quantity measured	Current (I)	Potential Difference (V)	Small Current (I)
Connection	Series	Parallel	Usually in measuring circuit
Resistance	Very low (~0)	Very high (~∞)	Moderate
Purpose	Measure current	Measure voltage	Detect very small current
Conversion	–	From galvanometer (with series resistor)	Basic instrument

7. EXAM BOOSTER

MOST IMPORTANT DERIVATIONS

- Magnetic field due to a long straight current carrying wire ($B = \frac{\mu_0 I}{2\pi r}$)
- Magnetic field at centre of circular loop ($B = \frac{\mu_0 I}{2R}$)
- Magnetic field inside long solenoid ($B = \mu_0 nI$)
- Force between two parallel current carrying conductors ($\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$)
- Torque on a rectangular current loop ($\tau = NBIA\sin\theta$)
- Deflection in moving coil galvanometer ($\theta = \frac{NBA}{k}$)

FREQUENTLY ASKED CONCEPTS

- Direction of magnetic field around a current carrying conductor
- When is magnetic force zero?
- Why does a charged particle move in a circle in a magnetic field?
- Relation between magnetic field and force on moving charge / current element
- Conversion of galvanometer to ammeter and voltmeter
- Why magnetic force does no work?
- Torque and stable/unstable equilibrium of current loop

HIGH-WEIGHTAGE FORMULAE (MUST MEMORISE)

- $\vec{F} = q(\vec{v}\times\vec{B})$
- $F = |q|vB\sin\theta$
- $B = \frac{\mu_0 I}{2\pi r}$ (straight wire)
- $B = \frac{\mu_0 I}{2R}$ (circular loop)
- $B = \mu_0 nI$ (solenoid)
- $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{encl}$
- $\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$
- $\vec{\tau} = \vec{\mu}\times\vec{B}$
- $\tau = NBIA\sin\theta$
- $S_I = \frac{NBA}{k}$
- $S_V = \frac{NBA}{kG}$

Multiple Choice Questions

1. A metallic rod of mass per unit length 0.5 kg/m is placed horizontally on a smooth plane inclined at 30° to the horizontal. A uniform magnetic field B = 0.25 T acts vertically upwards. To prevent the rod from sliding down the incline, the current I required to flow through the rod is:
(a) 7.14 A (b) 11.32 A (c) 14.76 A (d) 5.98 A
2. A particle of charge -2 mC moves with a velocity vector $v = (2\hat{i} + 3\hat{j}) \times 10^6$ m/s through a region with a uniform magnetic field $B = 2\hat{j}$ T. The Lorentz force F acting on the particle is:
(a) 8×10^3 N along $+\hat{k}$ (b) 4×10^3 N along $-\hat{k}$
(c) 8×10^3 N along $-\hat{k}$ (d) 12×10^3 N along $+\hat{k}$
3. Two long parallel wires are separated by a distance of 10 cm, carrying currents $I_1 = 5$ A and $I_2 = 10$ A in opposite directions. An electron is projected exactly midway between the wires with a velocity of 10^7 m/s parallel to the wires. The magnitude of the net magnetic force on the electron is:
(a) 9.6×10^{-17} N (b) 1.92×10^{-16} N (c) 3.2×10^{-16} N (d) Zero
4. A very long straight wire carries a current I along the positive Y-axis. At a certain instant, a charge +Q at position (x, 0, 0) moves with velocity $v = v\hat{i}$. The direction of the magnetic force on the charge is:
(a) Along –Z (b) Along –Y (c) Along +Z (d) Along +Y
5. A deuteron (2u, +e) and a proton (1u, +e) enter a magnetic field with the same kinetic energy. If the deuteron describes a circle of radius 0.5 m, the radius of the proton's path is:
(a) $0.5 / \sqrt{2}$ m (b) $0.5\sqrt{2}$ m (c) 0.25 m (d) 1.0 m
6. Two identical circular coils of radius R and N turns are placed concentrically such that their planes are at right angles. If currents I and $\sqrt{3}I$ flow through them respectively, the resultant magnetic field at the center is:
(a) $\mu_0 NI / 2R$ (b) $2\mu_0 NI / R$ (c) $\mu_0 NI / R$ (d) $\sqrt{2}\mu_0 NI / R$
7. A non-conducting ring of radius R has a total charge Q distributed uniformly. It rotates with an angular velocity ω about its axis. A uniform magnetic field B is applied perpendicular to the axis. The torque on the ring is:
(a) $(1/2)Q\omega R^2 B$ (b) $Q\omega R^2 B$ (c) $(1/4)Q\omega R^2 B$ (d) Zero
8. Three parallel long wires are placed such that they form an equilateral triangle of side d in the cross-sectional plane. Each carries current I in the same direction. The force per unit length on any one wire is:
(a) $\mu_0 I^2 / 2\pi d$ (b) $\sqrt{3}\mu_0 I^2 / 2\pi d$ (c) $\mu_0 I^2 / \pi d$ (d) $2\mu_0 I^2 / \pi d$
9. A square loop of side L carrying current I_2 is placed in the same plane as a long straight wire carrying current I_1. The side of the loop nearest to the wire is at a distance L. The net force on the loop is:
(a) $\mu_0 I_1 I_2 / 2\pi$ (b) $\mu_0 I_1 I_2 / 4\pi$ (c) $\mu_0 I_1 I_2 / 6\pi$ (d) Zero
10. A circular loop of radius 10 cm carries 5 A current. If it is placed in a uniform field B = 0.2 T such that its plane is perpendicular to the field, the net force and torque are respectively:
(a) 0.1 N, 0.01 Nm (b) 0, 0 (c) 0.5 N, 0 (d) 0, 0.05 Nm

11. A moving coil galvanometer (MCG) has a resistance of 100 Ω. It gives a full-scale deflection for 10 mA. The current sensitivity is 2 div/mA. The voltage sensitivity of the galvanometer is:
(a) 20 div/V (b) 0.02 div/V (c) 200 div/V (d) 5 div/V
12. A galvanometer of resistance G is shunted by a resistance S. To protect the instrument, a fuse of resistance R_f is added in series only to the galvanometer branch. If the original full-scale deflection current was I_g, the new maximum current I that the ammeter can measure is:
(a) I_g [1 + (G + R_f)/S] (b) I_g [1 + G/(S + R_f)]
(c) I_g [(G + S)/S] (d) I_g [1 + S/(G + R_f)]
13. A moving coil galvanometer has its number of turns increased by 25% to increase its current sensitivity. However, due to the thinner wire used, the internal resistance of the coil increases by 50%. The resulting percentage change in its voltage sensitivity is:
(a) 25% increase (b) 16.67% decrease (c) 20% decrease (d) 10% decrease
14. A square conducting loop of side a and current I is placed in a uniform magnetic field B. The minimum work required by an external agent to rotate the loop from its most stable equilibrium orientation to its most unstable equilibrium orientation is:
(a) Zero (b) I a^2 B (c) 2 I a^2 B (d) -I a^2 B
15. Using Ampere circuital law, magnetic field inside a long solenoid is independent of:
(a) Current (b) Turn density (c) Core permeability (d) Amperian loop shape
16. Figure of merit of a moving coil galvanometer is the current
(a) Needed for full scale deflection (b) Needed to just move the needle
(c)Needed to move the needle by 1 division on scale (d) None of these
17. A charged particle moving along +x enters a region where a uniform magnetic field exists along +y. If the particle is negatively charged, initial deflection is toward:
(a) +z (b) –z (c) +y (d) –x
18. A rectangular loop carrying current I is free to rotate in a uniform magnetic field. Stable equilibrium occurs when magnetic moment is:
(a) Parallel to B (b) Antiparallel to B (c) Perpendicular to B (d) Zero
19. A charged particle enters a magnetic field and continues undeflected. This can occur if:
(a) v ∥ B only (b) q = 0 only (c) v = 0 only (d) More than one of these situations
20. At the centre of a regular hexagonal loop carrying current I, magnetic field is B. If current is reversed in three alternate sides only, resultant field is:
(a) Zero (b) B/3 (c) B/2 (d) B

1	(b)	2	(c)	3	(a)	4	(d)	5	(a)
6	(c)	7	(a)	8	(b)	9	(b)	10	(b)
11	(a)	12	(a)	13	(b)	14	(c)	15	(d)
16	(c)	17	(b)	18	(a)	19	(d)	20	(a)

ANSWER KEY WITH EXPLANATION

Assertion-Reason Questions

Instructions:

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is NOT the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

1. **Assertion:** The kinetic energy of a charged particle moving in a uniform magnetic field remains constant.
   Reason: A moving charged particle experiences a magnetic force that is directly proportional to its velocity.
2. **Assertion:** A radial magnetic field is essential in a moving coil galvanometer to maintain a linear scale.
   Reason: A radial magnetic field makes the magnetic torque on the coil inversely proportional to the current.
3. **Assertion:** Increasing the current sensitivity of a galvanometer by increasing the number of turns always increases its voltage sensitivity.
   Reason: Voltage sensitivity is inversely proportional to the resistance of the coil, which increases with the number of turns.
4. **Assertion:** A current-carrying solenoid tends to contract axially when current is passed through it.
   Reason: Parallel wires carrying currents in the same direction attract each other.
5. **Assertion:** The magnitude of the magnetic field at the center of a circular current-carrying loop is inversely proportional to its radius.
   Reason: The magnetic field lines of a circular loop form closed concentric circles strictly within the same plane as the loop.
6. **Assertion:** An electron and a proton projected with the exact same momentum into a transverse magnetic field will follow circular paths of the same radius.
   Reason: The mass of a proton is approximately 1836 times greater than the mass of an electron.
7. **Assertion:** To convert a galvanometer into an ammeter, a high resistance is connected in parallel with it.
   Reason: An ideal ammeter should have zero resistance so that it does not alter the main current flowing through the circuit.

ANSWERS

1. B, 2. C, 3.D, 4. A, 5. C, 6. B, 7. D

Two-Mark Questions

1. A circular coil of radius R carries a steady current I. Deduce the distance from the centre of the coil, along its axis, where the magnetic field becomes one-eighth (1/8) of its value at the centre.
2. A long straight solid wire carrying current I is placed coaxially inside a long hollow tube carrying an equal current I in the opposite direction. Using Ampere's circuital law, find the magnetic field in the annular region between them and completely outside the tube.
3. A positively charged particle enters a region of mutually perpendicular uniform electric (E) and magnetic (B) fields. If its velocity $v > E/B$, Will the electric force or magnetic force dominate the deflection? Justify your answer.

4. An electron enters a uniform magnetic field with velocity v. Show mathematically that its kinetic energy remains constant, even though its linear momentum changes continuously.
5. A straight horizontal conducting wire of mass m and length L is placed in a uniform horizontal magnetic field B perpendicular to it. What should be the magnitude and direction of the current in the wire so that it experiences no tension in its supporting wires?
6. Two infinitely long straight parallel wires separated by a distance d carry currents I and 3I in opposite directions. Locate the exact point on the line joining them where the net magnetic field is zero.
7. An electron in a hydrogen atom jumps from the first orbit to the second orbit. How does the ratio of its orbital magnetic moment to its orbital angular momentum change? Give reason.
8. A square loop of side a carrying current I lies flat in the X-Y plane. A uniform magnetic field $B = B_0\,(\hat{i} + \hat{k})$ is applied. Calculate the magnitude of the magnetic torque acting on the loop.
9. Why is a radial magnetic field required in a moving coil galvanometer? If flat magnetic poles are used instead, how will the relationship between current (I) and deflection angle (θ) change?
10. A student mistakenly connects a laboratory ammeter in parallel with a 10 Ω resistor in an active circuit. Explain the electrical consequence of this error on the ammeter and the circuit.

Solutions:

1. Field on axis: $B_x = (\mu_0 I R^2) / [2(R^2 + x^2)^{3/2}]$. Field at centre: $B_c = \mu_0 I / 2R$.
   Given $B_x = B_c / 8$.
   $\Rightarrow (\mu_0 I R^2) / [2(R^2 + x^2)^{3/2}] = 1/8 * (\mu_0 I / 2R). \Rightarrow R^2 /((R^2 + x^2)^{3/2}) = 1 / 8R$
   $\Rightarrow 8R^3 = (R^2 + x^2)^{3/2} \Rightarrow 2R = \sqrt{(R^2 + x^2)} \Rightarrow 4R^2 = R^2 + x^2 \Rightarrow x = \sqrt{3}\, R$.
2. Annular region (radius r): Enclosed current is I.
   By Ampere's Law: $B(2\pi r) = \mu_0 I \Rightarrow B = \mu_0 I / (2\pi r)$.
   (ii) Outside the tube: Net enclosed current $I_{net} = I - I = 0$. Therefore, B = 0.
3. It will deflect towards the magnetic field.
   Justification: Magnetic force $F_m = qvB$, Electric force $F_e = qE$.
   Given $v > E/B \Rightarrow vB > E \Rightarrow qvB > qE$. Since $F_m > F_e$, the magnetic force dominates.
4. Magnetic force $F_m = q(v \times B)$.
   By properties of cross product, F_m is always perpendicular to velocity v.
   Work done $dW = F_m \cdot dx = F_m\, v\, dt = 0$ (since $F_m \perp v$).
   By Work-Energy Theorem, since W = 0, ΔK = 0. Hence, KE is constant.
5. For zero tension, magnetic force must balance weight: $F_m = mg \Rightarrow ILB = mg$.
   Magnitude of current I = mg / LB.
   Direction: By Fleming's Left Hand Rule, current must flow such that the force is directed vertically upwards (opposite to gravity).
6. Null point lies outside the wires, closer to the weaker current (I). Let distance be x from wire with current I. $\Rightarrow \mu_0 I / (2\pi x) = \mu_0(3I) / [2\pi(d + x)]. \Rightarrow 1/x = 3/(d + x) \Rightarrow d + x = 3x$
   $\Rightarrow x = d/2$. The point is at distance d/2 from the weaker wire on the outer side.
7. The ratio remains unchanged (1:1). Reason: The ratio of magnetic moment to angular momentum is the gyromagnetic ratio (e/2m). It is a universal constant for an electron and is independent of the orbit.

8. Magnetic moment $M = Ia^2\,\hat{k}$ (since loop is in X-Y plane). Torque $\tau = M \times B = (Ia^2\,\hat{k}) \times B_0(\hat{\imath} + \hat{k}) = Ia^2B_0(\hat{k} \times \hat{\imath}) + Ia^2B_0(\hat{k} \times \hat{k})$. $\tau = Ia^2B_0\,\hat{\jmath}$.Magnitude of torque = Ia^2B_0.
9. A radial field ensures the plane of the coil is always parallel to the magnetic field (angle is 0), ensuring maximum torque ($\tau = NIAB$) and a linear scale ($I \propto \theta$). If flat poles are used, $\tau = NIAB\sin(\alpha)$. The relation becomes non-linear ($I \propto \theta/\sin(\alpha)$), making the scale uneven and difficult to read.
10. Consequence: An ammeter has very low resistance. Connecting it in parallel creates a short circuit across the resistor. A massive current will flow through the ammeter, which will likely burn out its coil and blow the fuse, potentially damaging the circuit's power supply.

Three-Mark Questions

1. A thin, non-conducting ring of radius R carries a total charge Q uniformly distributed over its circumference. The ring is rotated with a constant angular speed ω about its central axis. (a) Deduce the equivalent electric current constituted by this rotating ring. (b) Obtain the expression for the magnetic field generated exactly at the centre of the ring.
2. A wire carrying a steady current I is bent into the shape of a sine wave $y = A\sin(x)$ from $x = 0$ to $x = \pi$. It is placed in a uniform magnetic field $B = B_0\,\hat{\jmath}$ (directed along the positive y-axis). Using the vector properties of magnetic force, deduce the net magnetic force acting on this curved wire.
3. Two infinitely long, insulated straight wires lie in the X-Y plane along the x-axis and y-axis, respectively. Both carry the exact same steady current I in the positive axis directions ($+\hat{\imath}$ and $+\hat{\jmath}$).
   (a) Determine the locus of all points in the X-Y plane where the net magnetic field is strictly zero.
   (b) Briefly describe the direction of the net magnetic field in the first and third quadrants.
4. In a lab expt. , a student finds that the 'figure of merit' of a given moving coil galvanometer is 0.005 A/div. The galvanometer scale has exactly 30 divisions, and the internal resistance of the coil is 20 Ω. Calculate the exact value of the resistance that must be connected to this galvanometer to convert it into a voltmeter capable of reading up to 30V.
5. A single point charge q moves with a constant velocity v (where $v \ll c$).
   (a) Write the expression for the magnetic field B produced by this moving charge at a position vector r.
   (b) If the charge moves along the x-axis, find the ratio of the magnitude of the magnetic field to the electric field (B/E) it produces at a distance r strictly along the y-axis.
6. An infinitely long, tightly wound solenoid carrying a current I has a uniform magnetic field B_0 well inside its core near the centre. By utilizing simple logical symmetry arguments (without performing complex integration), deduce the exact magnitude of the magnetic field exactly at one of the open ends of this semi-infinite solenoid.
7. A uniform conducting wire of length L carries a current I. It is bent to form a perfect square. Deduce the exact mathematical expression for the magnetic field produced at the geometric centre of this square.

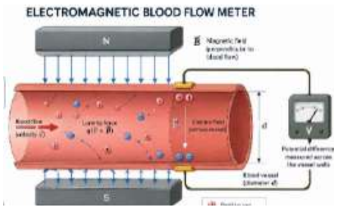
Solutions:

1. The time period of one revolution is $T = 2\pi / \omega$. The equivalent current I is defined as charge passing per unit time: $I = Q / T = Q / (2\pi / \omega) = (Q\omega) / (2\pi)$.
(b) The magnetic field at the centre of a circular current loop is $B = (\mu_0 I) / (2R)$.
Substituting the equivalent current I: $B = (\mu_0) / (2R) * (Q\omega / 2\pi) = (\mu_0 Q\omega) / (4\pi R)$.
2. The magnetic force on any arbitrarily curved wire in a UNIFORM magnetic field depends ONLY on the straight-line displacement vector (L) connecting its starting point to its ending point. $F = I(L \times B)$.
The wire starts at $x = 0$ and ends at $x = \pi$. The displacement vector $L = \pi\, \hat{i}$.
The magnetic field is $B = B_0\, \hat{j}$.
$F = I\, (\pi\, \hat{i} \times B_0\, \hat{j}) = I\pi B_0\, (\hat{i} \times \hat{j}) = I\pi B_0\, \hat{k}$.
The net force is $I\pi B_0$ directed along the positive z-axis.
3. (a) Field due to wire along x-axis at point (x,y) is $B_1 = (\mu_0 I) / (2\pi y)\, \hat{k}$ (for $y>0$). Field due to wire along y-axis is $B_2 = -(\mu_0 I) / (2\pi x)\, \hat{k}$ (for $x>0$).
For net field to be zero, $B_1 + B_2 = 0 \Rightarrow (\mu_0 I) / (2\pi y) = (\mu_0 I) / (2\pi x)$. Therefore, $y = x$. The locus of null points is the straight line $y = x$.
(b) In the 1st Quadrant ($x>0$, $y>0$): For $y>x$, field is out of page ($+\hat{k}$). For $y<x$, field is into page ($-\hat{k}$). In the 3rd Quadrant ($x<0$, $y<0$): The direction flips due to the signs of x and y, yielding out of page for $|y|>|x|$ and into page for $|y|<|x|$.
4. Figure of merit (k) is current per division. Total full-scale current I_g = k × (Total Divisions).
$I_g = 0.005$ A/div × 30 div = 0.15 A.
Given G = 20 Ω, desired voltage V = 30 V.
Series resistance required: $R_s = (V / I_g) - G$. $R_s = (30 / 0.15) - 20 = 200 - 20 = 180\ \Omega$.
A resistance of 180 Ω must be connected in series.
5. (a) Biot-Savart law for a moving charge: $B = (\mu_0/4\pi) * [q(v \times r) / r^3]$, where r is the position vector from the charge to the observation point.
(b) Electric field magnitude $E = (1/4\pi\varepsilon_0) * (q/r^2)$.
Magnetic field magnitude (since v and r are perpendicular, angle is 90°): $B = (\mu_0/4\pi) * (qv/r^2)$.
Ratio $B/E = [(\mu_0/4\pi) * (qv/r^2)] / [(1/4\pi\varepsilon_0) * (q/r^2)] = (\mu_0\varepsilon_0) * v$.
Since $\mu_0\varepsilon_0 = 1/c^2$, the ratio $B/E = v/c^2$.
6. Imagine an infinitely long solenoid spanning from $-\infty$ to $+\infty$. The field exactly at its centre (origin) is B_0.Now, conceptually cut this infinite solenoid into two identical semi-infinite halves at the origin. By the principle of superposition, the field at the origin B_0 is the vector sum of the fields produced by the left semi-infinite half and the right semi-infinite half. Since both halves are perfectly identical, they contribute equally to the field at the cut point. Therefore, $B_{half} + B_{half} = B_0 \Rightarrow 2B_{half} = B_0 \Rightarrow B_{half} = B_0 / 2$. The field at the open end of a semi-infinite solenoid is exactly half the field deep inside.
7. The total length is L, so each side of the square is $a = L/4$. The distance from the centre to any side is $d = a/2 = L/8$. The magnetic field at the centre due to one straight side of length

a is $B_1 = (\mu_0 I / 4\pi d)$ [sin(45°) + sin(45°)]. $B_1 = [\mu_0 I / 4\pi(L/8)] * (1/\sqrt{2} + 1/\sqrt{2}) = (2\mu_0 I / \pi L) * (2/\sqrt{2}) = (2\sqrt{2}\ \mu_0 I) / \pi L$.Since there are 4 identical sides and their magnetic fields all point in the same direction (e.g., into the page), the net field is $B_{net} = 4 \times B_1 = 4 * [(2\sqrt{2}\ \mu_0 I) / \pi L] = (8\sqrt{2}\ \mu_0 I) / \pi L$.

Case-Based Question

An Electromagnetic Blood Flow Meter measures blood velocity v without surgery. An electromagnet applies a uniform magnetic field B perpendicular to the blood flow. Blood contains free ions. The Lorentz force deflects these ions across the blood vessel of diameter d, creating a transverse electric field. Equilibrium is reached when the electric and magnetic forces balance, producing a steady potential difference V across the vessel walls.



1. Blood flows along +x and the magnetic field B is along +y. At steady state, where do the ions accumulate?
(a) Positive on +z, Negative on –z (b) Positive on -z, Negative on +z
(c) Both on +z (d) Both on –y
2. At equilibrium, what is the measured potential difference V?
(a) V = vB/d (b) V = vBd (c) V = B/vd (d) V = vd/B
3. An artery's cross-sectional area halves (A' = A/2) due to a blockage. If the volume flow rate (Q) remains constant, the new measured voltage V' is:
(a) V/2 (b) 2V (c) √2V (d) V
4. If pure deionized water is pumped through the meter instead of blood, the voltmeter reading will be:
(a) High (water has high permittivity) (b) Low (water is diamagnetic)
(c) Zero (no free charge carriers) (d) Zero (magnetic fields block water flow)

Answer Key

1. a, 2. b, 3. c, 4. c.

Five-Mark Questions

1. A beam containing a mixture of two singly ionized isotopes of an element, having masses m_1 and m_2 ($m_1 > m_2$), is accelerated from rest through a potential difference V. The beam then passes completely undeflected through a 'velocity selector' region containing mutually perpendicular uniform electric (E) and magnetic (B_1) fields. Finally, it enters a region containing only a uniform transverse magnetic field B_2.
   a) Deduce the relationship between the accelerating potential V and the fields E and B_1 in the first region for the particles to pass undeflected.
   b) Upon entering the second region (B_2), the isotopes separate and hit a photographic plate. Which isotope (m_1 or m_2) will hit the plate closer to the entry slit? Justify your answer mathematically.
   c) Write the exact mathematical expression for the spatial separation distance (Δx) between the two marks left by the isotopes on the photographic plate.
2. A student is provided with a moving coil galvanometer of resistance G = 100 Ω having a full-scale deflection current of I_g= 1 mA. They are asked to measure the potential difference across a 500 Ω resistor connected in series with a 10 V ideal battery and another 500 Ω resistor.

a) The student first connects the galvanometer directly across the 500 Ω resistor. Calculate the voltage reading it displays. Explain physically why this reading is wildly inaccurate compared to the 'true' voltage.

b) To fix this, the student converts the galvanometer into a voltmeter of range 0 - 10 V. Calculate the exact value of the series resistance required for this conversion.

c) The student now uses this newly constructed voltmeter to measure the voltage across the same 500 Ω resistor. Calculate the percentage error in the measurement compared to the true theoretical voltage.

3. Three infinitely long, straight, parallel wires A, B, and C lie in the same horizontal plane. Wires A and C are rigidly fixed at a separation distance of 2d and carry steady currents of I and 4I respectively, in the same direction. Wire B, carrying a current I_0 in the opposite direction, is free to move but is currently held in place between them.

a) Determine the exact geometrical position where Wire B must be placed so that it experiences zero net magnetic force when released.

b) If Wire B is displaced slightly from this equilibrium position strictly along the line joining A and C, will it execute oscillatory motion, or will it be pulled entirely towards one of the fixed wires? Justify your answer by analyzing the nature of the magnetic forces.

c) Does the equilibrium position of Wire B depend on the magnitude or the direction of the current I_0 flowing through it? Give a reason.

4. Two identical circular coils, C_1 and C_2, each of radius R and carrying the exact same current I in the same clockwise sense, are placed coaxially with their centers separated by a distance R.

a) Calculate the exact magnitude and direction of the net magnetic field at the midpoint O on the axis between the two coils.

b) A stationary proton is suddenly released at exactly the midpoint O. Describe its subsequent state of motion. Will it accelerate? Justify.

c) Now, a highly energetic alpha particle is shot precisely along the central axis of the coils from outside the system, passing through C_1, midpoint O, and then C_2. Describe how the kinetic energy and the linear momentum vector of the alpha particle change during this entire journey.

Solutions

1. For undeflected passage, Lorentz force is zero: $qE = qvB_1 \Rightarrow v = E/B_1$.Velocity is acquired by accelerating through V: $\frac{1}{2}mv^2 = qV$. Substituting v: $\frac{1}{2}m(E/B_1)^2 = qV \Rightarrow V = (mE^2) / (2qB_1^2)$.

(b) In field B_2, radius $r = mv / (qB_2)$. Since v, q, B_2 are identical for both, $r \propto m$. Since $m_2 < m_1$, $r_2 < r_1$. The lighter isotope (m_2) hits closer to the entry slit.

(c) Separation $\Delta x = \text{diameter}_1 - \text{diameter}_2 = 2r_1 - 2r_2 = (2v / qB_2)(m_1 - m_2)$. Substituting $v = E/B_1$: $\Delta x = (2E / qB_1B_2)(m_1 - m_2)$.

2. (a) True voltage (voltage divider): V_true = 10 * [500 / (500+500)] = 5 V. Parallel resistance of G and 500 Ω: R_p = (500 * 100) / 600 = 83.33 Ω. Total resistance = 500 + 83.33 = 583.33 Ω. Main current I = 10 / 583.33 = 0.0171 A. Voltage reading = I * R_p =

$0.0171 * 83.33 = 1.42$ V. Reason: The low resistance of G draws massive current, altering the circuit's equivalent resistance and severely dropping the measured voltage.
(b) Voltmeter conversion: $R_s = (V / I_g) - G = (10 / 0.001) - 100 = 10000-100 = 9900\ \Omega$
(c) New voltmeter $R_v = 10000\ \Omega$. Parallel with 500 Ω: $R'_p = (500 * 10000) / 10500 = 476.19\ \Omega$.Total resistance = 500 + 476.19 = 976.19 Ω. Main I = 10 / 976.19 = 0.01024 A. Measured Voltage $V_m = I * R'_p = 0.01024 * 476.19 = 4.878$ V. % Error = 2.44%.

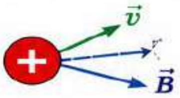
3. Let B be at distance x from A. Distance from C is (2d - x).
Force from A (repulsive, pushing right): $F_A = (\mu_0 I I_0) / (2\pi x)$.
Force from C (repulsive, pushing left): $F_C = (\mu_0 4I I_0) / (2\pi(2d - x))$.
Equilibrium: $F_A = F_C \Rightarrow 1/x = 4/(2d - x) \Rightarrow 2d - x = 4x \Rightarrow 5x = 2d \Rightarrow x = 2d/5$.
(b) Oscillatory motion (Stable equilibrium). If displaced right (towards C), distance from C decreases, so restoring force F_C (pushing left) increases. Distance from A increases, so F_A (pushing right) decreases. Net force is restoring.

No. The equilibrium position (x = 2d/5) only depends on the ratio of fixed currents I and 4I. I_0 cancels out mathematically, and reversing direction makes both forces attractive but they still balance at the exact same point.

4. (a) Midpoint distance x = R/2. Field due to one coil $B_1 = (\mu_0 I R^2) / [2(R^2 + (R/2)^2)^{(3/2)}] = (4\mu_0 I) / (5\sqrt{5} R)$. Net field $B_{net} = B_1 + B_2 = 2 * B_1 = (8\mu_0 I) / (5\sqrt{5} R)$. Direction: Along the common axis.
(b) Proton remains perfectly stationary. Magnetic force $F = q(v \times B)$. Since initial velocity v = 0, F = 0. It will not accelerate.
(c) Kinetic Energy: Remains strictly constant because magnetic force does absolutely zero work. Linear Momentum: The alpha particle's velocity is completely parallel to the magnetic field along the central axis ($v \parallel B$). Thus, $F = q(v \times B) = 0$. With no transverse or longitudinal forces, linear momentum remains completely unchanged in both magnitude and direction.

CHALLENGE CORNER

1. An electron and an alpha particle, moving with the exact same kinetic energy, enter a uniform magnetic field perpendicularly. Which particle will describe a circular path of a smaller radius?
2. A student is provided with two shunt resistors: 10 Ω and 0.01 Ω. Which resistor should they choose to convert a moving coil galvanometer into an ammeter, and how should it be connected?
3. A steady electric current flows through a long, hollow copper pipe. Is there a magnetic field produced inside the pipe?
4. A charged particle enters a uniform magnetic field such that its initial velocity makes an angle of 45° with the magnetic field lines. Describe the shape of its resulting trajectory and identify the velocity component responsible for the "pitch".
5. Two infinitely long parallel straight wires carry steady currents in the same direction. What is the physical nature of the magnetic force between them? If the current in the first wire is doubled and the distance separating the two wires is halved, how does the force per unit length change?
6. A bar magnet of magnetic moment M is placed in a uniform magnetic field B. What is the total work required to rotate the magnet from its most stable equilibrium position to its most unstable equilibrium position?
7. Under what exact condition will a charged particle pass completely undeflected through a region with mutually perpendicular electric and magnetic fields? Does this condition depend on the mass or charge of the particle?
8. If doubling the number of turns in a galvanometer coil perfectly doubles its current sensitivity, why does the voltage sensitivity remain completely unchanged?



MOVING CHARGES AND MAGNETISM

CLASS 12 PHYSICS – MOST ESSENTIAL FORMULA SHEET

1. MAGNETIC FIELD

- Biot–Savart Law $$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I d\vec{l} \times \hat{r}}{r^2}$$
- Magnetic field due to a long straight wire (at distance r) $$B = \frac{\mu_0 I}{2\pi r}$$
- Magnetic field at centre of circular loop (radius R) $$B = \frac{\mu_0 I}{2R}$$
- Magnetic field on axis of circular loop (at distance x) $$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}$$
- Magnetic field inside long solenoid $$B = \mu_0 n I = \mu_0 \frac{N}{\ell} I$$
- Magnetic field inside solenoid (with core of permeability μ_r) $$B = \mu_0 \mu_r n I$$
- Field due to infinite straight current sheet (surface current density K) $$B = \frac{\mu_0 K}{2}$$

2. AMPERE'S CIRCUITAL LAW

- Integral form $$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enc}}$$
- Differential form $$\nabla \times \vec{B} = \mu_0 \vec{J}$$

3. FORCE ON CHARGED PARTICLE (LORENTZ FORCE)

- Magnetic force $$\vec{F} = q(\vec{v} \times \vec{B})$$
- Magnitude $$F = |q|\, v\, B \sin\theta$$
- Electric force $$\vec{F}_E = q\vec{E}, \quad F_E = |q| E$$
- Combined (Electric + Magnetic) $$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

4. MOTION OF CHARGED PARTICLE IN MAGNETIC FIELD

- $\vec{v} \perp \vec{B}$ (circular path) $$F = qvB = \frac{mv^2}{r}$$ $$r = \frac{mv}{|q|B}, \quad T = \frac{2\pi m}{|q|B}, \quad \omega = \frac{|q|B}{m}$$
- $\vec{v} \parallel \vec{B}$: No force, straight line
- $\vec{v}$ at angle θ to $\vec{B}$ (helical path) $$v_{\perp} = v\sin\theta, \quad v_{\parallel} = v\cos\theta \qquad r \;\; mv\,\frac{v_{\perp n}\,\theta}{|q|B}$$
  Pitch (p) $$p = v_{\parallel} T = \frac{2\pi m v \cos\theta}{|q|B}$$

5. FORCE ON CURRENT-CARRYING CONDUCTOR

- Force on straight conductor $$\vec{F} = I(\vec{l} \times \vec{B})$$ $$F = BIl\sin\theta$$
- Force between two parallel current-carrying conductors $$\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi r}$$ (attractive if same direction, repulsive if opposite)
- Force on a moving conductor (length l) $$F = BIl$$ (when conductor moves perpendicular to B)

6. TORQUE AND MOMENT

- Magnetic dipole moment of a current loop $$\vec{\mu} = NIA\,\hat{n} \qquad (A = \text{area})$$
- Torque on current loop in uniform field $$\vec{\tau} = \vec{\mu} \times \vec{B}$$ $$\tau = \mu B \sin\theta$$
- Potential energy of dipole $$U = -\vec{\mu} \cdot \vec{B} = -\mu B \cos\theta$$
- Work done in rotating dipole (from θ_1 to θ_2) $$W = \mu B(\cos\theta_1 - \cos\theta_2)$$

7. MOVING COIL GALVANOMETER (MCG)

- Torque $$\tau = NBAI$$
- Restoring torque $$\tau_r = k\theta$$
- At equilibrium $$NBAI = k\theta$$
- Current sensitivity $$S_I = \frac{\theta}{I} = \frac{NBA}{k}$$
- Voltage sensitivity $$S_V = \frac{\theta}{V} = \frac{NBA}{kG}$$
- Figure of merit $$K = \frac{\theta}{I} = \frac{k}{NBA}$$

8. CONVERSION FORMULAE

- Ammeter (shunt S in parallel) $$S = \frac{I_g G}{I - I_g}$$ (I_g = full scale current, G = resistance of galvanometer)
- Voltmeter (series resistance R) $$R = \frac{V - I_g G}{I_g}$$ (V = required range)

9. INDUCTANCE AND ENERGY

- Self inductance of solenoid $$L = \mu_0 \mu_r \frac{N^2 A}{\ell}$$
- Magnetic energy stored $$U = \frac{1}{2} L I^2$$
- Energy density in magnetic field $$u = \frac{B^2}{2\mu_0}$$

10. IMPORTANT CONSTANTS

- Permeability of free space: $\mu_0 = 4\pi \times 10^{-7}\ T\,mA^{-1}$
- Charge on electron / proton: $e = 1.6 \times 10^{-19}\ C$
- Mass of electron: $m_e = 9.11 \times 10^{-31}\ kg$
- Mass of proton: $m_p = 1.67 \times 10^{-27}\ kg$
- Electron volt: $1\ eV = 1.6 \times 10^{-19}\ J$

KEY SYMBOLS: $\vec{B}$: Magnetic field, $\vec{E}$: Electric field, $\vec{v}$: Velocity, q : Charge, I : Current, N : Number of turns, A : Area, θ : Angle between vectors, $n = \frac{N}{\ell}$: Turn density

CHAPTER 05

MAGNETISM AND MATTER
CBSE CLASS 12 PHYSICS – CHAPTER GIST

1 CHAPTER CORE IDEA

Magnetic behavior of materials arises from intrinsic atomic moments and their response to external magnetic field.

2 CONCEPT FLOW MAP

Magnetic Dipole Moment → Magnetization (M) → Classification of Materials → H and B Relationship → Magnetic Susceptibility and Permeability

- Dia-, Para-, Ferro-magnetism
- Domain Theory (Ferro)
- Hysteresis (Ferro)
- Magnetic Energy

3 KEY LAWS & PRINCIPLES

Magnetic Dipole Moment (m)
A current loop acts as a magnetic dipole. Its strength and direction are given by the right hand rule.

Magnetization (M)
Magnetic dipole moment per unit volume of a material. It represents the overall magnetic strength of the material.

Magnetic Field (B) and Magnetizing Field (H)
$\vec{B}$
B is the total magnetic field inside a material. H is the magnetizing field produced by free currents.

Magnetic Susceptibility (χ)
χ
Measure of how much a material gets magnetized in an external field.

Permeability (μ)
μ
Measure of ability of a material to allow the formation of magnetic field within it.

Domain Theory (Ferromagnetism)
Ferromagnetic materials consist of domains. Magnetization occurs due to alignment of domains in an external field.

Hysteresis
Lag of B behind H in a ferromagnetic material when magnetizing field is cycled. Shows retentivity and coercivity.

4 ESSENTIAL FORMULA BANK

- **Magnetic dipole moment of a current loop:**
$$m = NIA$$
N = number of turns, I = current, A = area
- **Magnetization:**
$$M = \frac{m}{V}$$
m = magnetic dipole moment, V = volume
- **Relation between B and M:**
$$B = \mu_0(H + M)$$
μ_0 = permeability of free space
- **Magnetic susceptibility:**
$$\chi_m = \frac{M}{H}$$
Dimensionless
- **Relative permeability:**
$$\mu_r = 1 + \chi_m$$
- **Permeability of material:**
$$\mu = \mu_0\mu_r$$
- **For linear, isotropic material:**
$$B = \mu H$$
- **Energy density in magnetic field:**
$$u = \frac{1}{2}B \cdot H = \frac{1}{2}\mu H^2$$
u = energy per unit volume

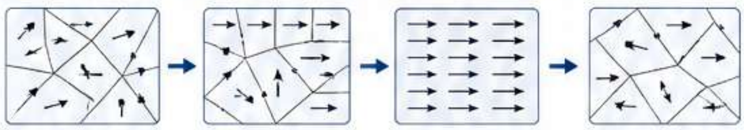
5 CLASSIFICATION OF MAGNETIC MATERIALS

Diamagnetic
- Weakly repelled by magnetic field
- χ_m is small and negative
- $\mu_r < 1$ (slightly less than 1)
- **Ex:** Bismuth, Copper, Water

Paramagnetic
- Weakly attracted by magnetic field
- χ_m is small and positive
- μ_r is slightly greater than 1
- **Ex:** Aluminium, Platinum, Oxygen

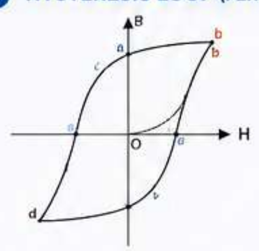
Ferromagnetic
- Strongly attracted by magnetic field
- χ_m is large and positive
- $\mu_r \gg 1$
- **Ex:** Iron, Cobalt, Nickel

6 DOMAIN THEORY (FERROMAGNETIC MATERIALS)



Unmagnetized State	Magnetization	Saturation	Demagnetization
Domains are randomly oriented. Net magnetization is zero.	Under external field, domains align in field direction. Material becomes magnetized.	All domains aligned. Further increase in field doesn't increase magnetization.	When field is removed, domains become random again. Net magnetization is zero.

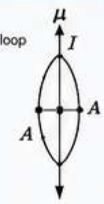
7 HYSTERESIS LOOP (FERROMAGNETIC MATERIALS)



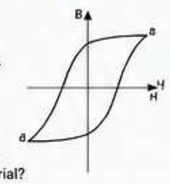
- **Oa** – Initial magnetization
- **ab** – To saturation
- **bc** – Field reduced to zero → **Retentivity (B_r)**
- **cd** – Reverse field → Coercivity (H_c)
- **dO** – Complete demagnetization

11 EXAM BOOSTER SECTION

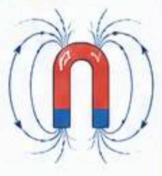
MOST IMPORTANT DERIVATIONS
- Expression for magnetic dipole moment of a current loop
- Relation $B = \mu_0(H + M)$
- Relation $\mu_r = 1 + \chi_m$
- Expression for energy density $u = \frac{1}{2}BH$
- Hysteresis loop and its parameters



FREQUENTLY ASKED CONCEPTS
- Why do diamagnetic materials have $\mu_r < 1$?
- Why do ferromagnetic materials show hysteresis?
- Why do some materials retain magnetization?
- Why can't a permanent magnet be made of paramagnetic material?



HIGH-WEIGHTAGE FORMULAE
- $m = NIA$
- $M = \frac{m}{V}$
- $B = \mu_0(H + M)$
- $\chi_m = \frac{M}{H}$, $\mu_r = 1 + \chi_m$
- $u = \frac{1}{2}BH = \frac{1}{2}\mu H^2$



Multiple Choice Questions

1. A short bar magnet has a magnetic dipole moment m. Let B_{ax} and B_{eq} be the magnetic fields at an axial point and an equatorial point, respectively, at the same distance r from the centre of the magnet. Which of the following relations is correct?
(a) $B_{ax} = 2B_{eq}$ (b) $B_{ax} = -2B_{eq}$ (c) $B_{eq} = -2B_{ax}$ (d) $B_{ax} = B_{eq}$
2. A planar circular current-carrying loop of radius a has a magnetic dipole moment m. If the radius of the loop is doubled while keeping the current constant, what will be the new magnetic dipole moment?
(a) 2m (b) 4m (c) m/2 (d) m/4
3. According to Gauss's Law in magnetism, the surface integral of the magnetic field over a closed surface is zero. What is the fundamental physical implication of this law?
(a) Magnetic field lines are always straight. (b) Magnetic monopoles do not exist.
(c) Magnetic poles always attract each other. (d) The magnetic field inside a conductor is zero.
4. An alloy has a very broad hysteresis loop with high retentivity and high coercivity. Based on the hysteresis curve, this material is best suited for making:
(a) Electromagnets (b) Transformer core
(c) Temporary magnets (d) Permanent magnets
5. A magnetic material obeys Curie's law. If its absolute temperature is increased from 300 K to 600 K, its magnetic susceptibility will:
(a) Double (b) Become half (c) Remain constant (d) Become four times
6. The intensity of magnetization (I) of a magnetic material is defined as the magnetic moment per unit volume. If a bar magnet of pole strength q_m, magnetic length 2l, and cross-sectional area A is considered, the intensity of magnetization I is equivalent to:
(a) q_m / A (b) q_m / 2l (c) $q_m \times$ A (d) q_m / (A × 2l)
7. Two identical bar magnets, each of geometric length 10 cm, are placed end-to-end. What is the approximate magnetic length of a single bar magnet from this pair?
(a) 10 cm (b) 5 cm (c) 8.4 cm (d) 11.6 cm
8. The residual magnetism left in a material when the external magnetizing force (H) is reduced to zero is known as:
(a) Coercivity (b) Susceptibility (c) Retentivity (d) Permeability
9. The unit of magnetic dipole moment is:
(a) Am (b) JT^{-1} (c) TmA^{-1} (d) Am^{-1}
10. A current loop of area A and N turns carries a current I. If you look at the face of the loop and the current appears to flow in the clockwise direction, what is the magnetic polarity of that face and the direction of the dipole moment relative to you?
(a) North polarity; dipole moment points towards you.
(b) South polarity; dipole moment points towards you.
(c) South polarity; dipole moment points away from you.
(d) North polarity; dipole moment points away from you.

Answer Key for MCQs

1. (b)	2. (b)	3. (b)	4. (d)	5. (b)
6. (a)	7. (c)	8. (c)	9. (b)	10. (c)

Assertion-Reason Type Questions

Directions: For the following questions, select the correct option:

(A) Both Assertion (A) and Reason (R) are true, and (R) is the correct explanation of (A).

(B) Both Assertion (A) and Reason (R) are true, but (R) is not the correct explanation of (A).
(C) Assertion (A) is true, but Reason (R) is false.
(D) Assertion (A) is false, but Reason (R) is true.

1. **Assertion (A):** The net magnetic flux through any closed Gaussian surface is always zero.
   Reason (R): Magnetic poles always exist in pairs (dipoles), and isolated magnetic monopoles do not exist.
2. **Assertion (A):** The magnetic field at an equatorial point of a short bar magnet is parallel to the magnetic dipole moment of the magnet.
   Reason (R): The angle between the equatorial field and the magnetic dipole moment is 180°.
3. **Assertion (A):** Steel is highly preferred over soft iron for making permanent magnets.
   Reason (R): Steel has a thicker hysteresis loop with much higher coercivity than soft iron, meaning it is not easily demagnetized.
4. **Assertion (A):** When a magnetic dipole is placed in a uniform magnetic field, the net force acting on it is always zero, but it may experience a torque.
   Reason (R): Torque on a magnetic dipole is given by $\tau = m \times B$.
5. **Assertion (A):** The magnetic susceptibility of a material varies directly with its absolute temperature.
   Reason (R): Curie's law states that m = C/T, meaning magnetization is inversely proportional to temperature.

Answer Key for Assertion-Reason

1 (A)	2 (D)	3 (A)	4 (B)	5 (D)

Two-Mark Questions

1. A wire of constant length L carrying a current I can be bent into a single-turn circular loop or a single-turn square loop. Which shape will produce a greater magnetic dipole moment? Justify your answer mathematically.
2. A student calculates the magnetic dipole moment of a 15 cm long bar magnet by assuming its poles lie exactly at its geometrical ends. Will the true, measurable magnetic moment be lesser or greater than this calculated value? Give a physical reason for your answer.
3. Material X exhibits a broad hysteresis loop with high retentivity and high coercivity, while Material Y exhibits a narrow loop with low coercivity. Which of these materials is suitable for making (i) a transformer core, and (ii) a permanent magnet? Give one fundamental reason for each choice.
4. The ferromagnetic iron core of a heavy-duty electromagnet accidentally overheats, and its temperature approaches 1000 K. What will happen to its lifting capacity, and what specific phase transition occurs at this temperature? Name the law that governs this behaviour.
5. A cylindrical permanent magnet of volume V and magnetic moment m is sliced exactly in half along its longitudinal axis (parallel to its length). How does the Intensity of Magnetization (I) of each half compare to that of the original magnet?

Answers (Hints)

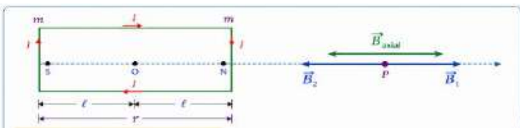
1. Magnetic dipole moment m = IA. For a constant perimeter L, a circle encloses a greater area (A_{circle} = L²/4π) compared to a square (A_{square} = L²/16). Since $A_{circle} > A_{square}$, the circular loop has the greater dipole moment.
2. The true magnetic poles reside slightly inside the geometrical boundaries of the magnet. Therefore, the effective magnetic length (2l) is shorter than the geometric length (15 cm), making the true dipole moment (m = q_m × 2l) lesser than calculated.
3. Material Y's narrow loop ensures minimal hysteresis energy loss during AC magnetization cycles. Material X's high coercivity ensures the permanent magnet cannot be easily demagnetized by stray external fields or mechanical shocks.
4. At roughly 1000 K, iron reaches its Curie Temperature and undergoes a phase transition from strongly ferromagnetic to weakly paramagnetic. This thermal agitation randomized magnetic domains, governed by Curie's Law ($\chi \propto 1/T$).
5. Intensity of Magnetization is defined as I = m/V. Slicing the magnet longitudinally exactly halves its volume (V → V/2) and its pole strength/magnetic moment (m → m/2). Therefore, the ratio (m/2)/(V/2) remains I, perfectly unchanged.

Three-Mark Questions

1. Derive the expression for the magnetic field B at an axial point of a magnetic dipole of magnetic length $2l$ and pole strength q_m. Deduce the expression for a short magnet.
2. Explain the analogy between a current-carrying planar loop and a magnetic dipole. State the Right-Hand Rule used to determine the direction of the dipole moment.
3. Draw a typical Hysteresis loop (Magnetization curve) for a ferromagnetic material. Label the points representing retentivity and coercivity. Based on the area of this loop, distinguish between materials used for temporary and permanent magnets.

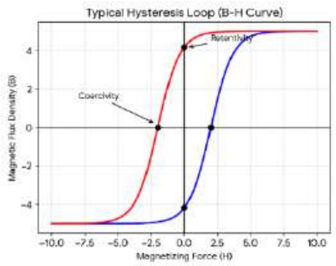
Answers

1. Net field B = B_N - B_S



   $B = (\mu_0 q_m / 4\pi) * [\,1/(r-l)^2 - 1/(r+l)^2\,]$
   $B = (\mu_0 q_m / 4\pi) * [\,4rl / (r^2 - l^2)^2\,]$
   Since dipole moment m = q_m × 2l:
   $B_{ax} = (\mu_0 / 4\pi) * [\,2mr / (r^2 - l^2)^2\,]$
   Short Magnet Approximation: If r >> l, then $r^2 - l^2 \approx r^2$.
   $B_{ax} = (\mu_0 / 4\pi) * (\,2m / r^3\,)$
2. A current-carrying planar loop acts as a magnetic dipole. A face with counter-clockwise current acts as a North pole; a face with clockwise current acts as a South pole. Dipole moment m = IA. Right-Hand Rule: Curl the fingers of your right hand in the direction of the current. Your extended thumb points in the direction of the magnetic dipole moment (and the North pole).

3. Retentivity: Residual magnetism when magnetizing field (H) is zero. Coercivity: Reverse field (-H) needed to fully demagnetize the material. Loop Area: Represents energy dissipated as heat per cycle. Distinction:
   • Temporary Magnets (e.g., Soft Iron): Require narrow loop (small area) for low energy loss. Low coercivity.
   • Permanent Magnets (e.g., Steel): Require broad loop (large area) to resist demagnetization. High coercivity.



Case-Based Question

Magnetic Properties and Hysteresis

When a magnetic material is subjected to a cycle of magnetization, the intensity of magnetization (I) does not exactly track the magnetizing force (H). As H increases, I increase and eventually reaches saturation. When H is reduced to zero, the material retains some magnetism, a property known as retentivity. To completely demagnetize the material (I=0), an opposite magnetizing force must be applied, known as coercivity. The closed curve representing one complete cycle of magnetization and demagnetization is called a hysteresis loop. The area under the hysteresis loop represents the energy dissipated as heat during one cycle. Materials are chosen for specific applications based on the shape of this loop.

1. The residual magnetism present in a substance when the external magnetizing force is reduced to zero is called:
   (a) Coercivity (b) Retentivity (c) Susceptibility (d) Permeability
2. To completely demagnetize a material, a negative magnetizing force is applied. This required opposing force is termed:
   (a) Magnetic intensity (b) Retentivity (c) Coercivity (d) Saturation point
3. A material designed to be used as a core for an electromagnet (a temporary magnet) should ideally possess:
   (a) High retentivity, low coercivity, and a thin hysteresis loop
   (b) Low retentivity, low coercivity, and a thin hysteresis loop
   (c) High retentivity, high coercivity, and a broad hysteresis loop
   (d) Low retentivity, high coercivity, and a broad hysteresis loop
4. The physical significance of the area enclosed by a hysteresis loop is:
   (a) The maximum magnetic field the material can produce.
   (b) The magnetic flux density of the material.
   (c) The loss of energy per cycle of magnetization and demagnetization.
   (d) The Curie temperature of the material.

Answer Key for Assertion-Reason

1 (b) 2 (c) 3 (a) 4 (c)

Five-Mark Questions

1. Consider a bar magnet of pole strength qm and magnetic length 2l. Derive the mathematical expression for the magnetic field at a point P located on the equatorial line at a distance r from the center of the magnet.

a) Show that for a short bar magnet, the magnetic field at an axial point is twice the magnetic field at an equatorial point located at the same distance.

2.
a) Define the following terms and state their SI units:
(i) Magnetic Field Intensity (H)
(ii) Magnetic Permeability (μ)
(iii) Magnetic Susceptibility (χ)
b) Establish the relation I = m/V = qm/A, showing how the intensity of magnetization relates to pole strength and cross-sectional area.

3.
a) Explain how a current-carrying circular loop of radius a and current I behaves like a magnetic dipole. Use the magnetic field expression for a point on the axial line at a large distance (x >> a) to prove this.
b) A circular coil of 100 turns and radius 5 cm carries a current of 2 A. Calculate its magnetic dipole moment.
c) Write the formula for the torque acting on this magnetic dipole if it is placed in a uniform magnetic field B at an angle θ.

Answers:

1. a) Equatorial Magnetic Field Derivation:
Let the point P be at distance r from the center. Distance from N or S pole to P is $\sqrt{(r^2 + l^2)}$.
Magnetic field at P due to North pole: $B_N = (\mu_0/4\pi) * [q_m / (r^2 + l^2)]$
Magnetic field at P due to South pole: $B_S = (\mu_0/4\pi) * [q_m / (r^2 + l^2)]$
Vertical components (B sinθ) cancel out. Horizontal components (B cosθ) add up.
Net Field Beq = 2 * B_N * cosθ.
From geometry, $\cos\theta = l / \sqrt{(r^2 + l^2)}$.
$B_{eq} = 2 * (\mu_0/4\pi) * [q_m / (r^2 + l^2)] * [l / \sqrt{(r^2 + l^2)}]$
$B_{eq} = (\mu_0/4\pi) * [(q_m * 2l) / (r^2 + l^2)^{3/2}]$
Since magnetic dipole moment $m = q_m * 2l$: **$B_{eq} = (\mu_0/4\pi) * [m / (r^2 + l^2)^{3/2}]$**
b) Short Bar Magnet Comparison:
For a short magnet, r >> l, so $(r^2 + l^2) \approx r^2$.
Equatorial field becomes: $B_{eq} = (\mu_0/4\pi) * (m / r^3)$
We know the Axial field is: $B_{ax} = (\mu_0/4\pi) * (2m / r^3)$: $B_{ax} = 2 * B_{eq}$. (Hence proved).

2. a) Definitions and SI Units:
(i) Magnetic Field Intensity (H): The degree or extent to which an external magnetic field can magnetize a substance. SI Unit: A/m (Ampere per meter).
(ii) Magnetic Permeability (μ): The ability of a material to allow the passage of magnetic field lines through it. SI Unit: T·m/A or H/m (Henry/meter).
(iii) Magnetic Susceptibility (χ): The ratio of the intensity of magnetization (I) induced in the material to the applied magnetizing field intensity (H). SI Unit: Dimensionless (No unit).

b) Establishing the Relation I = m/V = q_m/A:

Intensity of Magnetization (I) is defined as the magnetic dipole moment per unit volume:
I = m / V
For a bar magnet of length 2l and cross-sectional area A, Volume V = A * $2l$
The magnetic dipole moment m = q_m * $2l$ (where q_m is pole strength)
Substituting these into the formula: I = (q_m * $2l$) / (A * $2l$)
Cancelling $2l$ gives: I = q_m / A. (Hence proved).

3. a) Current Loop as a Magnetic Dipole:
A current-carrying loop has two faces behaving as opposite magnetic poles (Clockwise = South, Anticlockwise = North).
The magnetic field on the axis of a circular loop is: $B = (\mu_0 * I * a^2) / [2 * (x^2 + a^2)^{(3/2)}]$
For a large distance (x >> a), a^2 is neglected: $B = (\mu_0 * I * a^2) / (2 * x^3)$
Multiply numerator and denominator by π: $B = (\mu_0 * I * \pi * a^2) / (2\pi * x^3)$
Since Area $A = \pi * a^2$, we get $B = (\mu_0 * 2IA) / (4\pi * x^3)$
Comparing this with a short bar magnet ($B = (\mu_0/4\pi) * 2m/x^3$), we see the loop acts as a dipole with magnetic moment m = IA.
b) Calculation of Magnetic Dipole Moment:
Formula: m = N * I * A
Given: N = 100, I = 2 A, r = 5 cm = 0.05 m   Area $A = \pi * r^2 = 3.14 * (0.05)^2 = 0.00785\ m^2$
m = 100 * 2 * 0.00785 = 1.57 $A \cdot m^2$
c) Torque Formula:
$\tau = mB \sin\theta$ (In vector form: $\tau = m \times B$)
Where m is the magnetic dipole moment, B is the magnetic field, and θ is the angle between them.

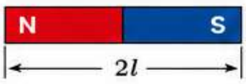
MAGNETISM AND MATTER

CLASS 12 PHYSICS – FORMULA SHEET

1. BAR MAGNET

- Magnetic dipole moment of a bar magnet

$$\boxed{M = m(2l)}$$

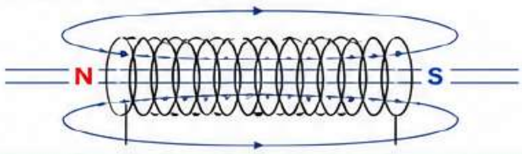


where, m = pole strength

$2l$ = magnetic length

2. BAR MAGNET AS AN EQUIVALENT SOLENOID

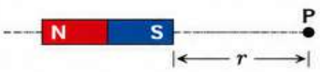
(Qualitative treatment only)



A bar magnet behaves like a current carrying solenoid.
Outside field is similar to a bar magnet.

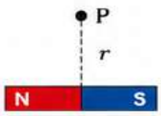
3. MAGNETIC FIELD DUE TO A MAGNETIC DIPOLE (BAR MAGNET)

- At a point on the axial line (distance r from centre)



$$B_{\text{axial}} = \frac{\mu_0}{4\pi}\frac{2M}{r^3}$$

- At a point on the equatorial line (distance r from centre)



$$B_{\text{equatorial}} = \frac{\mu_0}{4\pi}\frac{M}{r^3}$$

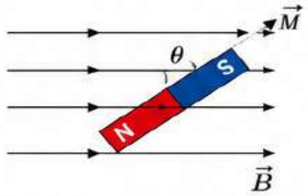
(Direction opposite to dipole moment)

Where, M = magnetic dipole moment of the bar magnet

r = distance of point from centre of dipole

4. TORQUE ON MAGNETIC DIPOLE (BAR MAGNET) IN UNIFORM MAGNETIC FIELD

(Qualitative treatment only)



Torque (Vector form)

$$\vec{\tau} = \vec{M} \times \vec{B}$$

Torque (Magnitude)

$$\tau = MB\sin\theta$$

5. POTENTIAL ENERGY OF MAGNETIC DIPOLE

$$U = -\vec{M}\cdot\vec{B} = -MB\cos\theta$$

where, θ = angle between $\vec{M}$ and $\vec{B}$

6. WORK DONE IN ROTATION OF DIPOLE

(from θ_1 to θ_2)

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

7. MAGNETISATION OF MATERIALS

- Magnetisation (I or M)

$$I = \frac{\text{Magnetic moment}}{\text{Volume}}$$

(SI unit : $A\,m^{-1}$)

8. MAGNETIC SUSCEPTIBILITY AND RELATIVE PERMEABILITY

- Magnetic susceptibility

$$\chi_m = \frac{I}{H}$$

- Relative permeability

$$\mu_r = 1 + \chi_m$$

where, H = magnetising field intensity

9. EFFECT OF TEMPERATURE ON MAGNETIC PROPERTIES (PARAMAGNETIC MATERIALS)

- Curie's Law

$$\chi = \frac{C}{T}$$

where, χ = susceptibility

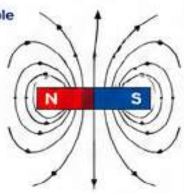
C = Curie constant

T = absolute temperature (in K)

As temperature increases, susceptibility decreases
(paramagnetic materials become less magnetic).

10. MAGNETIC FIELD LINES (KEY POINTS)

- Magnetic field lines emerge from North pole and enter South pole outside the magnet and form closed continuous curves.
- Inside the magnet, field lines go from South pole to North pole.
- No two magnetic field lines intersect each other.
- The tangent to a field line at any point gives the direction of $\vec{B}$ at that point.



11. MAGNETIC PROPERTIES OF MATERIALS

Property	Diamagnetic	Paramagnetic	Ferromagnetic
Susceptibility (χ_m)	Negative	Small Positive	Large Positive
Relative permeability (μ_r)	Less than 1	Slightly greater than 1	Much greater than 1
Nature	Weakly repelled	Weakly attracted	Strongly attracted
Examples	Bi, Cu, Au, Ag, Water	Al, Pt, Mg, O_2	Fe, Co, Ni, Gd

KEY SYMBOLS

M : Magnetic dipole moment; m : Pole strength; $2l$: Magnetic length; $\vec{B}$: Magnetic field

r : Distance from centre; $\vec{\tau}$: Torque; θ : Angle between $\vec{M}$ and $\vec{B}$; U : Potential energy

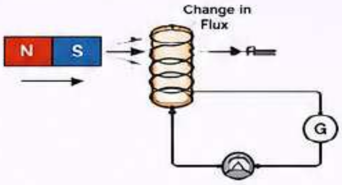
I or M : Magnetisation; H : Magnetising field intensity; χ_m : Magnetic susceptibility; μ_r : Relative permeability

CHAPTER 06

ELECTROMAGNETIC INDUCTION

1. WHAT IS ELECTROMAGNETIC INDUCTION?

It is the phenomenon of inducing an EMF in a conductor whenever the magnetic flux linked with it changes.



Key Insight

Change in magnetic flux
→ Induced EMF
(No change, No EMF)

2. FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION

1st Law

Whenever the magnetic flux linked with a conductor changes, an EMF is induced in it.

2nd Law

The magnitude of induced EMF is equal to the rate of change of magnetic flux linked with the conductor.

$$e = -N\frac{d\Phi_B}{dt}$$

N = Number of turns
Φ_B = Magnetic flux linked with the coil
(–) sign → Lenz's Law (direction of induced EMF)

Magnetic Flux (Φ_B)

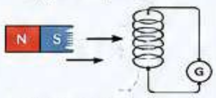
$$\Phi_B = BA\cos\theta$$

B = Magnetic field
A = Area of coil
θ = Angle between B and normal to the area

3. LENZ'S LAW (Direction of Induced EMF)

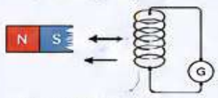
The induced EMF (and current) is always in such a direction that it opposes the change in magnetic flux that produces it.

Increase in Flux
(Approaching Magnet)



Induced current creates N face to oppose the approach.

Decrease in Flux
(Receding Magnet)



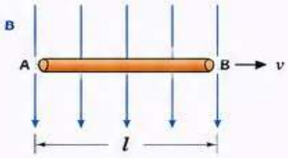
Induced current creates S face to oppose the recession.

Remember

Nature never allows a change without putting up opposition!

4. MOTIONAL EMF

When a conductor moves in a magnetic field and cuts magnetic field lines, an EMF is induced in it.

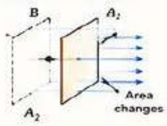


$$e = Blv\sin\theta$$

B = Magnetic field
l = Length of conductor
v = Velocity
θ = Angle between v and B

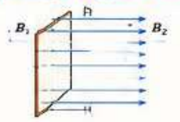
5. INDUCED EMF IN DIFFERENT CASES

(A) Change in Area



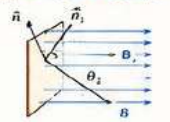
⇒ Φ_B changes
⇒ EMF induced

(B) Change in Magnetic Field



⇒ Φ_B changes
⇒ EMF induced

(C) Change in Angle (θ)

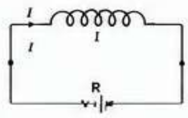


⇒ Φ_B changes
⇒ EMF induced

Quick Recall Any change in B, A, or θ → change in Φ_B → EMF induced

6. SELF INDUCTION

The phenomenon of inducing an EMF in the same circuit due to a change in current in it.



Self Induced EMF

$$e_L = -L\frac{dI}{dt}$$

L = Self inductance of the coil
Unit of L → Henry (H)

Why Negative?

Due to Lenz's Law. It opposes the change in current producing it.

Energy in Inductor

Energy stored in inductor

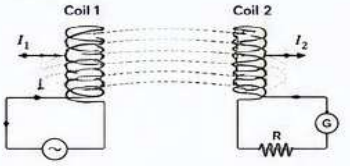
$$U = \frac{1}{2}LI^2$$

Factors Affecting Self Inductance (L)

- Number of turns (N) ↑ → L ↑
- Area of cross-section (A) ↑ → L ↑
- Length of coil (l) ↑ → L ↓
- Nature of core (μ) ↑ → L ↑

7. MUTUAL INDUCTION

The phenomenon of inducing an EMF in one coil due to a change in current in a nearby coil.



Mutually Induced EMF

$$e_2 = -M\frac{dI_1}{dt}$$

M = Mutual inductance
Unit → Henry (H)

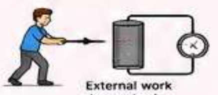
Factors Affecting M

- Number of turns of both coils
- Area of cross-section
- Distance between coils
- Nature of medium

8. ENERGY CONSIDERATIONS

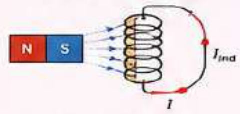
Lenz's Law ensures

- Conservation of energy
- No free energy is created
- Work must be done to change the flux



External work is required.

Induced Current always Opposes the Change



Opposition → Lenz's Law
Conservation → Energy

Think!

No change in flux?
Then No EMF induced!

9. IMPORTANT APPLICATIONS

Electric Generator

Mechanical energy → Electrical energy (AC Generators)

Transformer

Mutual induction is the working principle.

Induction Cooktop

Eddy currents produce heat in the utensil.

Wireless Charging

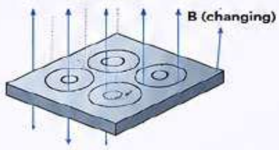
Energy transfer through mutual induction.

Metal Detectors

Change in flux detected by search coils.

10. EDDY CURRENTS

Loops of current induced in a bulk conductor when it is exposed to a changing magnetic field.



Effects

- Cause heating of the conductor
- Waste of energy

Reduction Methods

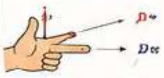
- Laminated cores
- Use of alloys (high resistance)

11. COMPARISON TABLE

Property	Self Induction	Mutual Induction
Definition	EMF induced in the same circuit due to change in current in it.	EMF induced in one circuit due to change in current in another circuit.
Symbol	L (Henry)	M (Henry)
EMF	$e_L = -L\frac{dI}{dt}$	$e_2 = -M\frac{dI_1}{dt}$
Depends on	Coil properties only	Both coils + medium + relative position

12. MEMORY TRICKS

Right Hand Rule
(Direction of Induced Current)



Thumb → Motion / Cause
Forefinger → Magnetic Field
Middle finger → Induced Current

EMF Formula
← Remember →

$$e = -N\frac{d\Phi_B}{dt}$$

"e = – N d Phi by dt"
(Change in Phi → EMF)

ELI Rule

E	I
Leads	Leads
I in Capacitor	E in Inductor

13. EXAM BOOSTER (CBSE)

- ★ Draw neat diagrams (Flux, Lenz's Law, Generators)
- ★ Always write reason in Lenz's Law based questions
- ★ Use Faraday's Law: e ∝ rate of change of flux
- ★ Focus on direction in numerical + theory
- ★ Aspertion-Reason, MCQs, Case Study → High Weightage

14. COMMON MISTAKES TO AVOID

- ✗ Ignoring the negative sign in Faraday's law.
- ✗ Forgetting Lenz's Law in direction questions.
- ✗ Not identifying what causes the change in flux.
- ✗ Confusing self inductance with mutual inductance.

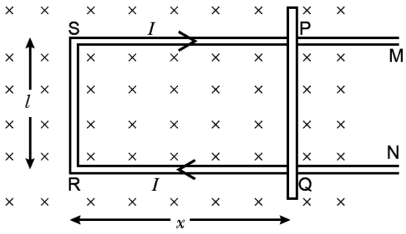
✓ Direction of induced current (Lenz's Law)
✓ Faraday's Law applications
✓ Self & Mutual Induction basics

PYQ TIP

Revise NCERT examples, diagrams and derivations. They are commonly asked in exams!

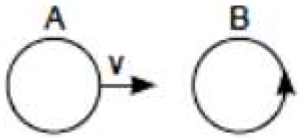
MULTIPLE CHOICE QUESTIONS

1. Figure shows a rectangular conductor PSRQ in which movable arm PQ has a resistance ‘r and resistance of PSRQ is negligible. The magnitude of emf induced when PQ is moved with a velocity v does not depend on (CBSE 2025)



(a) magnetic field **B** (b) velocity field **v**
(c) resistance r (d) length of PQ

2. There are two coils A and B as shown in Figure. A current starts flowing in B as shown, when A is moved towards B and stops when A stops moving. The current in A is counter clockwise. B is kept stationary when A moves. We can infer that (CBSE 2025)



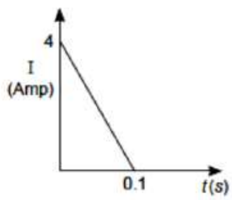
(a) there is a constant current in the clockwise direction in A.

(b) there is a varying current in A. (c) there is no current in A.

(d) there is a constant current in the counterclockwise direction in A.

3. A coil of 100 turns carries a current of 5 mA and creates a magnetic flux of 10^{-5} weber. The inductance is (CBSE 2025)
(a) 0.2 H (b) 2.0 mH (c) 0.02 mH (d) 0.002 H

4. In a coil of resistance 10 π, the induced current developed by changing magnitude of change in flux through the coil in weber is (CBSE 2025)
(a) 8 (b) 2 (c) 6 (d) 4



5. The current in the primary coil of a pair of coils changes from 7A to 3A in 0.04 s. The mutual inductance between the two coils is 0.5 H. The induced emf in the secondary coil is (CBSE 2025)
(a) 50 V (b) 75V (c) 100 V (d) 220 V

6. Rohan and his sister were playing with two coils of insulated copper wire. They placed the coils close to each other. Rohan noticed that whenever the current in one coil was changed rapidly, a deflection was observed in the galvanometer connected to the other coil. The mutual inductance of such a pair of coils depends upon the:
(a) relative orientation of the two coils (b) number of turns in the coils
(c) nature of the material placed between the coils (d) All of the above

7. During a school science exhibition, a square loop of side 0.50 m was placed in a uniform magnetic field of 0.4T acting perpendicular to the plane of the loop. To demonstrate electromagnetic induction, the loop was rotated by an angle of 60° about one of its sides in 0.2 seconds. The value of the induced emf in the loop will be:
(a) 0.1 V (b) 0.25 V (c) 0.5 V (d) 1.0 V

8. In a school physics laboratory, an electromagnet A (a long solenoid) is connected to a battery and a rheostat, as shown in the figure. An aluminium ring B is placed coaxially facing one end

of the electromagnet. The current I through the electromagnet can be increased or decreased by adjusting the rheostat. Which of the following statements is correct?
(a) If the current I is increased, the ring B is attracted towards the electromagnet.
(b) If the current I is decreased, the ring B is repelled away from the electromagnet.
(c) If the current I is increased suddenly, the ring B is repelled away from the electromagnet.
(d) The ring B will always be attracted towards the electromagnet irrespective of whether the current is increased or decreased.
9. A metallic ring is placed on top of a fixed solenoid as shown in the figure. When the current in the solenoid is suddenly switched on, the ring jumps up. This happens because:
(a) The ring is attracted upwards due to the magnetic field of the solenoid.
(b) A repulsive force acts on the ring due to Lenz's law.
(c) The ring experiences an upward force due to gravity.
(d) The current in the solenoid produces eddy currents that heat the ring.
10. A bicycle mechanic was repairing a bicycle wheel having ten metallic spokes. Each spoke is 0.50 m long. The wheel was rotated at a speed of 120 revolutions per minute in a plane perpendicular to the Earth's magnetic field. The magnitude of the Earth's magnetic field at that place was 0.4 Gauss. The induced emf between the axle and the rim of the wheel is equal to:
(a) 1.256×10^{-3} V (b) 6.28×10^{-5} V (c) 1.256×10^{-4} V (d) 6.28×10^{-2} V
11. A farmer installed a small coil of area A_0 near an electromagnet in his irrigation pump system. The magnetic field linked with the coil changed uniformly from B_0 to $4B_0$ in a time interval t. The magnitude of the emf induced in the coil will be:
(a) $\frac{3A_oB_o}{t}$ (b) $\frac{4A_oB_o}{t}$ (c) $\frac{3B_o}{A_ot}$ (d) $\frac{4B_o}{A_ot}$
12. Karan dropped a small bar magnet vertically along the axis of a long hollow metallic cylinder held in the vertical position. The magnet will fall with:
(a) $a > g$ (b) $a < g$ (c) $a = g$ (d) $a = 0$
13. A student constructed two solenoids of the same length and same cross-sectional area for an electromagnet project. In the second solenoid, he doubled the number of turns per unit length while keeping all other dimensions the same. The self-inductance of the second solenoid will become:
(a) Halved (b) Doubled (c) Four times (d) Eight times
14. A conducting circular loop of face area 2.5×10^{-3} m² is placed perpendicular to a magnetic field which varies as B=0.5 sin(100πt) T. The magnitude of induced emf in the loop at t = 0s: (NEET 2025)
(a) 125π mV (b) 12.5π mV (c) 125π V (d) 12.5π V
15. Rohan constructed a long solenoid for his school science project. He wanted to increase its self-inductance. The self-inductance of the long solenoid cannot be increased by:
(a) increasing its area of cross-section (b) increasing its length
(c) changing the medium inside it (d) increasing the current through it

ANSWERS

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

TAKE THE CHALLENGE

1. The magnetic potential energy stored in a certain inductor is 25 mJ, when the current in the inductor is 60 mA. This inductor is of inductance (NEET-2018) (a) 1.389 H
(b) 138.88 H (c) 0.138 H (d) 13.89 H

2. The self inductance L of a solenoid of length l and area of crosssection A, with a fixed number of turns N increases as
(a) l and A increase. (b) l decreases and A increases.
(c) l increases and A decreases. (d) both l and A decrease.

3. An emf can be induced in stationary coil if it is kept in
(a) Stationary uniform magnetic field (b) Stationary non uniform magnetic field
(c) Time varying magnetic field (d) Not possible

4. The battery of a mobile phone is rated as 4.2 V, 5800 mAh. How much energy is stored in it when fully charged?
(a) 87.7 kJ (b) 43.8 kJ (c) 48.7 kJ (d) 24.4 kJ

5. A loop, made of straight edges has six corners at A (0, 0, 0), B (L, 0, 0), C (L, L, 0), D (0, L, 0) E (0, L, L) and F (0, 0, L). A magnetic field ($B=B_o$ (i+ k) T is present in the region. The flux passing through the loop ABCDEFA (in that order) is
(a) B_oL^2 (b)$2B_oL^2$ (c) $\sqrt{2}B_oL^2$ (d) $4B_oL^2$

1-(d), 2-(b), 3-(c), 4-(a), 5-(b)

ASSERTION-REASON

In the following questions 9 and 10, a statement of assertion (A) is followed by a statement of reason (R). Mark the correct choice as:
(a) Both assertion (A) and reason (R) are true and reason (R) is the correct explanation of assertion (A).
(b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).
(c) Assertion (A) is true but reason (R) is false.
(d) Assertion (A) is false but reason (R) is true.
(e) Both Assertion (A) and Reason(R) are false.

1. **Assertion (A):** Mutual induction is the phenomenon in which the emf is induced in the coil due to change in magnetic flux.
Reason (R): It follows law of conservation of energy.

2. **Assertion (A):** Making and breaking of current in a coil produces no momentary current in the neighbouring coil of another circuit.
Reason (R): Momentary current in the neighbouring coil of another circuit is an eddy current

3. **Assertion (A):** If primary coil is connected by voltmeter and secondary coil by ac source. If large copper sheet is placed between two coils, induced emf in primary coil is reduced
Reason (R): Copper sheet between coils has no effect on induced emf in primary coil.

4. **Assertion (A):** An electric lamp is connected in series with a long solenoid of copper with air core and then connected to AC source. If an iron rod is inserted in solenoid the lamp will become dim.
Reason (R): If an iron rod is inserted in solenoid, the inductance of solenoid increases.

5. **Assertion (A):** Induced emf produced in a coil will be more when the magnetic flux linked with the coil is more.
Reason (R): Induced emf produced is directly proportional to the magnetic flux (CBSE 2026)

6. **Assertion (A):** A changing magnetic flux linked with a closed circuit induces an emf in the circuit.
Reason (R): The induced emf is directly proportional to the rate of change of magnetic flux linked with the circuit as given by Faraday's law.
7. **Assertion (A):** An induced current always opposes the cause that produces it.
Reason (R): This opposition is due to Lenz's law.
8. **Assertion (A):** When a magnet is moved towards a coil, a current is induced in the coil.
Reason (R): The magnetic flux linked with the coil changes with time.
9. **Assertion (A):** A conductor moving parallel to the direction of a uniform magnetic field experiences no induced emf.
Reason (R): The rate of change of magnetic flux is maximum when the motion of the conductor is along the magnetic field.
10. **Assertion (A):** The induced emf in a coil depends on the rate of change of current in the neighbouring coil.
Reason (R): Mutual inductance must exist between the two nearby coils.
11. **Assertion (A):** The self-inductance of a coil is a measure of its ability to resist any change in current flowing through it.
Reason (R): When the current in a coil changes, a back emf is induced in the coil which opposes the change in current.
12. **Assertion (A):** An ideal transformer has 100% efficiency.
Reason (R): There is no loss of energy in a practical transformer due to heat, eddy currents or hysteresis.
13. **Assertion (A):** The core of a transformer is made of soft iron and is laminated.
Reason (R): Lamination of the core reduces eddy current losses and soft iron increases magnetic coupling.
14. **Assertion (A):** No emf is induced in a stationary coil placed in a constant magnetic field.
Reason (R): Emf is induced in a coil only when there is a change in magnetic flux linked with the coil.
15. **Assertion (A):** The mutual inductance between two coils depends on their relative orientation.
Reason (R): Changing the orientation of the coils affects the amount of magnetic flux linking the two coils.

ANSWERS

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

TAKE THE CHALLENGE

1. **Assertion (A):** When a coil is rotated in a uniform magnetic field about an axis perpendicular to the field, emf is induced in it which is maximum for the orientation of coil in which magnetic flux through the coil is zero.

Reason (R): In an electric generator, electrical energy is generated by rotating a coil in a magnetic field.

2. **Assertion (A)**: It is more difficult to push a magnet into a coil with more loops.

Reason (R): This is because emf induced in each current loop resists the motion of the magnet.

3. **Assertion (A)**: At any instant, if the current through an inductor is zero, then the induced emf may not be zero.

Reason (R): An inductor tends to keep the flux constant.

4. **Assertion (A)**: A system cannot have mutual inductance without having self-inductance.

Reason (R): If mutual inductance of system is zero, its self-inductance must be zero.

5**. Assertion (A)**: Only a change of magnetic flux with time, will maintain an induced current in the coil.

Reason (R): The presence of a large magnetic flux will maintain an induced current in the coil.

1-(b), 2-(a), 3-(b), 4-(c), 5-(c)

2 MARKS QUESTIONS

1. A light copper ring is freely suspended by a light string. A bar magnet is held horizontally with its length along the axis of the ring. The magnet is moved towards the ring with its N pole facing the loop. What will happen to the ring and its position? Explain.

2. In a laboratory experiment, a student observed that the magnetic flux φ (in Wb) linked with a coil varies with time t (in seconds) according to the relation: $\varphi = 5At^2 + Bt - 2C$ where A, B and C are positive constants.

(a) Find the expression for the induced emf in the coil as a function of time.

(b) At what value of time (t) will the magnitude of induced emf be minimum?

3. A bar magnet falls freely from a height 'h' through a closed metallic ring as shown in the figure.

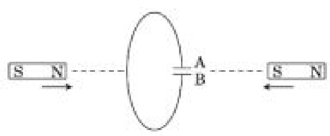
(a) Will the acceleration of the bar magnet be equal to 'g' while passing through the ring? Give reason.

(b) What will happen to the acceleration of the magnet if the ring is cut open so that it does not form a closed loop? Explain.

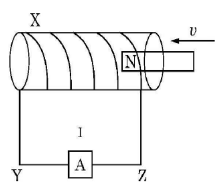
4. (a) How does the mutual inductance of a pair of coils change when the distance between the two coils is increased?

(b) How does the mutual inductance of a pair of coils change when the number of turns in each coil is increased? Give reason in each case.

5. During a physics demonstration in the laboratory, two identical bar magnets are placed on opposite sides of a metallic circular loop connected to an uncharged capacitor 'C' as shown in the figure. Both the magnets are moved quickly towards the loop simultaneously. Predict the polarity of the plates A and B of the capacitor. Give reason for your answer.

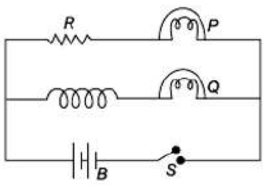


6. In a science laboratory experiment, two identical coils of the same radius, number of turns and area, one made of copper wire and the other of aluminium wire are rotated with the same angular speed in a uniform external magnetic field. Which of the two coils will have a greater induced current? Give reason for your answer.

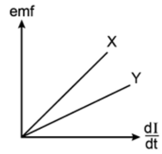


7. In the given figure, X is a coil wound over a hollow wooden pipe. A permanent magnet is pushed at a constant speed v from the right into the pipe and it comes out of at the left end of the pipe. During the entry and the exit of the magnet. What will be the current in the wire YZ.

8. The given figure shows an inductor L and resistor R connected in parallel to a battery B through a switch S. The resistance of R is the same as that of the coil that makes L. Two identical bulbs, P and Q are put in each arm of the circuit as shown in the figure. When S is closed, which of the two bulbs will light up earlier? Justify your answer.



9. State Faraday's law of electromagnetic induction. Express it mathematically. A conducting loop is placed in a magnetic field that is decreasing at a constant rate. What is the direction of induced current in the loop?



10. The figure shows the variation of induced emf as a function of rate of change of current for two identical solenoids X and Y. One is air cored and the other is iron cored. Which one of them is iron cored and why?

SOLUTIONS- 2 MARKS QUESTIONS

1. Explaining the effect on the motion and position of the ring.Current is induced in the ring. Reason- Due to electromagnetic induction. The ring will be repelled. Reason- As per Lenz's law, Current is induced in the anticlockwise direction and magnetic moment associated with this current has north polarity.

2. (a) Induced emf, $\varepsilon = -\frac{d\varphi}{dt} = -(10At + B)$

(b) The magnitude of induced emf will be minimum at $t = 0\ s$

3. (a) No, acceleration < g. Reason: As the magnet falls, magnetic flux through the ring changes → induced current flows (Faraday's law) → opposing magnetic field is produced (Lenz's law) → retarding force acts on the magnet.

(b) Acceleration = g. Reason: Ring is open → no induced current → no opposing force.

4. Mutual Inductance (M) ∝ (N_1 N_2) / d

(a) When distance (d) is increased → Mutual inductance decreases.

(b) When number of turns (N_1 and N_2) are increased → Mutual inductance increases.

5. Polarity: Plate A becomes positive (+) and Plate B becomes negative (–). Reason: Magnetic flux through the loop increases (due to approach of both N-poles towards the loop). Induced current flows in the direction that opposes the increase in flux (Lenz's law).

6. Induced current is greater in the copper coil. Reason: Induced emf is the same in both ($\varepsilon = NBA\omega sin\omega t$), but resistance of copper coil is less $\rho_{Cu} < \rho_{Al}$, so $I = \varepsilon/R$ is larger for copper.

7. Z to Y and then Y to Z by using Lenz law.

8. When switch S is closed, bulb P will light up earlier. Bulb P is connected in series with a resistor. So, the current in bulb P will instantly rise to its steady value. On the other hand, bulb Q is in series with an inductor. On closing the switch S, current in bulb Q will grow exponentially to its steady value which will be the same as for bulb P. This is due to the production of induced emf in the inductor. However, the steady state value of current will be the same in both the bulbs.

9. Faraday's Law definition: $\varepsilon = -\frac{d\varphi}{dt}$. Direction of induced current is such that it tries to increase the magnetic flux (opposes the decrease).

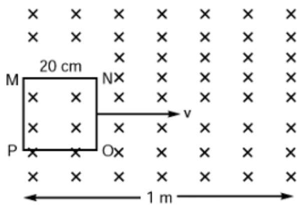
10. From the graph, $= \frac{\varepsilon}{\frac{dI}{dt}} = L$. Slope of X is more than that of Y. Hence X is iron-cored because inductance of iron cored coil is more than that of air-cored coil.

3 MARKS QUESTIONS

1. (a) Define mutual inductance of a pair of coils. Write its SI unit. (CBSE 2026)

(b) A long solenoid of radius R and length L has n turns per unit length. A circular loop of radius r $(< R)$ is placed inside at the centre of the solenoid such that its axis coincides with the axis of the solenoid. Obtain the mutual inductance of the solenoid and the loop.

2. A square loop MNOP of side 20 cm is placed horizontally in a uniform magnetic field acting vertically downwards as shown in the figure. The loop is pulled with a constant velocity of 20 cms^{-1} till it goes out of the field.

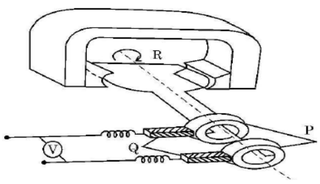


(a) Depict the direction of the induced current in the loop as it goes out of the field.
(b) For how long would the current in the loop persist?

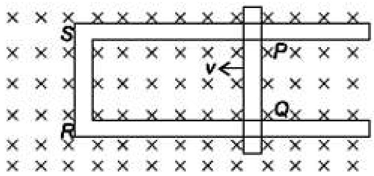
3. State Faraday's law of electromagnetic induction. Briefly describe two methods for producing induced emf. (CBSE 2026)

4. Two coils, one of radius 0·5 cm having 10 turns and the other of radius 5 cm having 50 turns are placed coaxially in air such that their centres are coincident. Calculate: (CBSE 2026)
(a) the magnetic flux through the smaller coil if the larger coil carries a current of 3 A, and
(b) the mutual inductance of the two coils.

5. (a) Identify the machine in the given figure.
(b) Identify the parts P, Q and R of the machine
(c) Give the polarities of the magnetic poles.



6. Figure shows a rectangular loop conducting PQRS in which the arm PQ is free to move. A uniform magnetic field acts in the direction perpendicular to the plane of the loop. Arm PQ is moved with a velocity v towards the arm RS. Assuming that the arms QR, RS and SP have negligible resistances and the moving arm PQ has the resistance r. Obtain the expression for



(a) the current in the loop
(b) the force and
(c) the power required to move arm PQ.

7. How does the mutual inductance of a pair of coils change when
(a) the distance between the coils is increased?
(b) the number of turns in each coil is decreased?
(c) a thin iron sheet is placed between the two coils, other factors remaining the same? Justify your answer in each case.

8. A conducting coil of 50 turns and area $5/\pi$ cm^2 is rotating along the axis of solenoid of length 50cm and 2000 turns, carrying current of 5 A. What will be the value of maximum emf generated? (CBSE SQP 2025-26)

9. The currents through two inductors of self-inductance 12 mH and 24 mH are increasing with time at the same rate. Draw graphs showing the variation of the: (CBSE COMPT. 2025)
(a) Magnitude of emf induced with the rate of change of current in each inductor.

(b) Energy stored in each inductor with the current flowing through it.

10. In a physics laboratory, a student is studying a long solenoid used in an electromagnet. Using Faraday's law of electromagnetic induction and Lenz's law, derive an expression for the self-inductance of this long solenoid in terms of its geometry (number of turns N, area of cross-section A and length l) and the permeability of the medium (μ) inside the solenoid.

SOLUTIONS- 3 MARKS QUESTIONS

1. (a) Define Mutual induction and write its SI Unit
   (b) Derive to get $M = \mu_0 n^2 \pi r^2 l$
2. (a) Clockwise MNOP.
   (b) v = 20 cm/s; d = 20 cm , Time taken by the loop to move out of magnetic field, t=1 sec
3. The magnitude of the induced emf in a circuit is equal to the time rate of change of magnetic flux through the circuit.
Methods of producing induced emf:
(i) By changing magnetic field with time.
(ii) By changing area of the coil with time in the magnetic field.
(iii) By changing the angle between magnetic field and normal to the coil with time (Any two)
4. Using suitable formulas we get,
   (a) 1.48×10^{-6} Wb
   (b) $M_{12} = 4.92 \times 10^{-7}$ H
5. (a) AC generator
   (b) P -Slip rings Q -Carbon brushes R-Armature coil
   (c) Left side of the magnet is North & right side is South or vice-versa.
6. (a) $I = \frac{Blv}{r}$ (b) $F = B^2 l^2 \frac{v}{r}$ (c) $P = B^2 l^2 \frac{v^2}{r}$
7. (a) Mutual inductance decreases. (b) Mutual inductance decreases. (c) Mutual inductance increases. Using Formula: $M = (\mu_0 \mu_r N_1 N_2 A) / d$ (or $M = \varphi_{21} / I_1$)
8. The instantaneous induced emf is given by: $\varepsilon = NBA\omega \sin \omega t$
The maximum value of induced emf is: $\varepsilon_{max} = NBA\omega$
Substituting the values: ε_{max}= 2mV
9. (a) Graph is a straight line passing through origin for both. Slope for 24 mH inductor is twice the slope for 12 mH inductor.
(b) Graph is a parabola opening upwards for both. For same current I, energy stored in 24 mH inductor is twice that in 12 mH inductor.
10. Derive the correct result. $L = \mu n^2 Al$, where $n = \frac{N}{l}$

5 MARKS QUESTIONS

1. (a) State Faraday's law of electromagnetic induction.
   (b) Derive an expression for the self-inductance of an air-filled long solenoid of length l and cross-sectional area A having N turns.
   (c) A conducting rod of length 50 cm, with one end pivoted, is rotated with angular speed of 60 rpm in a uniform magnetic field of 4.0 mT directed perpendicular to the plane of rotation of rod. Find the emf induced in the rod. (CBSE 2026)

2. (a) State Lenz's law. Give one example to illustrate this law. "The Lenz's law is a consequence of the principle of conservation of energy." Justify this statement.

(b) A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from 2.0 A to 4.0 A in 0.1 s, what is the induced emf in the loop while the current is changing?

3. (a) Define coefficient of self-induction. Obtain an expression for mutual-inductance of a long solenoid of length 'l', area of cross-section 'A' having 'N' turns.

(b) Calculate the self-inductance of a coil using the following data obtained when an AC source of frequency $\frac{200}{\pi}$ Hz and a DC source is applied across the coil.

AC Source		
S.No	V (Volts)	I (A)
1	3.0	0.5
2	6.0	1.0
3	9.0	1.5

DC Source		
S.No	V (Volts)	I (A)
1	4.0	1.0
2	6.0	1.5
3	8.0	2.0

SOLUTIONS- 5 MARKS QUESTIONS

1. (a) Stating Faraday's law
   (b) Deriving Expression for self-inductance.
   (c) Finding the induced e.m.f $e = 3.14\ mV$
2. State the law. $e = 7.54\ \mu V$
3.

For dc part, $R = \frac{V}{I} = 4\ \Omega$ (in each case)

For ac part, $f = \frac{200}{\pi}$ Hz

Total impedance

$Z = 6\ \Omega$ (in each part)

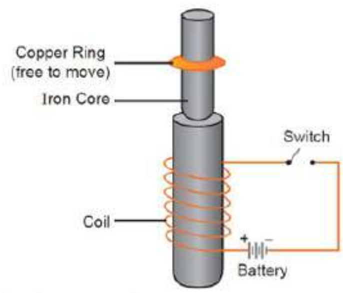
$X_L = \omega L = 2\pi f L = \sqrt{Z^2 - R^2} = \sqrt{6^2 - 4^2} = \sqrt{20}$

Thus, $2\pi f L = \sqrt{20}$

or $L = \frac{\sqrt{20}}{2\pi \times \frac{200}{\pi}} = \frac{\sqrt{20}}{400} = \frac{1}{20\sqrt{20}}$ H

CASE BASED QUESTIONS

1. Consider the experimental set up shown in the figure. This jumping ring experiment is an outstanding demonstration of some simple laws of Physics. A conducting non-magnetic ring is placed over the vertical core of a solenoid. When current is passed through the solenoid, the ring is thrown off.



(i) The direction of induced current in the ring in jumping ring experiment is such that the polarity developed in the ring is same as that of the polarity on the face of the coil, then ring will jump up due to
(a) attractive force when the switch is closed in the circuit.
(b) repulsive force when the switch is closed in the circuit.
(c) attractive force when the switch is closed in the circuit.
(d) repulsive force when the switch is closed in the circuit.
(ii) What will happen if the terminals of the battery are reversed and the switch is closed?
(a) Ring will not be jump. (b) Ring will jump again.
(c) Current will not induced in the ring. (d) none of these
(iii) The jumping ring experiment based on which of the following law?
(a) Lenz's Law (b) Faraday's law (c) Snell's Law (d) both (a) and (b)
(iv) Two identical circular loops A and B of metal wire are lying on a table without touching each other. Loop A carries a current which increases with time. In response the loop B

(a) remains stationary. (b) is attracted by loop A.
(c) is repelled by loop A. (d) rotates about its centre of mass with centre of mass fixed.

OR

An emf of 200 V is induced in a circuit when current in the circuit falls from 5 A to 0 A in 0.1 second. The self-inductance of the circuit is

(a) 3.5 H (b) 3.9 H (c) 4 H (d) 4.2 H

2. Electromagnetic induction is defined as the production of an electromotive force across an electric conductor in the changing magnetic field. The discovery of induction was done by Michael Faraday in the year 1831. Electromagnetic induction finds many applications such as in electrical components which includes transformers, inductors, and other devices such as electric motors and generators. Alternating current is defined as an electric current which reverses in direction periodically. In most of the electric power circuits, the waveform of alternating current is the sine wave.

(i). How to increase the energy stored in an inductor by four times?
(a) By doubling the current (b) This is not possible
(c) By doubling the inductance (d) By making current √2 times

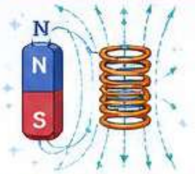
(ii). Consider an inductor whose linear dimensions are tripled and the total number of turns per unit length is kept constant, what happens to the self-inductance?
(a) 9 times (b) 3 times (c) 27 times (d) 13 times

(iii). Lenz law is based on which of the following conservation>
(a) Charge (b) Mass (c) Momentum (d) Energy

(iv). What will be the acceleration of the falling bar magnet which passes through the ring such that the ring is held horizontally and the bar magnet is dropped along the axis of the ring?
(a) It depends on the diameter of the ring and the length of the magnet
(b) It is equal due to gravity (c) It is less than due to gravity
(d) It is more than due to gravity

Answer:

1. (i) (b) The direction of induced current in the ring is such that the polarity developed in the ring is same as that of the polarity on the face of the coil, hence it will jump up due to repulsive force.
(ii) (b) The polarity of the induced current in the ring will get reversed on changing the terminals of the battery, so the ring will jump again. (iii) (d)
(iv) (c) Opposite currents are induced in loops, so loops repel each other.
OR (c) Self inductance, L = 4 H
2. (i). (a) By doubling the current (ii). (c) 27 times (iii). (d) Energy (iv). (c)



ELECTROMAGNETIC INDUCTION

CLASS 12 PHYSICS – FORMULA SHEET

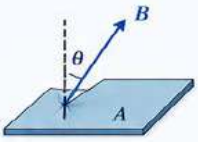
CBSE SYLLABUS | NEP 2020 ALIGNED | QUICK REVISION | EXAM READY

1 MAGNETIC FLUX (Φ) ⭐ MOST IMPORTANT

$$\Phi = BA\cos\theta$$

For N turns:

$$\Phi = NBA\cos\theta$$



Φ = Magnetic Flux (weber, Wb)
B = Magnetic field (tesla, T)
A = Area (m^2)
θ = Angle between B and normal to area

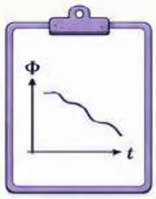
2 FARADAY'S LAWS OF INDUCTION

For a single turn:

$$\varepsilon = -\frac{d\Phi}{dt}$$

For N turns:

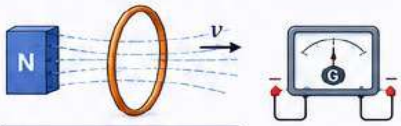
$$\varepsilon = -N\frac{d\Phi}{dt}$$



ε = Induced EMF (volt)
$\frac{d\Phi}{dt}$ = Rate of change of flux

3 LENZ'S LAW ⭐ MOST IMPORTANT

The induced EMF (or current) is in such a direction that it opposes the change in magnetic flux that produces it.

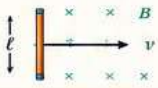


Nature opposes change.
That is Lenz's Law.

4 MOTIONAL EMF (ε) ⭐ MOST IMPORTANT

(i) Straight Conductor

$$\varepsilon = B\ell v$$

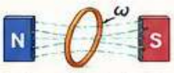


(ii) Rotating Rod about one end

$$\varepsilon = \frac{1}{2}B\omega\ell^2$$

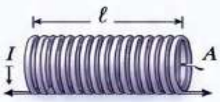
(iii) Rotating Coil (N turns)

$$\varepsilon = NBA\omega\sin(\omega t)$$



B = Magnetic field (T), ℓ = Length (m), v = Velocity (m/s),
ω = Angular velocity (rad/s), N = Number of turns

5 SELF INDUCTANCE (L)



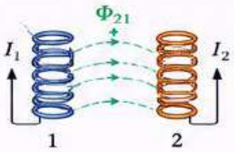
$$L = \frac{\Phi}{I}$$

$$\varepsilon = -L\frac{dI}{dt}$$

Solenoid: $$L = \frac{\mu_0 N^2 A}{\ell}$$

L – Self inductance (henry, H)
Φ = Magnetic flux (weber)
I = Current (ampere)
$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
N = Number of turns, A = Area (m^2), ℓ = Length (m)

6 MUTUAL INDUCTANCE (M)



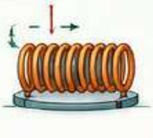
$$M = \frac{\Phi_{21}}{I_1}$$

$$\varepsilon_2 = -M\frac{dI_1}{dt}$$

M = Mutual inductance (henry, H)
Φ_{21} = Flux in coil 2 due to current in coil 1

Note:
Mutual inductance depends on size, shape, distance between coils and core.

7 ENERGY IN INDUCTOR



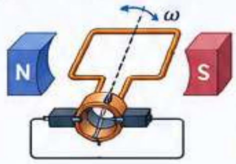
$$U = \frac{1}{2}LI^2$$

Energy Density

$$u = \frac{B^2}{2\mu_0}$$

U = Energy stored (joule, J)
u = Energy density (J m^{-3})
B = Magnetic flux density (tesla, T)

8 AC GENERATOR



Peak EMF:

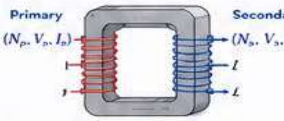
$$\varepsilon_0 = NBA\omega$$

Instantaneous EMF:

$$\varepsilon = NBA\omega\sin(\omega t)$$

N = Number of turns, B = Magnetic field (T)
A = Area (m^2), ω = Angular speed (rad/s)

9 TRANSFORMER



$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad \frac{I_p}{I_s} = \frac{N_s}{N_p} \qquad P_p \approx P_s$$

Efficiency:

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$$

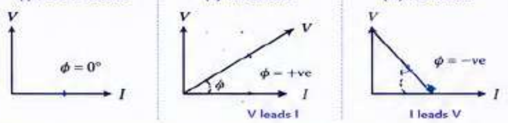
$S = V_{rms}I_{rms}$
$P = V_{rms}I_{rms}\cos\phi$
$Q = V_{rms}I_{rms}\sin\phi$
$\tan\phi = \frac{Q}{P}$
$S^2 = P^2 + Q^2$

Ideal Transformer
- No power loss
- $P_p = P_s$
- $\eta = 100\%$

10 COMPARISON TABLE

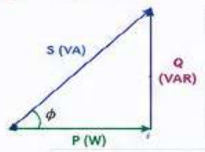
Property	Resistance (R)	Inductive Reactance (X_L)	Capacitive Reactance (X_C)
Formula	R	$X_L = \omega L$	$X_C = \frac{1}{\omega C}$
Cause	Opposition in pure resistor	Self inductance	Capacitance
Depends on	–	f, L	f, C
Phase (V w.r.t. I)	In phase	V leads I by 90°	I leads V by 90°
Unit	ohm (Ω)	ohm (Ω)	ohm (Ω)

11 PHASOR DIAGRAMS (KEY CASES)



$\phi = 0° \rightarrow \cos\phi = 1$ | $0 < \phi < 90° \rightarrow \cos\phi = +ve$ | $-90° < \phi < 0° \rightarrow \cos\phi = +ve$

12 POWER TRIANGLE



$S = V_{rms}I_{rms}$
$P = V_{rms}I_{rms}\cos\phi$
$Q = V_{rms}I_{rms}\sin\phi$
$\tan\phi = \frac{Q}{P}$
$S^2 = P^2 + Q^2$

Power Factor $= \cos\phi = \frac{P}{S}$

13 IMPORTANT CONDITIONS

- ✓ Resonance (LCR Series): $X_L = X_C$ or $\omega_0 = \frac{1}{\sqrt{LC}}$
- ✓ At resonance: $\phi = 0$, $Z = R$ (minimum), I = maximum
- ✓ Power factor unity at resonance.
- ✓ Net inductive: $X_L > X_C \rightarrow \phi > 0$ (V leads I)
- ✓ Net capacitive: $X_C > X_L \rightarrow \phi < 0$ (I leads V)

14 MEMORY TRICKS

"L Leads, C Cheats"
In inductor (L), Voltage leads Current.
In capacitor (C), Current leads Voltage.

"N over P – Voltage; P over S – Current"
$\frac{V_s}{V_p} = \frac{N_s}{N_p}$ | $\frac{I_p}{I_s} = \frac{N_s}{N_p}$

"Flux First, EMF Next"
Change in Flux ($d\Phi/dt$) gives rise to EMF.

"Oppose the Change"
Lenz's Law – Nature opposes change.

15 COMMON MISTAKES

- ✗ Using peak values in power formula.
- ✗ Forgetting negative sign in Faraday's law.
- ✗ Confusing phase relations in RL and RC circuits.
- ✗ Ignoring units (H, Wb, T, Ω).
- ✗ Wrong transformer turn ratio.

16 PYQ TIPS

Very important topics in CBSE PYQs:
- Lenz's Law & direction of induced current
- EMF in moving/rotating conductors
- Self & mutual inductance problems
- AC generator & transformer formulas
- Power & power factor in AC circuits

Practice NCERT Examples & Previous Years' Questions!

SYMBOLS & THEIR MEANINGS

Φ : Magnetic Flux (Wb)
ε : Induced EMF (V)
I : Current (A)
V : Voltage (V)
V_{rms} : RMS Voltage (V)
I_{rms} : RMS Current (A)
ω : Angular Frequency (rad s^{-1})
f : Frequency (Hz)

SI UNITS

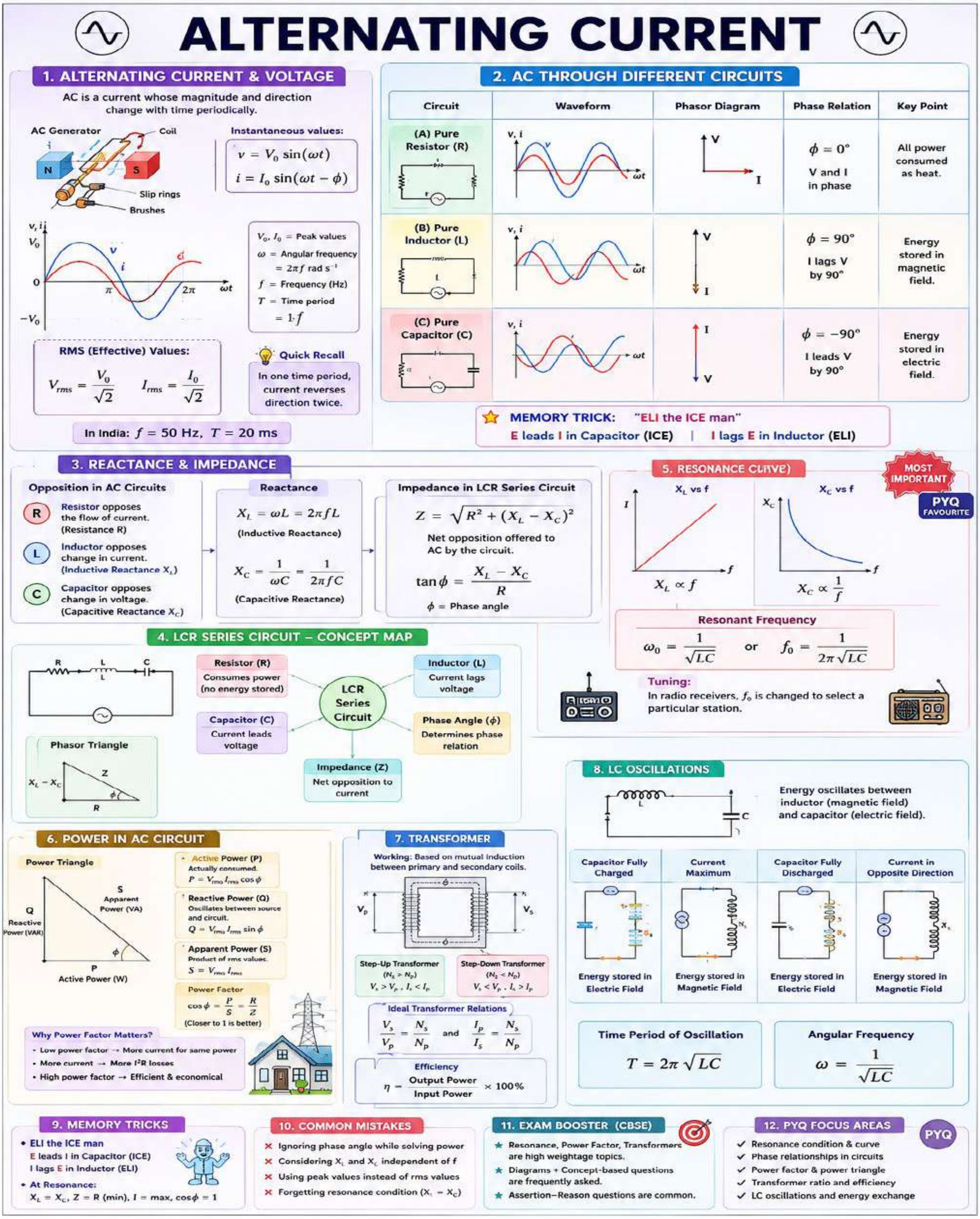
Flux (Φ) : Weber (Wb)
Inductance (L, M) : Henry (H)
Resistance (R, X) : Ohm (Ω)
Capacitance (C) : Farad (F)
Magnetic field (B) : Tesla (T)

CONSTANTS

$\pi = 3.1416$
$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
1 H = 1 Wb A^{-1}
1 F = 1 C V^{-1}

CONCEPT CLEAR.
FORMULAS STRONG.
SUCCESS LONG!
KEEP CALM &
CRACK THE EXAM!

CHAPTER 07



ALTERNATING CURRENT
1. ALTERNATING CURRENT & VOLTAGE
AC is a current whose magnitude and direction change with time periodically.
AC Generator
Coil
N
S
Slip rings
Brushes
Instantaneous values:
$v = V_0 \sin(\omega t)$
$i = I_0 \sin(\omega t - \phi)$
V_0, I_0 = Peak values
ω = Angular frequency = $2\pi f$ rad s^{-1}
f = Frequency (Hz)
T = Time period = $1/f$
RMS (Effective) Values:
$V_{rms} = \frac{V_0}{\sqrt{2}}$ $I_{rms} = \frac{I_0}{\sqrt{2}}$
Quick Recall
In one time period, current reverses direction twice.
In India: f = 50 Hz, T = 20 ms
2. AC THROUGH DIFFERENT CIRCUITS
Circuit | Waveform | Phasor Diagram | Phase Relation | Key Point
(A) Pure Resistor (R) | $\phi = 0°$ V and I in phase | All power consumed as heat.
(B) Pure Inductor (L) | $\phi = 90°$ I lags V by 90° | Energy stored in magnetic field.
(C) Pure Capacitor (C) | $\phi = -90°$ I leads V by 90° | Energy stored in electric field.
MEMORY TRICK: "ELI the ICE man"
E leads I in Capacitor (ICE) | I lags E in Inductor (ELI)
3. REACTANCE & IMPEDANCE
Opposition in AC Circuits
R Resistor opposes the flow of current. (Resistance R)
L Inductor opposes change in current. (Inductive Reactance X_L)
C Capacitor opposes change in voltage. (Capacitive Reactance X_C)
Reactance
$X_L = \omega L = 2\pi f L$ (Inductive Reactance)
$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$ (Capacitive Reactance)
Impedance in LCR Series Circuit
$Z = \sqrt{R^2 + (X_L - X_C)^2}$
Net opposition offered to AC by the circuit.
$\tan\phi = \frac{X_L - X_C}{R}$
ϕ = Phase angle
5. RESONANCE CURVE
MOST IMPORTANT
PYQ FAVOURITE
X_L vs f
$X_L \propto f$
X_C vs f
$X_C \propto \frac{1}{f}$
Resonant Frequency
$\omega_0 = \frac{1}{\sqrt{LC}}$ or $f_0 = \frac{1}{2\pi\sqrt{LC}}$
Tuning:
In radio receivers, f_0 is changed to select a particular station.
4. LCR SERIES CIRCUIT – CONCEPT MAP
LCR Series Circuit
Resistor (R) Consumes power (no energy stored)
Inductor (L) Current lags voltage
Capacitor (C) Current leads voltage
Phase Angle (ϕ) Determines phase relation
Impedance (Z) Net opposition to current
Phasor Triangle
$X_L - X_C$
Z
R
8. LC OSCILLATIONS
Energy oscillates between inductor (magnetic field) and capacitor (electric field).
Capacitor Fully Charged – Energy stored in Electric Field
Current Maximum – Energy stored in Magnetic Field
Capacitor Fully Discharged – Energy stored in Electric Field
Current in Opposite Direction – Energy stored in Magnetic Field
Time Period of Oscillation
$T = 2\pi\sqrt{LC}$
Angular Frequency
$\omega = \frac{1}{\sqrt{LC}}$
6. POWER IN AC CIRCUIT
Power Triangle
S Apparent Power (VA)
Q Reactive Power (VAR)
P Active Power (W)
Active Power (P) Actually consumed. $P = V_{rms} I_{rms} \cos\phi$
Reactive Power (Q) Oscillates between source and circuit. $Q = V_{rms} I_{rms} \sin\phi$
Apparent Power (S) Product of rms values. $S = V_{rms} I_{rms}$
Power Factor
$\cos\phi = \frac{P}{S} = \frac{R}{Z}$
(Closer to 1 is better)
Why Power Factor Matters?
• Low power factor → More current for same power
• More current → More I^2R losses
• High power factor → Efficient & economical
7. TRANSFORMER
Working: Based on mutual induction between primary and secondary coils.
V_p
V_s
Step-Up Transformer ($N_s > N_p$) $V_s > V_p$, $I_s < I_p$
Step-Down Transformer ($N_s < N_p$) $V_s < V_p$, $I_s > I_p$
Ideal Transformer Relations
$\frac{V_s}{V_p} = \frac{N_s}{N_p}$ and $\frac{I_p}{I_s} = \frac{N_s}{N_p}$
Efficiency
$\eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$
9. MEMORY TRICKS
• ELI the ICE man
E leads I in Capacitor (ICE)
I lags E in Inductor (ELI)
• At Resonance:
$X_L = X_C$, Z = R (min), I = max, $\cos\phi = 1$
10. COMMON MISTAKES
× Ignoring phase angle while solving power
× Considering X_L and X_C independent of f
× Using peak values instead of rms values
× Forgetting resonance condition ($X_L = X_C$)
11. EXAM BOOSTER (CBSE)
★ Resonance, Power Factor, Transformers are high weightage topics.
★ Diagrams + Concept-based questions are frequently asked.
★ Assertion–Reason questions are common.
12. PYQ FOCUS AREAS
PYQ
✓ Resonance condition & curve
✓ Phase relationships in circuits
✓ Power factor & power triangle
✓ Transformer ratio and efficiency
✓ LC oscillations and energy exchange

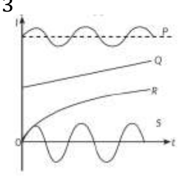
MULTIPLE CHOICE QUESTIONS

1. A series LCR circuit with $R=3\ \Omega$, $X_c=4\ \Omega$, $X_L=8\ \Omega$ is connected to a 220 V, 50 Hz ac source. The power factor for the circuit is (CBSE 2026)

(a) 0.30 (b) 0.45 (c) 0.50 (d) 0.60

2. The figure shows the variation of capacitive reactance (X_c) of two ideal capacitors of capacitances C_1 & C_2 with the reciprocal of angular frequency ($1/\omega$) of ac source. The value of C_1/C_2 is (CBSE 2026)

(a) $1/2$ (b) 2 (c) $\sqrt{3}$ (d) $\frac{1}{\sqrt{3}}$



3. The figure shows variation of current (I) with time (t) in four devices P, Q, R and S. The device in which an alternating current flow is

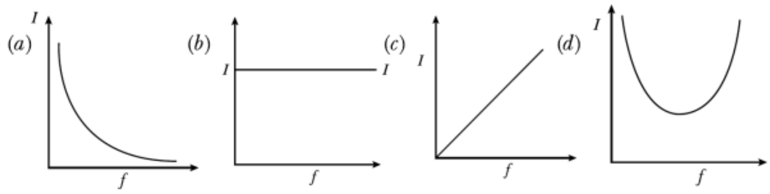
(a) P (b) Q (c) R (d) S

4. An ac voltage $V = V_0 \sin wt$ is applied to a series combination of a resistor R and an element X. The instantaneous current in the circuit is $I = I_o sin(wt + \pi/4)$.Then which of the following is correct?

(a) X is a capacitor and $X_C = \sqrt{2}\ R$ (b) X is an inductor and $X_L = R$

(c) X is an inductor and $X_L = \sqrt{2}\ R$ (d) X is a capacitor and $X_C = R$

5. Which of the following graphs on the right side represent the variation of current (I) with frequency (f) in an AC circuit containing a pure capacitor?



6. The rms and the average value of an ac voltage $V = V_o\ sinwt$ volt over a cycle respectively will be: (CBSE 2026)

(a) $\frac{V_o}{2}, \frac{V_o}{\sqrt{2}}$ (b) $\frac{V_o}{\pi}, \frac{V_o}{2}$ (c) $\frac{V_o}{\sqrt{2}}, 0$ (d) $V_o, \frac{V_o}{\sqrt{2}}$

7. In a laboratory, an inductor (L), a capacitor (C), and a resistor (R) were happily connected in series with an AC source. One day, the frequency of the AC supply was gradually decreased. As the frequency dropped, the reactance of:

(a) both L and C decreased (b) L decreased but C increased

(c) both L and C increased (d) L increased but C decreased

8. An ac circuit has a resistance of 12 ohm and an impedance of 15 ohm. The power factor of the circuit will be

(a) 0.8 (b) 0.4 (c) 0.125 (d) 1.25

9. In an AC circuit, an inductor was connected to an alternating voltage source. Initially, it had a certain inductive reactance X_L Suddenly, the frequency of the AC source was made 4 times its initial value. What will happen to the inductive reactance?

(a) It becomes 2 times (b) It becomes 3 times

(c) It becomes 4 times (d) It remains unchanged

10. An alternating current in a circuit is given by $I = 20\sin(100\pi\ t + 10.05\pi)$ A . The r.m.s value of current & its frequency respectively are

(A) 10A & 100 Hz (B) 10 A & 50 Hz (C) 10 $\sqrt{2}$A & 50Hz (D) 20 $\sqrt{2}$A & 100Hz

11. An ac voltage is given as v = 14 sin (314t) V. The average and the effective value of the voltage (in V) over a cycle are respectively: (CBSE 2026)

(a) 14 and 7 (b) 10 and 14 (c) 0 and 10 (d) 10 and 0

12. An LCR series circuit with a resistance of 100 Ω is connected to an ac source of 200 V (r.m.s.) and angular frequency 300 rad/s. When only the capacitor is removed, the current lags behind the voltage by 60^0. When only the inductor is removed the current leads the voltage by 600. The average power dissipated is

(a) 50 W (b) 100 W (c) 200 W (d) 400W

13. A power transformer is used to step up an alternating e.m.f. of 220 V to 11 kV to transmit 4.4 kW of power. If the primary coil has 1000 turns, what is the current rating of the secondary? Assume 100% efficiency for the transformer

(a) 4 A (b) 0.4 A (c) 0.04 A (d) 0.2 A

14. In an ideal transformer, the no. of turns of primary and secondary coil are 500 and 400 respectively. If 220 V is supplied to the primary coil, then ratio of currents in primary and secondary coils is

(a) 4: 5 (b) 5: 4 (c) 5: 9 (d) 9: 5

15. To reduce the resonant frequency in an L-C-R series circuit with a generator

(a) the generator frequency should be reduced

(b) another capacitor should be added in parallel to the first

(c) the iron core of the inductor should be removed

(d) dielectric in the capacitor should be removed

ANSWERS

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

TAKE THE CHALLENGE

1. If an LCR circuit contains L = 8H , C = 0.5 μF, R = 100 Ω in series. Then the resonant angular frequency will be:

(a) 600 rad/s (b) 500 rad/s (c) 600 Hz (d) 500 Hz

2. To reduce the resonant frequency in an LCR series circuit with a generator

(a) the generator frequency should be reduced.

(b) another capacitor should be added in parallel to the first.

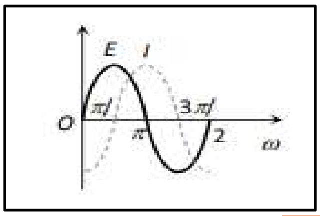
(c) the iron core of the inductor should be removed.

(d) dielectric in the capacitor should be removed.

3. The output of a step-down transformer is measured to be 24 V when connected to a 12 watt light bulb. The value of the peak current is

(a) $1/\sqrt{2}$ A (b) $\sqrt{2}$ A (c) 2A (d) $2\sqrt{2}$A

4. The variation of the instantaneous current (I) and the instantaneous emf (E) in a circuit is as shown in fig. Which of the following statements is correct?



(a) The voltage lags behind the current by $\frac{\pi}{2}$

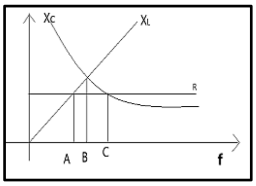
(b)The voltage leads the current by $\frac{\pi}{2}$

(c) The voltage and the current are in phase

(d)The voltage leads the current by π

5. The figure shows variation of R, X_L and X_C with frequency f in a series L, C, R circuit. Then for what frequency point, the circuit is inductive

(a) A (b) B (c) C (d)All points



1-(b), 2-(b), 3-(a), 4-(b), 5-(c)

ASSERTION-REASON

In the following questions 9 and 10, a statement of assertion (A) is followed by a statement of reason (R). Mark the correct choice as:

(a) Both assertion (A) and reason (R) are true and reason (R) is the correct explanation of assertion (A).

(b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).

(c) Assertion (A) is true but reason (R) is false.

(d) Assertion (A) is false but reason (R) is true.

(e) Both Assertion (A) and Reason(R) are false.

1. **Assertion (A):** In a pure resistive circuit, voltage and current are in the same phase

Reason (R):. In resistors, energy is alternately stored and released.

2. **Assertion (A):** In an ideal LC circuit, the current oscillates indefinitely.

Reason (R): There is no energy loss in an ideal LC circuit.

3. **Assertion (A):** In an LCR circuit at resonance, the impedance is minimum.

Reason (R): At resonance, the inductive and capacitive reactance cancel each other.

4. **Assertion (A):** The average power consumed in a pure inductive circuit is zero.

Reason (R): In a pure inductive circuit, the current leads the voltage by 90^0

5. **Assertion (A):** The power factor in a purely capacitive circuit is zero.

Reason (R): In a capacitive circuit, the current leads the voltage by 90^0

6. **Assertion (A):** In an AC circuit containing only a capacitor, current lags the voltage by 90^0

Reason (R): Capacitors offer no resistance to AC current.

7. **Assertion (A):**. The power consumed in an AC circuit is given by $P=V_{RMS}\, I_{RMS} \cos\phi$

Reason (R): The product $V_{RMS}\, I_{RMS}$ gives the apparent power.

8. **Assertion (A):** The voltage across the inductor leads the current by 90^0.

Reason (R): The induced emf in the inductor opposes the change in current.

9. **Assertion (A):** The quality factor of an LCR series circuit increases with increase in resistance.

Reason (R): Higher resistance causes sharper resonance

10. **Assertion (A):** In a transformer, higher value of alternating voltage can be converted into lower voltage and vice versa

Reason (R): A transformer works on the principle of electromagnetic induction.

11. **Assertion (A):** The alternating current lags behind the emf by a phase angle of $\pi/2$, when AC flows through an inductor.

Reason (R): The inductive reactance increase as the frequency of AC source decrease.

12. **Assertion (A):** In series LCR resonance circuit, the impedance is equal to the ohmic resistance.

Reason (R): At resonance, the inductive reactance exceeds the capacitive reactance

13. **Assertion (A):** When capacitive reactance is smaller than the inductive reactance in LCR

series circuit, emf leads the current
Reason (R): The phase angle is the angle between alternating emf and alternating current of the circuit
14. **Assertion (A):** When alternating current flows through a pure inductor, the current lags behind the voltage by a phase angle of 90° ($\pi/2$).
Reason (R): The inductive reactance increases as the frequency of the AC source decreases.
15. **Assertion (A):** A transformer cannot work on DC supply.
Reason (R): Transformers work on the principle of mutual induction, which requires a changing magnetic flux.

ANSWERS

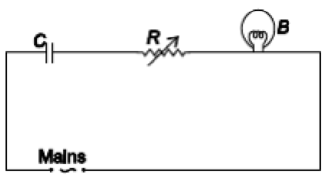
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
c	a	a	c	a	e	b	b	e	b	c	c	b	c	a

TAKE THE CHALLENGE

1. **Assertion (A)**: At an airport, a person is made to walk through the doorway of a metal detector.
Reason (R): Metal detector works on the principle of resonance in AC circuits.
2. **Assertion (A)**: Smaller the band width, sharper the resonance and easier it is to tune an LCR circuit.
Reason (R): Resonant frequency is arithmetic mean of half power frequencies.
3. **Assertion (A)**: An electric lamp is connected in series with a long solenoid of copper with air core and then connected to ac source. If an iron rod is inserted in solenoid, the lamp will become dim.
Reason (R): If an iron rod is inserted in solenoid, the inductance of solenoid increases.
4. **Assertion (A)**: At frequency greater than resonant frequency, circuit is inductive in nature.
Reason (R): Reciprocal of reactance is called susceptance.
5. **Assertion (A)**: Average power consumed in an ac circuit is equal to average power consumed by resistors in the circuit.
Reason (R): Average power consumed by capacitor and inductor is zero
1-(b), 2-(c), 3-(a), 4-(b), 5-(a)

2 MARKS QUESTIONS

1. An inductor of $5/\pi$ H and, a capacitor of $50/\pi$ μF and a resistor of 400 Ω are connected in series across an ac voltage $v = 140 \sin(100\pi t)$ V. Calculate: (i) impedance of the circuit, and (ii) rms value of current that flows in the circuit.
2. A capacitor C, a variable resistor R and a bulb B are connected in series to the ac mains in circuit as shown. The bulb glows with some brightness. How will the glow of the bulb change if (i) a dielectric slab is introduced between the plates of the capacitor, keeping resistance R to be the same; (ii) the resistance R is increased keeping the same capacitance?



3. An alternating voltage of frequency f is applied across a series LCR circuit. Let f_r be the resonance frequency for the circuit. Will the current in the circuit lag, lead or remain in phase with the applied voltage when (i) $f > f_r$, (ii) $f < f_r$? Explain your answer in each case.

4. Draw the graphs showing the variations of (i) inductive reactance, and (ii) capacitive reactance,
with frequency of applied voltages in ac circuit. How do the values of (i) inductive, and (ii) capacitive reactance change, when the frequency of applied voltage is tripled?
5. The coil of an ac generator consists of 100 turns of wire, each of area 0.5m^2. The resistance of the wire is 100 Ω. The coil is rotating in a magnetic field of 0.8 T perpendicular to its axis of rotation, at a constant angular speed of 60 radian per second. Calculate the maximum emf generated and power dissipated in the coil.
6. Prove that an ideal capacitor in an ac circuit does not dissipate any average power.
7. Define 'quality factor' of resonance in series LCR circuit. What is its SI unit.
8. A bulb B and an inductor are connected in series to the ac mains. The bulb glows with some brightness. How will the glow of the bulb change when a paramagnetic slab is introduced in side the inductor.
9. Mention any two characteristics properties of the material suitable of making the core of transformer.
10. Calculate the quality factor of a series LCR circuit with L= 2.0 H, C= 2 μF and R= 10Ω.

SOLUTIONS- 2 MARKS QUESTIONS

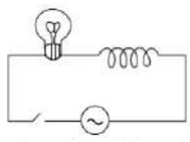
1. Using $Z = \sqrt{R^2 + (\omega L - \frac{1}{\omega L})}$ and $I_{rms} = \frac{V_o}{Z\sqrt{2}}$, we get. Z=500 ohm and I_{rms}=0.2A

2. If slab is inserted between the plates, capacitance will increase and X_c decrease so Z will decrease making the current in bulb more and hence, the bulb will shine brighter.
(ii) If R is increased, Z will increase making the current less and again the bulb will glow dimly.
3. As the frequency of the AC source increases, $X_c$decreases while X_L increases. (i) Hence for f > f_r circuit turns inductive in nature and current lags behind the voltage by certain phase angle. (ii) For f< f_r circuit is capacitive in nature as $X_C > X_L$ and current leads the voltage by certain phase angle.
4. Suitable graphs as per NCERT. (i) Inductive reactance also gets tripled and ii) Capacitive reactance reduces to one third.
5. Using formula e_o=NBAw, we get e_o =2400 V and P=e_{rms}^2/R = 28.8 kW
6. P_{avg} is proportional to cosφ and φ is 90^0 so average power dissipated is zero.
7. Write definition, no unit and dimensions.
8. X_L increases so brightness decreases.
9. Mention any two.
10. Q=$\frac{1}{R}\sqrt{\frac{L}{C}}$ so Q= 100

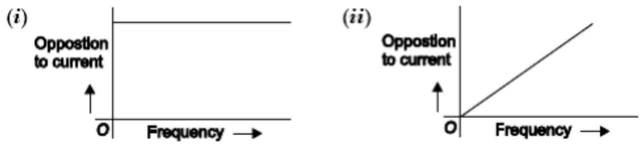
3 MARKS QUESTIONS

1. Define the terms (i) resonant frequency, and (ii) power factor of a series LCR circuit. For what value of the power factor will the power dissipated in the circuit be maximum? (CBSE 2026)
2. The number of turns in the primary and the secondary coil of an ideal transformer are 100 and 5000 respectively. If 3.3 kW power is supplied to the transformer at 220 V, find
(i) Current in the primary coil, and (ii) output voltage. (CBSE 2026)
3. (a) Can a transformer step up or step down dc power supply ?
(b) Can a step up transformer work as a step down transformer?
(c) Does a step up transformer contradict the principle of conservation of energy? Justify your answer. (CBSE 2026)

4. A light bulb and an open coil inductor are connected to an ac source through a key as shown in the figure. The switch is closed and after sometime, an iron rod is inserted into the interior of the inductor.The glow of the light bulb (a) increases; (b) decreases; (c) is unchanged, as the iron rod is inserted. Give your answer with reason. What will be your answer if ac source is replaced by a dc source?



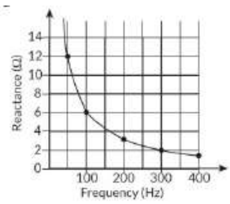
5. (a) The graphs (i) and (ii) represent the variation of the opposition offered by the circuit element to the flow of alternating current with frequency of the applied emf. Identify the circuit element corresponding to each graph.



(b) Write the expression for the impedance offered by the series combinations of the above two elements connected across the ac. Which will be ahead in phase in this circuit, voltage or current?

6. Show that the current leads the voltage in phase by π/2 in an ac circuit containing an ideal capacitor.

7. The figure shows the graphical variation of the reactance of a capacitor with frequency of ac source. (a) Find the capacitance of the capacitor. (b) An ideal inductor has the same reactance at 100 Hz frequency as the capacitor has at the same frequency. Find the value of inductance of the inductor. (c) Draw the graph showing the variation of the reactance of this inductor with frequency.



8. A resistor of 30 Ω and a capacitor of 250/π μF are connected in series to a 200 V, 50 Hz ac source. Calculate (i) the current in the circuit, and (ii) voltage drops across the resistor and the capacitor (iii) Is the algebraic sum of these voltages more than the source voltage? If yes, solve the paradox.

9. A series LCR circuit with R = 20Ω L = 2 H and C = 50 F is connected to a 200 volts ac source of variable frequency. What is (i) the amplitude of the current, and (ii) the average power transferred to the circuit in one complete cycle, at resonance? (iii) Calculate the potential drop across the capacitor.

10. A step-up transformer has 200 and 3000 turns in its primary and secondary coils respectively. The input voltage given to the primary coil is 90 V.

Calculate:

(1) The output voltage across the secondary coil

(2) The current in the primary coil if the current in the secondary coil is 2.0 A.

. SOLUTIONS- 3 MARKS QUESTIONS

1. (i) Frequency at which X_L=X_C, (ii) cosϕ=Z/R, (iii) P is maximum when cosϕ=1.

2. Using $\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_P}{I_S}$ and $P = V_p I_P$, we get $I_P = 15A$ and $V_s = 11000V$

3. (a) No, Transformers work on the principle of mutual induction because D.C. provides a constant current, there will be no change in magnetic flux.

(b) Yes, By reversing the connections, the secondary winding can be used as the primary.

(c) No, A step-up transformer changes low voltage into high voltage, and the current is reduced by the same proportion.

4. When an iron core is inserted, it gets magnetized and the magnetic field inside the coil increases. The L of the coil increases. Consequently, the X_L of the coil increases. A large fraction

of the applied ac voltage appears across the inductor and the voltage across the bulb decreases. Thus, the glow of the bulb decreases. In case of a dc source, the glow of the bulb does not change.
5. (a) In graph (i), the opposition to the flow of current does not depend upon frequency, the circuit element is a resistor. In graph (ii), the opposition increases with frequency, the current element is an inductor.(b) When the resistor R and the inductance L are connected in series across an ac source, then impedance Z of the circuit is given by $Z = \sqrt{R^2 + X_L^2}$ where X_L is an inductive reactance. In an L-R circuit, the voltage is ahead of the current.
6. Derive to obtain $I = I_o \sin(wt + \frac{\pi}{2})$
7. (a) $C = 265\ \mu F$ (b) $L = 9.6\ mH$ (c) suitable graph
8. (i) Using formula for X_c and Z, we get I_{rms} = 4A (ii) V_R=120V and V_C=160V (iii) $V_R + V_C$ =280V While V_{rms} of the source is 200 V. Yes, the voltages across the combination is more than the voltage of the source. The voltage across the resistor and capacitor are not in phase. This paradox can be resolved as when the current passes through the capacitor, it leads the voltage VC by phase π/2. So voltage of the source can be given as V_{rms} =200V.
9. (i) At resonance Z=R so I=V/R I_{rms}=10A and $I_o=I_{rms}\sqrt{2}$ =14.14A
Average power transferred to the circuit in one complete cycle at resonance: $P = I^2_{rms}R$ = 2000W
$\omega_o = \frac{1}{\sqrt{LC}}$ = 100 rad/s , $X_c = 1/\omega C$, $V_c = I_{rms}X_c$ = 2000V
10. (i) secondary voltage = 1350V
(ii) current in the primary coil = 30A

5 MARKS QUESTIONS

1. (a) Draw a labelled diagram of a step-up transformer. State the principle on which it works and obtain the ratio of secondary voltage to primary voltage in terms of number of turns and currents in the two coils. (CBSE 2026)
(b) The ratio of the number of turns in the primary to the secondary of an ideal transformer is 1:5. If 5 kW power at 200 V is supplied to the primary, find
(i) current in the primary, and
(ii) output voltage.
2. (a) A series combination of L, C and R is connected to an a.c. source. Using a phasor diagram, derive an expression for the impedance of the circuit and phase difference between V and I. (CBSE 2026)
(b) Under what conditions the
(i) Impedance of the circuit is minimum?
(ii)Wattless current flows in the circuit?

OR

(i) With the help of a labelled diagram, explain the principle, construction and working of an a.c. generator.
(ii) Deduce an expression for the induced emf in the coil of the generator.
(iii) If T is the time period of the rotation of the coil, at what values of T in a cycle, the emf generator is maximum?
3. (i) you are given three circuit elements X , Y and Z. They are connected one by one across a given ac source. It is found that V and I are in phase of element X. V leads I by $\frac{\pi}{2}$ for element Y where I leads V by $\frac{\pi}{2}$ for element Z. Identify elements X, Y and Z.

(ii) Establish the expression for total opposition offered to circuit when elements X, Y and Z are connected in series to an ac source. Show the variation of current in circuit with the frequency of the applied source when only Y & Z are connected in circuit.
(iii) In a series LCR circuit obtain, the conditions under which impedance is minimum, justify why circuit becomes purely resistive at resonance?

SOLUTIONS- 5 MARKS QUESTIONS

1. (a) Drawing labelled diagram of step-up transformer. Stating the principle. Obtaining the ratio of voltages in terms of number of turns and current.

(b) Using $\frac{V_S}{V_p} = \frac{N_S}{N_p} = \frac{I_P}{I_S}$ and $P = V_p I_P$, we get $I_P = 25\ A$ and $V_S = 1000V$

2. (a) Deriving expression for Impedance of series LCR circuit and Phase difference between V & I.

(b) (i)Minimum when $X_L=X_C$

(ii) When average power consumer is zero.

OR

(i) For ac generator, labelled diagram / construction. It is based on the principle of Electromagnetic Induction. Working: When coil is rotated in magnetic field, magnetic flux linked with it changes and emf is induced in the coil.
(ii) Deducing expression for induced emf $\varepsilon = NBA\omega sin\omega t$
(iii) Emf generated is maximum at T/4 and 3T/4
3. (i) X-resistor Y-inductor Z-Capacitor
(ii) Deduce expression for Z. Graph for LC combination circuit.
(iii) Condition of resonance, $X_c = X_L$ so Z=R

CASE BASED QUESTIONS

1. Capacitor used in old radio sets is gang capacitor. It consists of two sets of parallel circular plates one of which can rotate manually by means of a knob. The rotation causes overlapping areas of plates to change, thus changing its capacitance. Air gap between plates acts as dielectric. The capacitor has to be tuned in to the corresponding frequency of a station so that the LC combination of the radio set resonates at the frequency of the desired station. When capacitive reactance (X_C) is equal to the inductive reactance (X_L), then the resonance occurs and the resonant frequency is given by $\boldsymbol{\omega}_0 = \sqrt{\frac{1}{LC}}$. Current amplitude becomes maximum at the resonant frequency. It is important to note that resonance phenomena is exhibited by a circuit only if, both L and C are present in the circuit. Only then, the voltage across L and C cancel each other (both being out of phase) and the current amplitude is max. , where $I_m = V_m / R$. This means that we cannot have resonance in a RL or RC circuit.
(i) Name the phenomena involved in tuning a radio set to a particular station
(a) Stabilization (b) Resonance (c) Rectification (d) Reflection
(ii) Capacitor used in radio set for tuning is a
(a) Parallel plate capacitor (b) Spherical capacitor (c) gang capacitor (d) electrolytic capacitor.
(iii) Resonance occurs only when:
(a) $X_c = R$ (b) $X_L = R$ (c) $X_c > X_L$ (d) $X_L = X_c$
(iv) Resonance may occur in
(a) LC circuit (b) RC circuit (c) LR circuit (d) resistor only circuit

2. A transformer is an electrical device which is used for changing a.c. voltages. It is based on the phenomenon of mutual induction. It can be shown that $\frac{Es}{Ep} = \frac{Ip}{Is} = \frac{ns}{np}$ = K, where symbols have their standard meaning. For a step up transformer, K>1 and for a step down transformer, K<1. The numbers of turns in the primary and secondary coils of a transformer are 2000 and 50 respectively. The primary coil is connected to main of 120 V and secondary to a night bulb of 0.6 ohm. The efficiency of transformer is 80 %.

(i) A transformer is used:

(a) to transform electric energy into mechanical energy. (b) to obtain suitable DC voltage

(c) to transform AC into DC (d) to obtain suitable AC voltage.

(ii) Which quantity is increased in step-down transformer?

(a) Resistance (b) power (c) current (d) charge

(iii) In step-up transformer, relation between number of turns in primary (N_p) and number of turns in secondary (N_s) is

(a) $N_s > N_p$ (b) $N_p > N_s$ (c) $N_s = N_p$ (d) $N_p = 2 N_s$

(iv) Voltage across the secondary of transformer is

(a) 120 V (b) 360 V (c) 40 V (d) 3 V

3. Series LCR circuits at resonance admit maximum current at particular frequencies. Therefore, it is called acceptor circuit because at resonance, impedance of LCR circuit is minimum and it easily accepts that current out of the many currents whose frequency is equal to the resonant frequency. This circuit is used in radio and TV receivers to tune the desired frequency or filtered unwanted frequencies. The amplitude of the current with the frequency of the signal from the desired station becomes maximum and hence it is received by the radio or TV receiver. The maximum current flows through for that a.c. voltage which has frequency equal to $f_r = \frac{1}{2\pi\sqrt{LC}}$ .If Q-value of circuit is large the signals of the other stations will be very weak. Quality factor determines the clarity of reception.

(i) The current admitted by series LCR circuit corresponding to resonant frequency is

(a) maximum (b) minimum (c) zero (d) 10A

(ii) In a series LCR circuit L=8H, C=0.5μF and R=100Ω. The resonant frequency of the circuit is:

(a) 1000 / π Hz (b) 500 / π Hz (c) 250 / π Hz (d) 125 / π Hz

(iii) At resonance, in a series LCR circuit, which relation does not hold?

(a) $\omega = \frac{1}{LC}$ (b) $\omega = \frac{1}{\sqrt{LC}}$ (c) $L\omega = \frac{1}{\omega_c}$ (d) $C\omega = \frac{1}{L\omega}$

(iv) Nita switched on the radio set to listen to her favourite music but found the reception was not clear. Also there was there was overlapping of signals. So she adjusted the tuner. Name the phenomenon involved here

(a) reception (b) bandwith (c) resonance (d) filtration

1 i-b, ii-c , iii-d , iv-a
2 i-d ii-d iii-d iv-a
3 i-d ii-a iii-b iv-c

ALTERNATING CURRENT

CLASS 12 PHYSICS – FORMULA SHEET

CBSE SYLLABUS | NEP 2020 ALIGNED | QUICK REVISION | EXAM READY

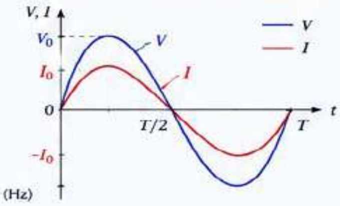
1 ALTERNATING CURRENT & VOLTAGE (MOST IMPORTANT)

Instantaneous Values

$$v = V_0 \sin(\omega t)$$
$$i = I_0 \sin(\omega t)$$

V_0, I_0 = Peak (maximum) values

$\omega = 2\pi f$ (rad s^{-1}), f = frequency (Hz)



QUICK RECALL

- AC reverses direction periodically.
- Average value of sinusoidal AC over a complete cycle = 0
- RMS value is the equivalent DC value producing same power in a resistor.

2 RMS VALUE & PEAK VALUE

RMS (Effective) Values

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$
$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

TRICK

$$RMS = \frac{Peak}{\sqrt{2}}$$
$$Peak = RMS \times \sqrt{2}$$

Key Point

In AC circuits, V_{rms}, I_{rms} are used for power calculations.

3 REACTANCE

Inductive Reactance

$$X_L = \omega L = 2\pi f L$$

Unit: ohm (Ω)

Capacitive Reactance

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

Unit: ohm (Ω)

Note: X_L increases with f, X_C decreases with f

4 IMPEDANCE & PHASE RELATION

Impedance (Z)

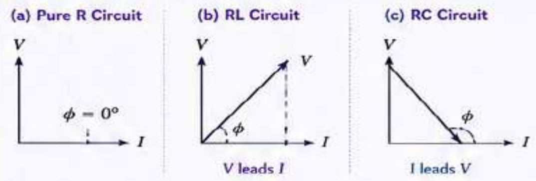
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Phase Angle (ϕ)

$$\tan\phi = \frac{X_L - X_C}{R}$$

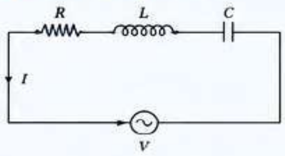
Z is always positive. Unit: ohm (Ω)

5 PHASOR DIAGRAMS (KEY CASES)



Note: For LCR circuit, phase angle ϕ can be leading or lagging depending on X_L and X_C.

6 LCR SERIES CIRCUIT



$$I_0 = \frac{V_0}{Z}$$
$$I_{rms} = \frac{V_{rms}}{Z}$$
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$\tan\phi = \frac{X_L - X_C}{R}$$

Phase: Current lags voltage by ϕ if $X_L > X_C$ (inductive)
Current leads voltage by ϕ if $X_C > X_L$ (capacitive)

7 RESONANCE (LCR CIRCUIT)

At Resonance:

- $X_L = X_C$
- $\phi = 0$ (I and V in phase)
- $Z = R$ (minimum)
- Current is maximum
- Power factor = 1

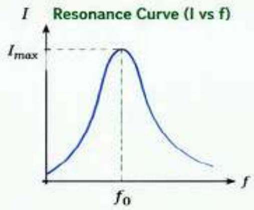
Resonant Angular Frequency

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Resonant Frequency

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Helpful to select a particular frequency.



8 POWER IN AC CIRCUIT

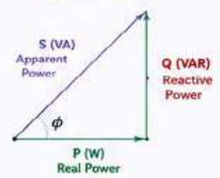
Average Power (Real Power)

$$P_{avg} = V_{rms} I_{rms} \cos\phi$$
or
$$P_{avg} = \frac{V_0 I_0}{2} \cos\phi$$

Power Factor

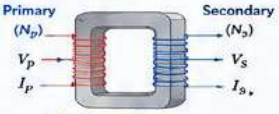
$$\cos\phi = \frac{R}{Z}$$

POWER TRIANGLE



$$S^2 = P^2 + Q^2$$
$$\tan\phi = \frac{Q}{P}$$

9 TRANSFORMER



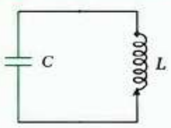
Ideal Transformer

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad \frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Efficiency

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$$

10 LC OSCILLATIONS



$$\omega = \frac{1}{\sqrt{LC}}$$
$$T = 2\pi\sqrt{LC}$$
$$f = \frac{1}{2\pi\sqrt{LC}}$$

Key Point

Energy oscillates between electric field of C and magnetic field of L.
Total energy remains constant.

11 X_L vs X_C vs Z

Quantity	Formula	Depends on	Nature
X_L	$2\pi f L$	f, L	Inductive (increases with f)
X_C	$\frac{1}{2\pi f C}$	f, C	Capacitive (decreases with f)
Z	$\sqrt{R^2 + (X_L - X_C)^2}$	R, X_L, X_C	Combination (always +ve)

12 IMPORTANT CONDITIONS

- ✓ Resonance: $X_L = X_C$ or $\omega_0 = \frac{1}{\sqrt{LC}}$
- ✓ Power factor unity: $\phi = 0$ (at resonance)
- ✓ Net inductive: $X_L > X_C$ (current lags)
- ✓ Net capacitive: $X_C > X_L$ (current leads)

13 DIFFERENCE

Feature	Resistance (R)	Reactance (X)	Impedance (Z)
Definition	Opposition in pure resistor	Opposition due to L or C	Total opposition in AC circuit
Depends on	Does not depend on f	Depends on f	Depends on R, L, C and f
Power	Consumes power	Does not consume power	Consumes power
Unit	Ohm (Ω)	Ohm (Ω)	Ohm (Ω)

14 MEMORY TRICKS

"ELI the ICE man"
ELI → X_L (Inductor)
ICE → X_C (Capacitor)
X_L increases, X_C decreases with f

"The Z Rule"
Impedance Z is the resultant of R and $(X_L - X_C)$

"Power Formula"
Use $P = V_{rms} I_{rms} \cos\phi$
Remember: cos = Power Factor

15 COMMON MISTAKES

- ✗ Using peak values in power formula.
- ✗ Forgetting unit of reactance (ohm).
- ✗ Using X_L instead of X_C or vice versa.
- ✗ Ignoring phase angle ϕ in calculations.
- ✗ Incorrect transformer turn ratio.

16 PYQ TIPS

Questions often come from:

- ➤ Resonance condition & ω_0
- ➤ Power factor & power formula
- ➤ Transformer ratios
- ➤ Phasor diagrams (RL, RC, LCR)

Practice NCERT & PYQs!

KEEP CALM STAY FOCUSED CRACK THE EXAM!

17 SYMBOLS, UNITS & CONSTANTS

V, I : Voltage (V), Current (A)
V_{rms}, I_{rms} : Peak values
f : RMS values
R : Resistance (Ω)
X_L : Inductive Reactance (Ω)
X_C : Capacitive Reactance (Ω)
Z : Impedance (Ω)
L : Inductance (H)
C : Capacitance (F)
N : Number of turns
ϕ : Phase angle (rad or °)
$\pi = 3.1416$
$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
1 H = 1 Wb A^{-1}
1 F = 1 C V^{-1}

CHAPTER 08

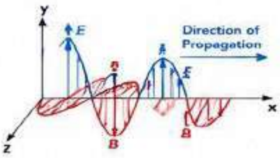
ELECTROMAGNETIC WAVES

CBSE CLASS XII PHYSICS

Electromagnetic waves are transverse waves which do not require a material medium for their propagation. They travel even in vacuum with speed c.

1 GENERATION OF ELECTROMAGNETIC WAVES

- When an accelerated charge oscillates, it produces time-varying electric and magnetic fields.
- According to Maxwell, a changing electric field produces a changing magnetic field and vice-versa.
- These mutually perpendicular fields propagate in space in the form of electromagnetic waves.



Key Points

- $E \perp B \perp$ direction of propagation
- E and B are in phase
- Electric and magnetic fields perform SHM in mutually perpendicular planes

2 PROPERTIES OF ELECTROMAGNETIC WAVES

- Do not require material medium.
- Travel with speed c in vacuum.
- E and B fields are perpendicular to each other and to the direction of propagation.
- All electromagnetic waves are transverse.
- Obey laws of reflection, refraction, interference, diffraction and polarization.
- In vacuum, all EM waves travel with same speed c.

Speed in Vacuum

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

$$= 3.0 \times 10^8\ m\ s^{-1}$$

Where,

$\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1} (permeability of free space)

$\varepsilon_0 = 8.854 \times 10^{-12}$ F m^{-1} (permittivity of free space)

3 MATHEMATICAL DESCRIPTION

Sinusoidal EM Wave

Electric Field:

$$E = E_0 \sin(kx - \omega t)$$

Magnetic Field:

$$B = B_0 \sin(kx - \omega t)$$

Where,

E_0 = amplitude of electric field (V m^{-1})

B_0 = amplitude of magnetic field (T)

k = wave number $= \frac{2\pi}{\lambda}$ (rad m^{-1})

ω = angular frequency $= 2\pi f$ (rad s^{-1})

λ = wavelength (m)

f = frequency (Hz)

t = time (s)

x = distance in direction of propagation (m)

Relation between E_0 and B_0

$$\frac{E_0}{B_0} = c \quad \text{or} \quad E_0 = cB_0$$

Wave Relations

$$c = \lambda f$$

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

$$k = \frac{2\pi}{\lambda}$$

4 ENERGY, MOMENTUM AND PRESSURE

Energy Density

Electric Field:

$$u_E = \frac{1}{2}\varepsilon_0 E^2$$

Magnetic Field:

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

Total Energy Density (u):

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

In EM wave, average u_E = average u_B

$$\Rightarrow u_{avg} = \varepsilon_0 E_{rms}^2$$

Intensity (I)

Average energy crossing unit area per unit time.

$$I = \langle S \rangle = c\, u_{avg} = \frac{1}{2} c\varepsilon_0 E_0^2$$

Also, $I = \frac{c}{2\mu_0} B_0^2$

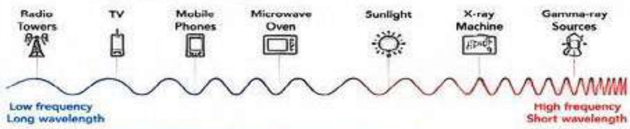
Radiation Pressure (P)

$P = \frac{I}{c}$ (perfect absorber)

$P = \frac{2I}{c}$ (perfect reflector)

5 ELECTROMAGNETIC SPECTRUM

The EM spectrum arranged according to increasing frequency (f) or decreasing wavelength (λ).



Region	Wavelength (m)	Frequency (Hz)	Uses / Sources
Radio Waves	> 1	$< 3 \times 10^8$	Radio, TV, communication
Microwaves	$10^{-3} - 1$	$3 \times 10^8 - 3 \times 10^{11}$	Radar, ovens, Wi-Fi
Infrared (IR)	$10^{-6} - 10^{-3}$	$3 \times 10^{11} - 3 \times 10^{14}$	Heating, remote controls
Visible Light	400 – 700 nm	$4.3 \times 10^{14} - 7.5 \times 10^{14}$	Vision, photography
Ultraviolet (UV)	10^{-8} – 400 nm	$7.5 \times 10^{14} - 3 \times 10^{16}$	Sterilization, fluorescent lamps
X-rays	$10^{-11} - 10^{-8}$	$3 \times 10^{16} - 3 \times 10^{19}$	Medical imaging
Gamma rays	$< 10^{-11}$	$> 3 \times 10^{19}$	Cancer treatment, nuclear

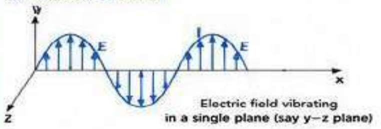
Visible Light

Violet	400 nm
Indigo	450 nm
Blue	475 nm
Green	520 nm
Yellow	570 nm
Orange	590 nm
Red	700 nm

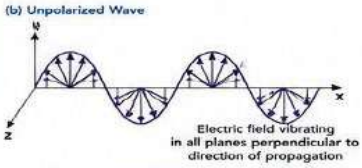
6 POLARIZATION OF ELECTROMAGNETIC WAVES

Polarization is the phenomenon of restricting the direction of vibration of the electric field vector.

(a) Plane Polarized Wave



(b) Unpolarized Wave



PYQ

Why can electromagnetic waves be polarized while sound waves cannot be?

MEMORY TRICK

Electromagnetic waves are SELF-sustaining waves of oscillating E and B fields!

QUICK REVISION

- EM waves are transverse.
- $E \perp B \perp$ direction of propagation.
- Do not need a medium.
- Speed in vacuum: $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$
- All EM waves travel with same speed in vacuum.
- Energy is shared equally between E and B fields.
- EM waves show reflection, refraction, interference, diffraction, polarization.

FORMULA SUMMARY

Speed in vacuum	$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$
Wave equation	$c = \lambda f$
Angular frequency	$\omega = 2\pi f$
Wave number	$k = \frac{2\pi}{\lambda}$
Amplitude relation	$E_0 = cB_0$
Energy density	$u = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$
Intensity	$I = \frac{1}{2}c\varepsilon_0 E_0^2 = \frac{c}{2\mu_0}B_0^2$
Radiation pressure	$P = \frac{I}{c}$ (absorber) $P = \frac{2I}{c}$ (reflector)

INTERFERENCE OF EM WAVES

Superposition of two coherent EM waves produces interference.

Conditions

- Coherent sources
- Same frequency
- Constant phase difference
- Same state of polarization

Result

- Constructive interference (bright): $\Delta = n\lambda$
- Destructive interference (dark): $\Delta = (2n+1)\frac{\lambda}{2}$

where, Δ = path difference

COMMON MISTAKES

- Thinking EM waves need medium.
- Forgetting $E \perp B \perp$ direction.
- Confusing f and ω.
- Using v instead of c in vacuum.
- Forgetting $E_0 = cB_0$.
- Not converting units in numerical problems.

INTERFERENCE vs DIFFRACTION

	Interference	Diffraction
Cause	Superposition of waves from two coherent [illegible]	Bending/spreading of waves around edges or through aperture
Source(s)	Two coherent sources	Single source
Fringe Pattern	Bright & dark fringes of equal width (ideal) [illegible]	Central maximum is brightest & widest; side maxima weaker
Dependence	Depends on d, D, λ	Depends on a, λ
Condition	Requires coherence	No coherence required

PYQ TIPS

- Derivations are important: Generation of EM waves, expression for speed of light, energy density.
- Learn diagrams neatly.
- Know the EM spectrum order.
- Practice numericals regularly.
- Focus on NCERT end-of-chapter questions and previous 10 years' board questions.

BOARD EXAM TIPS

- Write all formulas with symbols.
- Draw labelled diagrams first.
- Use correct units (SI).
- Show all steps in derivations.
- Attempt NCERT in-text & exemplar questions.
- Revise PYQs before exam.

SYMBOLS & UNITS

Symbol	Quantity	SI Unit
E	Electric field	V m^{-1}
B	Magnetic field	tesla (T)
c	Speed of light in vacuum	m s^{-1}
λ	Wavelength	metre (m)
f	Frequency	hertz (Hz)
ω	Angular frequency	rad s^{-1}
μ_0	Permeability of free space	T m A^{-1}
ε_0	Permittivity of free space	F m^{-1}

"Electromagnetic waves are nature's universal messengers."

MULTIPLE CHOICE QUESTIONS

1. Which of the following has the minimum wavelength?

(a) X-rays (b) Ultraviolet rays (c) Gamma rays (d) Cosmic rays

2. Which of the following can produce a propagating electromagnetic wave?

(a) A stationary charge (b) A chargeless particle

(c) An accelerating charge (d) A charge moving at constant velocity

3 Which one of the following correctly represents the change in wave characteristics (all in vacuum) from microwaves to X rays in electromagnetic spectrum?

	Speed	Wavelength	Frequency
a)	Remains same	Decreases	Remains same
b)	Remains same	Decreases	Increases
c)	Increases	Increases	Decreases
d)	Remains same	Decreases	Remains same

4 X rays are more harmful to human beings than ultraviolet radiations because X-rays:

a) Have frequency lower than that of ultraviolet radiations
b) Have wavelength smaller than that of ultraviolet radiations
c) Move faster than ultraviolet radiations in air
d) Are mechanical waves but ultraviolet radiations are electromagnetic waves

5 Displacement current exists only when

a) electric field is changing b) magnetic field is changing
c) electric field is constant d) magnetic field is constant

6 The momentum (in kg m/s) of a photon of wavelength 500nm is:

a) 6.63×10^{-25} b) 1.326×10^{-27} c) 2.652×10^{-26} d) 3.978×10^{-24}

7 The phase difference between the oscillations of electric and magnetic field in an electromagnetic wave is:

a) π b) $\pi/2$ c) zero d) $3\,\pi/2$

8 A plane electromagnetic wave propagating along x direction can have the following pairs of E and B **:**

a) E_x, B_y b) E_x, B_x c) E_y, B_x d) E_z, B_y

9 In the process of charging of a capacitor, the current produced between the plates of the capacitor is

a) $\mu_0 \frac{d\varphi_E}{dt}$ b) $\frac{1}{\mu_0}\frac{d\varphi_E}{dt}$ c) $\varepsilon_0 \frac{d\varphi_E}{dt}$ d) $\frac{1}{\varepsilon_0}\frac{d\varphi_E}{dt}$

10 $\vec{E}$and $\vec{B}$ represent the electric and the magnetic fields of an electromagnetic wave respectively. The direction of propagation of the wave is along:

a) $\vec{B}$ b) $\vec{E}$ c) $\vec{E}$ x $\vec{B}$ d) $\vec{B}\, x\, \vec{E}$

Answers

1(c) Gamma rays B X-rays , Micro and UV as wavelength decreases in this order

2(c) An accelerating charge

3(b) wavelength of X is smaller than UV

4(a) displacement current is $\varepsilon_0 \left(\frac{d\varphi_E}{dt}\right)$ so it exists only if electric field is changing

5(c) During welding, a high-intensity electric arc is generated, which emits a large amount of ultraviolet rays

6 c 7 c 8 d 9 c 10 c

ASSERTION AND REASON QUESTIONS

For each question, select the correct option:

(a) Both Assertion and Reason are true, and Reason is the correct explanation of Assertion.
(b) Both Assertion and Reason are true, but Reason is not the correct explanation of Assertion.
(c) Assertion is true, but Reason is false.
(d) Assertion is false, but Reason is true.

Q1. Assertion (A): Electromagnetic waves do not require a material medium for their propagation.
Reason (R): Electromagnetic waves consist of oscillating electric and magnetic fields, which are self-sustaining in vacuum.

Q2. Assertion (A): In an electromagnetic wave, the electric and magnetic fields are always perpendicular to each other.
Reason (R): The directions of electric and magnetic fields in an EM wave are independent of the direction of wave propagation.

Q3. Assertion (A): The speed of electromagnetic waves in vacuum is equal to $1/\sqrt{\mu 0 \varepsilon 0}$
Reason (R): The values of μ_0 and ε_0 determine the properties of vacuum with respect to magnetic and electric fields, respectively

Q4. Assertion (A): X-rays can be used to detect fractures in bones.
Reason (R): X-rays have controlled penetrating power and are absorbed differently by different tissues.

Q5. Assertion (A): Ultraviolet rays are more energetic than infrared rays.
Reason (R): The frequency of ultraviolet rays is greater than that of infrared rays.

Q6. Assertion (A): Gamma rays have the longest wavelength in the electromagnetic spectrum.
Reason (R): Gamma rays have the lowest frequency among all EM waves.

Q7. Assertion (A): Microwaves are suitable for radar systems used in aircraft navigation.
Reason (R): Microwaves can penetrate through the ionosphere and reach long distances without significant attenuation.

Q8 Assertion (A): Electromagnetic waves carry both energy and momentum.
Reason (R): The energy and momentum in EM waves are carried by the magnetic field only.

Q9. Assertion (A): Infrared radiation is used in night vision device**s.**
Reason (R): Infrared radiation is emitted by hot bodies and can be detected even in the absence of visible light.

Q10. Assertion (A): The electric field vector in an EM wave oscillates in the direction of propagation.
Reason (R): Electromagnetic waves are longitudinal in nature.

ANSWERS

1. (a) EM waves are self-propagating due to mutual induction of E and B fields and do not need a medium.
2. (c) The fields are perpendicular to each other and to the direction of wave propagation they are not independent.
3. (a) Speed of EM wave in vacuum is derived using these constants.

4. (a) Bones absorb more X-rays than soft tissue, producing contrast.
5. (a) Energy E = h; higher frequency = higher energy.
6. (d) Gamma rays have the shortest wavelength and highest frequency.
7. (a) Microwaves are used in radar as they can travel in the atmosphere and reflect from objects.
8.(c) Energy is shared by both electric and magnetic fields, not just magnetic.
9. (a) IR is emitted due to heat and used for thermal imaging.
10. (d) EM waves are transverse, not longitudinal; E field is perpendicular to propagation.

EXERCISE QUESTIONS

Q1 Assertion: The center of sensitivity of our eyes coincides with the centre of the wavelength distribution of the sun.

Reason: Humans have evolved with visions most sensitive to the strongest wavelengths received from the sun.

Q2 Assertion: When Infrared waves are incident on a surface vibrate not only the electrons, but the entire atom or molecules of a substance.

Reason: Due to vibration internal energy increases and consequently temperature decreases.

Q3 Assertion: Displacement current has the same physical effect as the conduction current.

Reason: During charging of a capacitor both conduction and displacement current are present in different regions of space.

Q4 Assertion: the speed of electromagnetic waves is less in vacuum and it increases as move to a medium.

Reason: The relative permittivity and permeability of a medium is less than that of vacuum.

Q5 Assertion: Ultraviolet radiations are used in LASIK eye surgery.

Reason: Ultraviolet radiations can be focused into very narrow beams of high precision applications.

Answers

1. A 2.C 3. B 4. D 5. A

VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

Q1 You are given a 2μF parallel plate capacitor. How would you establish an instantaneous displacement current of 1mA in the space between its plates?

Q2 (i) How are infrared waves produced? Write their one important use.

(ii) The thin ozone layer on top of the stratosphere is crucial for human survival. Why?

Q3 (i) Which part of the electromagnetic spectrum is used in operating a RADAR?

(ii)Why microwaves are considered suitable for radar systems used in aircraft navigation?

Q4 (i) Do electromagnetic waves carry energy and momentum?

(ii) How is the speed of EM-waves in vacuum determined by the electric and magnetic fields?

Q5 The amplitude of the magnetic field of a harmonic electromagnetic wave in vacuum is B_0=510 nT. What is the amplitude of the electric field part of the wave?

Q6 An E.M. wave, Y_1, has a wavelength of 1cm while another e.m. wave, Y_2, has a frequency of 10^{15} Hz. Name these two types of waves and write one useful application for each.

Q7 How are electromagnetic waves produced? Write their two characteristics.

Q8 A laser beam of wavelength 500nm and power 5nW strikes normally on a perfectly reflecting surface of area 1 mm^2 of a body. It rebounds back from the surface. Find the force exerted by the laser beam on the body.

Q9 A laser beam of frequency 3.0 x 10^{14} Hz produces average power of 9mW find i) the energy of photon of the beam and ii) the number of photons emitted per second on an average by the source.

Q10 Identify the electromagnetic wave whose wavelength range is from about

(a) 10^{-12} m to about 10^{-18} m (b) 10^{-3}m to about 10^{-1}m. Write one use of each.

ANSWERS

1: by giving a varying potential difference of 500 V/s

2: The thin ozone layer in the upper atmosphere (stratosphere) is crucial because it absorbs most of the harmful ultraviolet (UV) radiation from the Sun. Without it, UV rays would reach Earth's surface and cause severe health issues like skin cancer, cataracts, and damage to ecosystems.

3. Microwaves (typically in the range of 1 mm to 30 cm wavelength or 1 GHz to 30 GHz frequency) are used in RADAR systems.

SUITABILITY: Short Wavelengths allow for high resolution and accurate detection of small and distant objects. Penetration Capability: They can travel long distances through the atmosphere with minimal attenuation due to weather (like fog, rain). Efficient Reflection: Microwaves are strongly reflected by metal surfaces (like aircraft or terrain), making them ideal for object detection and ranging.

4 Yes**,** electromagnetic (EM) waves carry both energy and momentum**.** The energy is transported by the oscillating electric and magnetic fields. They exert radiation pressure on surfaces, proving they carry momentum as well. Speed of wave c = (v) = $\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ = 3x 10^8 m/s

5 E_o=153 V/m

6. Y_1 has a wavelength of 1 cm, which lies in the microwave region. Y_2 has a frequency of 10^{15} Hz, which falls in the ultraviolet (UV) region.

Y_1: Microwave, Application: Used in microwave ovens for cooking food.

Y_2: Ultraviolet (UV) wave, Application: Used for sterilizing medical instruments.

7. Electromagnetic waves are produced by an accelerated or oscillating electric charge, which creates a time-varying electric field. This changing electric field, in turn, generates a time-varying magnetic field, and together they propagate as an electromagnetic wave.

Characteristics:

Transverse Nature: Electric and magnetic fields oscillate perpendicular to each other and to the direction of wave propagation.

Do Not Require a Medium: They can travel through a vacuum at the speed of light (3×10^8 m/s).Or any other characteristics…

8. F=2P/c, This is because for a perfectly reflecting surface, the momentum transferred per second (i.e., force) is double compared to absorption.

F= 3.33x10^{-17} N, This is the force exerted by the laser beam on the reflecting surface.

9. E=h*ν*, h=6.626×10^{-34}Js, So E= 1.9878×10^{-19} J

no of photons= Power/Energy per photon, n= 9 x 10^{-3} W/1.9878×10^{-19} J = 4.52 x 10^{16} photons

10. (a) Wavelength range: 10^{-12} to 10^{-18} m, Electromagnetic Wave: Gamma rays, Used to kill cancer cells in radiation therapy. (b) Wavelength range: 10^{-3} to 10^{-1} m
Electromagnetic Wave: Microwaves, Used in microwave ovens to heat food.

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

1. State any three characteristics of electromagnetic waves. Why are electromagnetic waves called transverse waves?
2. Draw the electromagnetic spectrum in increasing order of wavelength. Write one important application of (i) Infrared rays (ii) Ultraviolet rays (iii) Gamma rays.
3. The frequency of an electromagnetic wave is 8 × 10^14 Hz. Calculate its wavelength. Name the part of the electromagnetic spectrum to which it belongs.
4. An electromagnetic wave travels in vacuum along the z-axis. The electric field oscillates along the x-axis. Write the direction of oscillation of magnetic field and explain how the direction of propagation is determined.
5. Why are microwaves preferred for satellite communication? Give three reasons.
6. (Competency Based) A TV remote stops working when a thick black sheet is placed between the remote and the television. Name the electromagnetic waves used in the remote and explain the reason behind this observation.
7. (Competency Based) During foggy conditions, visible light is not suitable for long-distance photography, but infrared cameras work effectively. Explain why.
8. (Competency Based) Doctors advise limited exposure to ultraviolet radiation, yet UV lamps are used in hospitals. Explain both statements with suitable reasons.
9. (Competency Based) A student observed that communication signals received from satellites are highly directional and carry large amounts of data. Which electromagnetic waves are used? Explain with reasons.
10. (Competency Based Numerical) The wavelength of a radio wave transmitted by a TV station is 6 m. Calculate its frequency. Why are such waves suitable for communication over large distances?

Answers

1. Characteristics: (i) Electromagnetic waves are transverse in nature. (ii) They can travel through vacuum. (iii) Electric and magnetic fields oscillate perpendicular to each other and to the direction of propagation. They are called transverse because the oscillations are perpendicular to the direction of motion.
2. Increasing order of wavelength: Gamma rays < X-rays < Ultraviolet < Visible < Infrared < Microwaves < Radio waves. Applications: Infrared rays – remote controls/thermal imaging; Ultraviolet rays – sterilization; Gamma rays – cancer treatment.
3. Given frequency, ν = 8 × 10^14 Hz. Using $c = \nu\lambda$, $\lambda = c/\nu = (3 \times 10^{8})/(8 \times 10^{14}) = 3.75 \times 10^{-7}$ m. The wave belongs to the visible/near ultraviolet region.
4. Magnetic field oscillates along the y-axis. The direction of propagation is perpendicular to both electric and magnetic fields and is given by $E \times B$ (right-hand rule).
5. Microwaves are preferred because: (i) They can penetrate the atmosphere easily. (ii) They suffer less attenuation. (iii) Their short wavelength allows highly directional transmission and large bandwidth.

6. Infrared waves are used in TV remotes. The black sheet absorbs or blocks infrared radiation, preventing the signal from reaching the television sensor.
7. Infrared waves have longer wavelength and undergo less scattering in fog compared to visible light. Hence, infrared cameras work more effectively in foggy conditions.
8. Excessive ultraviolet exposure can damage skin and eyes and may cause cancer. However, UV lamps are used in hospitals because ultraviolet radiation kills bacteria and microorganisms.
9. Microwaves are used for satellite communication because they are highly directional, can penetrate the atmosphere effectively, and carry large amounts of information due to high frequency.
10. Given wavelength, $\lambda = 6$ m. Using $\nu = c/\lambda = (3 \times 10^8)/6 = 5 \times 10^7$ Hz. Radio waves are suitable for long-distance communication because they can diffract around obstacles and follow the curvature of the Earth.

Practice Questions

1. State the main differences between electromagnetic waves and mechanical waves. Give any three points.
2. A source emits electromagnetic waves of wavelength 3×10^{-7} m. Calculate its frequency. Identify the region of the electromagnetic spectrum to which it belongs.
3. Explain why X-rays are used in medical diagnosis but gamma rays are generally not preferred for routine imaging.
4. During a disaster, communication systems based on radio waves continue to operate even when mobile networks fail. Explain why radio waves are suitable for long-distance communication.
5. A microwave signal of frequency 12 GHz is used for satellite communication. Calculate its wavelength. State one advantage of using microwaves for satellite communication.

Answers

1. Differences: (i) Electromagnetic waves do not require a material medium, whereas mechanical waves do. (ii) Electromagnetic waves are produced by oscillating electric and magnetic fields, whereas mechanical waves are produced by particle vibrations. (iii) Electromagnetic waves can travel through vacuum, whereas mechanical waves cannot.
2. Given wavelength, $\lambda = 3 \times 10^{-7}$ m. Using $\nu = c/\lambda = (3 \times 10^8)/(3 \times 10^{-7}) = 1 \times 10^{15}$ Hz. The wave belongs to the ultraviolet region.
3. X-rays have suitable penetrating power for imaging bones and tissues without causing excessive damage. Gamma rays are much more energetic and can cause severe damage to living cells, making them unsuitable for routine diagnosis.
4. Radio waves have long wavelengths and can diffract around obstacles and follow the curvature of the Earth. Hence they are effective for long-distance communication, especially during emergencies.

Long Answer Questions

1. (a) State any two properties of electromagnetic waves.
(b) Arrange the following electromagnetic waves in increasing order of wavelength: Gamma rays, Infrared rays, X-rays, Radio waves.
(c) Write one application each of X-rays and Infrared rays.

2. (a) Why are electromagnetic waves called transverse waves?
(b) Draw the sketch showing electric field, magnetic field, and direction of propagation of an electromagnetic wave.
(c) State the direction of magnetic field if the electric field oscillates along x-axis and the wave propagates along z-axis.
3. (a) State the relation between wavelength, frequency, and velocity of an electromagnetic wave.
(b) An electromagnetic wave has frequency 5×10^{14} Hz. Calculate its wavelength.
(c) Name the region of electromagnetic spectrum to which this wave belongs.
4. (a) Why are microwaves used in satellite communication? State any two reasons.
(b) Why are radio waves suitable for long-distance communication?
(c) Mention one application of microwaves other than communication.
5. (a) State any two harmful effects of ultraviolet radiation.
(b) Why are ultraviolet rays still used in hospitals?
(c) Name the electromagnetic waves used in sterilization and explain why they are suitable.

Answers

1. (a) Electromagnetic waves are transverse waves and can travel through vacuum.
(b) Increasing order of wavelength: Gamma rays < X-rays < Infrared rays < Radio waves.
(c) X-rays are used in medical diagnosis; Infrared rays are used in remote controls and thermal imaging.
2. (a) Electromagnetic waves are called transverse because electric and magnetic fields oscillate perpendicular to the direction of propagation.
(b) Electric field, magnetic field, and propagation direction are mutually perpendicular.
(c) If electric field is along x-axis and propagation is along z-axis, magnetic field oscillates along y-axis.
3. (a) Relation: $c = \nu\lambda$
(b) $\lambda = c/\nu = (3 \times 10^8)/(5 \times 10^{14}) = 6 \times 10^{-7}$ m = 600 nm.
(c) The wave belongs to the visible region.
4. (a) Microwaves are used in satellite communication because they penetrate the atmosphere easily and are highly directional.
(b) Radio waves can diffract around obstacles and travel long distances.
(c) Microwaves are also used in radar systems and microwave ovens.
5. (a) Harmful effects of ultraviolet radiation: skin cancer and eye damage.
(b) Ultraviolet rays are used in hospitals because they kill bacteria and microorganisms.
(c) Ultraviolet waves are used for sterilization due to their germicidal action.

Practice questions

1. (a) Why are X-rays used in medical diagnosis?
(b) Why are gamma rays not preferred for routine medical imaging?
(c) State one use of gamma rays in medicine.
2. (a) Explain why infrared waves are used in TV remote controls.
(b) During foggy conditions, infrared cameras work better than visible light cameras. Explain

why.
(c) Name one other application of infrared radiation.
3. (a) A radio station broadcasts waves of wavelength 25 m. Calculate its frequency.
(b) Name the region of electromagnetic spectrum corresponding to these waves.
(c) State one characteristic of these waves that makes them useful for communication.
4, What is displacement current? Obtain an expression for displacement current between the plates of a charging capacitor. Show that the displacement current in the capacitor equals the conduction current in the connecting wires.

Answers

1. (a) X-rays have suitable penetrating power and help image bones and tissues.
(b) Gamma rays are highly energetic and can damage living cells.
(c) Gamma rays are used in cancer treatment (radiotherapy).
2. (a) Infrared waves are used in remote controls because they are suitable for short-range communication.
(b) Infrared waves undergo less scattering in fog compared to visible light.
(c) Infrared radiation is also used in thermal imaging and night vision devices.
3. (a) Frequency $\nu = c/\lambda = (3 \times 10^8)/25 = 1.2 \times 10^7$ Hz.
(b) These waves belong to the radio wave region.
(c) Radio waves are useful for communication because they can travel large distances and diffract around obstacles.

4. Displacement current is the current equivalent arising due to the time-varying electric flux in a region where there is no conduction current (like the gap between capacitor plates).

Case Study 1: Development of Electromagnetic Waves

James Clerk Maxwell proposed that changing electric and magnetic fields can generate each other and travel through space as electromagnetic waves. Heinrich Hertz experimentally produced these waves later, while Jagdish Chandra Bose and Guglielmo Marconi contributed significantly to wireless communication systems.

Questions:
(i) Arrange the following EM waves in increasing order of frequency:
(a) Microwaves < Infrared < Ultraviolet < Gamma rays
(b) Gamma rays < Ultraviolet < Infrared < Microwaves
(c) Ultraviolet < Infrared < Microwaves < Gamma rays
(d) Gamma rays < Microwaves < Infrared < Ultraviolet
(ii) Visible light is an example of:
(a) Electromagnetic waves (b) Mechanical waves
(c) Longitudinal waves (d) Magnetic waves
(iii) Calculate the frequency of an EM wave of wavelength 500 km.
(a) 600 Hz (b) 500 Hz (c) 167 Hz (d) 15 Hz
(iv) The electric and magnetic field vectors in an EM wave are inclined at:
(a) 180° (b) 120° (c) 90° (d) 45°

Answers: (i) a (ii) a (iii) a (iv) c

1. Radio waves are generated by accelerating charges in antennas, microwaves by magnetrons, infrared waves by hot bodies, and ultraviolet rays by extremely hot objects like the Sun.
(i) Solar radiation mainly consists of:

(a) Transverse electromagnetic waves (b) Longitudinal electromagnetic waves
(c) Both transverse and longitudinal waves (d) None of these
(ii) The greenhouse effect is mainly caused by:
(a) Infrared rays (b) Ultraviolet rays (c) X-rays (d) Radio waves
(iii) The ozone layer is important because:
(a) It absorbs harmful ultraviolet radiation (b) It reduces greenhouse effect
(c) It reflects radio waves (d) None of these
(iv) Earth's atmosphere is richest in:
(a) Ultraviolet rays (b) Infrared radiation (c) X-rays (d) Microwaves
Answers: (i) a (ii) a (iii) a (iv) b

Production of Electromagnetic Waves

According to Maxwell's theory, accelerating charges produce electromagnetic waves. Oscillating electric and magnetic fields continuously regenerate each other and propagate through space.
Questions:
(i) Electromagnetic waves are produced by:
(a) Accelerating charges (b) Stationary charges
(c) Uniformly moving charges (d) None of these
(ii) Light can travel through vacuum because of its:
(a) Transverse nature (b) Electromagnetic nature
(c) Longitudinal nature (d) Both (a) and (c)
(iii) Find the wavelength of an EM wave of frequency 8.2×10^6 Hz.
(a) 36.6 m (b) 18.8 m (c) 42.8 m (d) 58 m
(iv) Infrared radiations have:
(a) Shorter wavelength than UV rays (b) Longer wavelength than UV rays
(c) Same wavelength as UV rays (d) No comparison possible
Answers: (i) a (ii) b (iii) a (iv) b

Applications of Electromagnetic Waves

Different electromagnetic waves are used in technology and healthcare. X-rays are used in airport security systems, while microwaves efficiently heat food containing water molecules.
Questions:
(i) Which radiation is used in airport luggage scanning?
(a) Gamma rays (b) X-rays (c) Microwaves (d) Infrared rays

(ii) Gamma rays of wavelength 1×10^{-12} m have frequency:
(a) 3×10^{20} Hz (b) 2×10^{12} Hz (c) 2.5×10^{5} Hz (d) 3.3×10^{12} Hz

(iii) Why do microwaves heat water-containing food efficiently?
(a) Microwaves are heat waves (b) Infrared rays produce heating
(c) Water molecules absorb microwave energy efficiently (d) Frequency has no effect

(iv) Which EM wave has the longest wavelength?
(a) X-rays (b) Gamma rays (c) Microwaves (d) Radio waves
Answers: (i) b (ii) a (iii) c (iv) d

ELECTROMAGNETIC WAVES

CLASS XII PHYSICS – FORMULA SHEET

CBSE 2026–27 (LATEST SYLLABUS)

1. MAXWELL'S EQUATIONS IN FREE SPACE

(i) Gauss's Law (Electric)

$$\oint \vec{E}\cdot d\vec{S} = \frac{Q_{\text{encl}}}{\varepsilon_0}$$

(ii) Gauss's Law (Magnetic)

$$\oint \vec{B}\cdot d\vec{S} = 0$$

(iii) Faraday's Law of Electromagnetic Induction

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

(iv) Ampere–Maxwell Law

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{\text{encl}} + \mu_0\varepsilon_0\frac{d\Phi_E}{dt}$$

where, $\Phi_E = \int \vec{E}\cdot d\vec{S}$

Displacement Current : $I_D = \varepsilon_0 \frac{d\Phi_E}{dt}$

2. BASIC RELATIONS FOR ELECTROMAGNETIC WAVES

- Speed of EM wave in vacuum (c):

$$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3.00\times10^8\ \text{m s}^{-1}$$

- Speed in a medium (v):

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

where, $n = \sqrt{\mu_r\varepsilon_r}$ (Refractive index)

- Wave equation:

$$c = \nu\lambda \quad \text{or} \quad v = \nu\lambda$$

- Wavelength: $\lambda = \frac{v}{\nu}$
- Frequency: $\nu = \frac{v}{\lambda}$
- Time period: $T = \frac{1}{\nu}$
- Wave number: $k = \frac{2\pi}{\lambda}$
- Angular frequency: $\omega = 2\pi\nu = \frac{2\pi}{T}$

3. NATURE OF EM WAVES

- Electromagnetic waves are transverse.
- $\vec{E} \perp \vec{B} \perp$ direction of propagation ($\vec{k}$)
- Electric and magnetic fields are in phase.
- Amplitudes are related by:

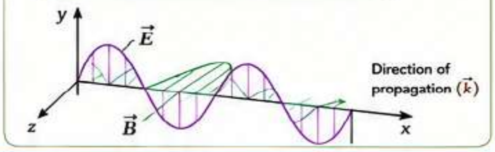
$$\frac{E_0}{B_0} = c \quad \text{or} \quad E_0 = cB_0$$

- Average energy density:

$$u = \frac{1}{2}\varepsilon_0 E_0^2 + \frac{1}{2\mu_0}B_0^2 \quad (= \varepsilon_0 E_0^2$$

- Average Poynting vector (intensity):

$$\langle\vec{S}\rangle = \frac{1}{\mu_0}E_0B_0 = \frac{E_0^2}{\mu_0 c} = \varepsilon_0 c E_0^2 \quad (\text{W/m}^2)$$



4. ENERGY, MOMENTUM & PRESSURE

- Energy density (u): $u = \varepsilon_0 E_0^2 = \frac{B_0^2}{\mu_0}$
- Energy flux / Intensity (I):

$$I = c\,u = \varepsilon_0 c E_0^2 = \frac{cB_0^2}{\mu_0} \quad (\text{W/m}^2)$$

- Momentum density (g):

$$g = \frac{I}{c^2} = \frac{u}{c} \quad (\text{kg m}^{-2}\ \text{s}^{-1})$$

- Radiation pressure (P) on a perfectly absorbing surface: $P = \frac{I}{c}$
- Radiation pressure on a perfectly reflecting surface: $P = \frac{2I}{c}$

5. PLANE ELECTROMAGNETIC WAVE (EQNS)

A wave travelling in +z direction:

$$\vec{E}(z,t) = E_0\sin(\omega t - kz)\,\hat{i}$$

$$\vec{B}(z,t) = B_0\sin(\omega t - kz)\,\hat{j}$$

where, $k = \frac{2\pi}{\lambda}$, $\omega = 2\pi\nu$, $E_0 = cB_0$

Electric field wave equation:

$$\frac{\partial^2\vec{E}}{\partial z^2} = \mu_0\varepsilon_0\frac{\partial^2\vec{E}}{\partial t^2}$$

Magnetic field wave equation:

$$\frac{\partial^2\vec{B}}{\partial z^2} = \mu_0\varepsilon_0\frac{\partial^2\vec{B}}{\partial t^2}$$

6. ELECTROMAGNETIC SPECTRUM

Radiation	Frequency (Hz)	Wavelength (m)
Radio waves	10^4 to 10^8	$> 10^{-1}$
Microwaves	10^8 to 10^{12}	10^{-1} to 10^{-3}
Infrared	10^{12} to 4×10^{14}	10^{-3} to 7×10^{-7}
Visible	4×10^{14} to 7.5×10^{14}	7×10^{-7} to 4×10^{-7}
Ultraviolet	7.5×10^{14} to 10^{16}	4×10^{-7} to 10^{-8}
X-rays	10^{16} to 10^{19}	10^{-8} to 10^{-11}
Gamma rays	10^{19} to 10^{24}	$< 10^{-11}$

Order of Increasing Frequency (ν) ⟶

Radio	Microwave	Infrared	Visible	UV	X-ray	Gamma

Order of Increasing Energy ($E = h\nu$) ⟶

7. QUANTUM NATURE (PHOTON)

- Energy of photon: $E = h\nu = \frac{hc}{\lambda}$
- Momentum of photon: $p = \frac{h}{\lambda} = \frac{E}{c}$
- Planck's constant: $h = 6.626\times10^{-34}$ J s
- 1 eV = 1.602×10^{-19} J

8. RELATIONS IN A MEDIUM

- Speed in medium: $v = \frac{c}{n}$
- Wavelength in medium: $\lambda_m = \frac{\lambda_0}{n}$
- Frequency remains same: $\nu_m = \nu_0$
- Wave impedance of medium: $Z = \sqrt{\frac{\mu}{\varepsilon}} = \frac{Z_0}{n}$

where, $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \mu_0 c = 377\ \Omega$

9. IMPORTANT CONSTANTS

- Speed of light in vacuum (c) = 3.00×10^8 m s^{-1}
- Permittivity of free space (ε_0) = 8.854×10^{-12} F m^{-1}
- Permeability of free space (μ_0) = $4\pi\times10^{-7}$ H m^{-1}
- Impedance of free space (Z_0) = 377 Ω
- Planck's constant (h) = 6.626×10^{-34} J s
- Elementary charge (e) = 1.602×10^{-19} C
- 1 eV = 1.602×10^{-19} J

10. POINTS TO REMEMBER

- ✓ EM waves do not require a material medium to propagate.
- ✓ They carry energy and momentum.
- ✓ They are transverse and can be polarized.
- ✓ In vacuum, all EM waves travel with the same speed (c).
- ✓ $\vec{E}$ and $\vec{B}$ are always perpendicular to each other and to direction of propagation.
- ✓ Electric field component is responsible for all optical phenomena.
- ✓ Produced by accelerating charges.

11. DIMENSIONS (For Quick Check)

$[\varepsilon_0] = [F\ m^{-1}] = [M^{-1}L^{-3}T^4A^2]$

$[\mu_0] = [H\ m^{-1}] = [MLT^{-2}A^{-2}]$

$[E_0] = [B_0] = [MLT^{-3}A^{-1}]$

$[I] = [W\,m^{-2}] = [MLT^{-3}]$

$[u] = [J\ m^{-3}] = [ML^{-1}T^{-2}]$

$[h] = [J\ s] = [ML^2T^{-1}]$

12. HANDY DERIVED RESULTS

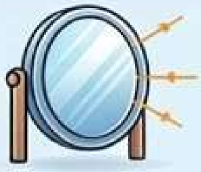
- $c^2 = \frac{1}{\mu_0\varepsilon_0}$
- $E_0 = cB_0$
- $I = \frac{E_0B_0}{\mu_0} = c\,u$
- $p = \frac{I}{c^2}$ (momentum density)
- $P_{\text{abs}} = \frac{I}{c}$, $P_{\text{ref}} = \frac{2I}{c}$

EM WAVES – KEY IDEA

A time-varying electric field produces a magnetic field, and a time-varying magnetic field produces an electric field. This self-sustaining process creates electromagnetic waves that travel through space.

CHAPTER 09

REFLECTION OF LIGHT



Mirror Formula

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

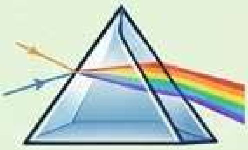
Focal Length

$$f = \frac{R}{2}$$

Linear Magnification

$$m = \frac{h'}{h} = -\frac{v}{u}$$

REFRACTION OF LIGHT

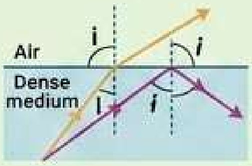


Snell's Law

$$\frac{\sin i}{\sin r} = n_{21} = \frac{n_2}{n_1}$$

Refractive Index

$$n = \frac{c}{v}$$



Apparent Depth

$$\text{Apparent Depth} = \frac{\text{Real Depth}}{n}$$

Critical Angle

$$\sin C = \frac{1}{n}$$

TIR Condition: $i > C$

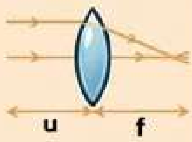
SPHERICAL SURFACES & LENSES

Refraction at Spherical Surface

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$

Lens Maker's Formula

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$



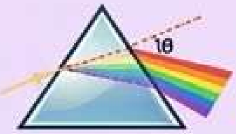
Thin Lens Formula

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Magnification

$$m = \frac{v}{u}$$

PRISMS



Angle of Deviation

$$\delta = i + e - A$$

Deviation for Small-Angle Prism

$$\delta = (n - 1)A$$

Prism Formula

$$n = \frac{\sin((A + D_m)/2)}{\sin(A/2)}$$

LENS COMBINATIONS & POWER

Power

$P = \frac{1}{f}$ (in meters)

Combination Power

$$P_{eq} = P_1 + P_2 + \ldots$$

Equivalent Focal Length

$$\frac{1}{F_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots$$

OPTICAL INSTRUMENTS

Simple Microscope

$M = 1 + \frac{D}{f}$ (near point)

$M = \frac{D}{f}$ (infinity)

Compound Microscope

$$M \approx \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$$

Astronomical Telescope

$M = \frac{f_o}{f_o}$ (Normal Adjustment)

Length $L = f_0 + f_e$

MULTIPLE CHOICE QUESTIONS

1. A beam of light is incident at 60° to a plane surface. The reflected and refracted rays are perpendicular to each other. What is the refractive index of the surface?

(a) 1√3 (b) √3 (c) 1/3 (d) 3

2. A concave mirror of focal length f produces a real and virtual image of an object of magnification m (m> 1) when placed at two different positions. The distance between the positions of the object is :

(a) $(m-1)f$ (b) $(1-m)f$ (c) $\frac{2f}{m}$ (d) zero

3. Two convex lenses are of focal length 20cm and 30cm are kept parallel to each other such that a parallel beam of incident light emerges out of the system parallel to the principal axis. The separation between the lenses must be

(a) 10cm (b) 20cm (c) 30cm (d) 50cm

4 A concave lens of focal length 20cm is cut into two equal parts perpendicular to the principal axis the power of each part will be

(a) -2.5D (b) -5D (c) -10D (d) -20D

5 Which of the following is not true about refraction of light through a glass slab

(a) The angle of incidence and emergence are equal

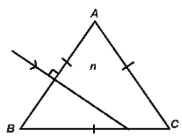
(b) Some part of incident light is reflected

(c) Light slows down inside the glass slab

(d) The lateral deviation is independent of angle of incidence.

6 The least value of refractive index 'n' for material of prism so that the light grazes along BC will be

(a) 1/√3 (b) 2/√3 (c) √(3/2) (d) √3



7 The refractive index of the material of a prism is √2 and its refracting angle is 30°. One of the refracting surfaces of the prism is made a mirror. A beam of monochromatic light entering the prism from the other face retraces its path, after reflection from mirror surface. The angle of incidence on prism is:

(a) 0° (b) 30° (c) 45° (d) 60°

8 An astronomical refractive telescope has an objective of focal length 20 m and an eyepiece of focal length 2 cm. Then in normal adjustment:

(a) the angular magnification is 1000

(b) the length of the telescope tube is 20.02 m

(c) the image formed is of inverted nature. (d) all of these

9 A particle moves towards a concave mirror of focal length 30 cm along its axis and with a constant speed of 4 cm/ sec. What is the speed of its image when the particle is at 90 cm from the mirror?

(a) 16 cm/ sec. (b) 1 cm/sec. (c) 8 cm/sec. (d) 4 cm/sec.

10 Two identical thin convex lens each of power P are in contact. A third lens is kept in contact with them so that the power of whole system is P only. The third lens must be a

(a) Convex lens of power P/3 (b) Concave lens of power P/2

(c) Convex lens of power P/2 (d) Concave lens of power P

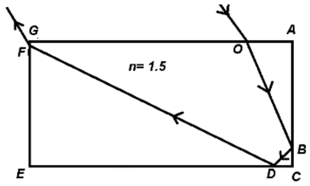
11 A square of side 1cm is viewed through a convex lens of focal length 'f' such that their distance is half the focal length. The area of the square in the image will be

(a) 4 cm^2 (b) 2.25 cm^2 (c) 1.44 cm^2 (d) 1cm^2

12 A lens made of material of Refractive index 'n' changes its nature in a medium of refractive index 'n_1' but disappears in a medium of refractive index 'n_2'. The ratio n_1: n_2 is 'x'. Choose the correct option

(a) $x>1$ (b) $x=1$ (c) $0<x<1$ (d) $x<0$

13 A beam of light moves into a glass slab of refractive index 1.5 as shown in figure. If OA= 3cm, AB= 4cm, BC = CD = 1cm, DE = 12cm and FG is negligible, the time spent by light ray in the glass slab will be



(a) 0.65 ns (b) 0.78 ns (c) 0.97 ns (d) 1.06ns

14 If an object is kept at the focus of a concave lens of focal length 50cm the image will be

(a) Virtual at infinity (b) real at infinity

(b) Virtual at 25cm (d) real at 25cm

15 When light suffers total internal reflection its phase changes by

(a) Zero (b) 90^0 (c) 180^0 (d) x and x varies with wavelength

16 If we dip a prism in water the minimum angle of deviation due to it will

(a) Decrease (b) not change (c) increase (d) depend on i (angle of incidence)

17 You are given four sources of light each one providing a light of a single colour – red, blue, green and yellow. Suppose the angle of refraction for a beam of yellow light corresponding to a particular angle of incidence at the interface of two media is 90°. Which of the following statements is correct if the source of yellow light is replaced with that of other lights without changing the angle of incidence?

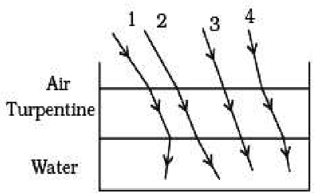
(a) The beam of red light would undergo total internal reflection.

(b) The beam of red light would bend towards normal while it gets refracted through the second medium.

(c) The beam of blue light would undergo total internal reflection.

(d) The beam of green light would bend away from the normal as it gets refracted through the second medium

18 The optical density of turpentine is higher than that of water while its mass density is lower. Fig shows a layer of turpentine floating over water in a container. For which one of the four rays incident on turpentine in Fig the path shown is correct?



(a) 1 (b) 2 (c) 3 (d) 4

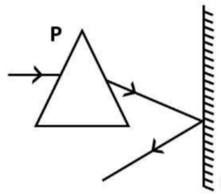
19 If I is the image of a point object O formed by spherical mirror, then which of the following statement is incorrect:

a) If O and I are on same side of the principal axis, then they have to be on opposite sides of the mirror.
b) If O and I are on opposite sides of the principal axis, then they have to be on same side of the mirror.
c) If O and I are on opposite side of the principal axis, then they can be on opposite side of

the mirror as well at same side of the mirror.

d) If O is on principal axis then I may not lie on principal axis.

20 A prism having an apex angle of 4^0 and refractive index of 1.50 is located in front of a vertical plane mirror as shown. A horizontal ray of light is incident on the prism. The total angle through which the ray is deviated is



a) 4^0 clockwise b) 178^0 clockwise

c) 2^0 clockwise d) 8^0 clockwise

21 A plano concave lens of focal length 10 cm is placed on a paper on which a coin is drawn. How far above its actual position does the coin appear to be?

a) 10 cm b) 15 cm c) 50 cm d) none of these

Answers

1. (b), 2. (c), 3. (d), 4. (a), 5. (d), 6. (b), 7. (c), 8. (d), 9. (b), 10. (d), 11. (a), 12. (a), 13. (c), 14.(c), 15.(d), 16. (a), 17.(c), 18.(b), 19(d), 20(b), 21.(d)

EXERCISE QUESTIONS

10 A source of red color is placed in front of a convex lens its diminished real image of almost same size is formed now red color source is replaced by blue color source choose the correct option:

a) Its real image is not formed. b) Slightly enlarged real images is formed

c) Highly diminished real image is formed. d) Nothing can be said.

11 A concave mirror of focal length 'f_1' is placed at a distance of 'd' from a convex lens of focal Length 'f_2'. A beam of light coming from infinity and falling on this convex lens-concave mirror combination returns to infinity. The distance 'd' must equal :

a) $f_1 + f_2$ b) f_1 c) f_2 d) a or b

12 A convex mirror forms virtual image of a point object at d distance from Its pole. It is cut horizontally into two equal parts and one part is removed. New position of image is found

a)same at d b) slightly away from d c)Slightly closer d) No images is formed to pole

13 A lens is made of flint glass (refractive index = 1.5). When the lens is immersed in a liquid of refractive index 1·25, the focal length

a) Increases by a factor of 1·5

b) Decreases to a factor of 2·5

c) Increases by a factor of 1·2

d)Decreases to a factor of

14 A bulb is located on a wall. Its image is to be obtained on a parallel wall with the help of convex lens. If the distance between parallel walls is 'd' then required focal length of lens placed in between the walls is

a) Only d/4 b) Only d/2

c) More than d/4 but less than d/2 d)Less than or equal to d/4

Answers : 11 c) 12 c) 13 d) 14 a) 15 d)

ASSERTION-REASON TYPE QUESTIONS

For these Questions two statements are given one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below

A. If both Assertion and Reason are true and Reason is correct explanation of Assertion.
B. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
C. If Assertion is true but Reason is false.
D. If both Assertion and Reason are false.

1. **Assertion:** The images formed by total internal reflections are much brighter than those

formed by mirrors or lenses.

Reason: There is no loss of intensity in total internal reflection.

2 **Assertion:** When light enters inside perfectly spherical water droplet it should not show total internal reflection inside the water droplet.

Reason: When light enters non perpendicular to spherical water droplet it is internally reflected.

3 **Assertion:** Law of reflection is applicable for all type of mirrors.

Reason: Rays which are parallel to principal axis are known as paraxial rays

4. **Assertion:** If objective and eye lenses of a microscope are interchanged then it can work as telescope.

Reason: The objective of telescope has small focal length.

5. **Assertion:** When water is filled inside a transparent drinking glass it may act like a lens.

Reason: Whenever the surface on which light is incident and the surface from which light is emerging out are parallel, we get dispersion of light.

6 **Assertion:** The formation of rainbow involves total internal reflection.

Reason: light source shall be in front of the observer to see s rainbow

7 **Assertion:** A prism bends incident light towards its apex angle

Reason: angle of minimum deviation due to prism is more for greater angle of incidence

8 **Assertion:** A glass slab does not show any dispersion

Reason: The speed of light in a depends on wavelength of light

9 **Assertion:** Refraction at a spherical surface can lead to an image that can be real or virtual.

Reason : A real image is formed when rays actually meet at a point physically.

10 **Assertion:** An object must be placed just outside the focus of objective ina compound microscope.

Reason: The objective shall form a real image that would be the object for eyepiece

<u>Answers</u>

1. a 2. d 3. b 4.d 5.c 6.c 7.d 8.b 9.b 10. a

EXERCISE QUESTION

1. **Assertion:** A concave mirror has f = 40 cm in air. It has f = 10 cm in water.

Reason: Focal length of a mirror is dependent of medium.

2. **Assertion:** A double convex lens (n= 1.5) has focal length 10 cm. When the lens is immersed in water (n = 4/3) its focal length becomes 40 cm.

Reason: Because the focal length of lens in liquid $\frac{1}{f} = \frac{n_l - n_m}{n_m}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

1. **Assertion:** Power of a lens depends on nature of material of lens, medium in which it is placed and magnitude radii of curvature of its surface.

Reason: Image formed by a convex mirror is always smaller in size.

4. **Assertion:** A ray of light travelling in air is incident on a glass slab. The ray gets partly reflected and partly refracted. The phase difference between the reflected and the refracted waves is non zero

Reason: Images formed by plane mirrors can not be photographed.

5. **Assertion:** The frequencies of incident, reflected and refracted beam of monochromatic light incident from one medium to another are same

Reason: The incident, reflected and refracted rays are coplanar.

ANSWERS

1. D 2. A 3.B 4.C 5.B

SHORT ANSWER TYPE QUESTIONS

1When we move away froma tower is height appear to decrease. Give reason?

2. Does the apparent depth of a tank of water change if viewed obliquely at different angles? If so, does the apparent depth increase or decrease?
3. Draw the ray for refraction of light through an air bubble inside water. Show that it is a divergent system.
4. Focal length is 50% of radius of curvature. Is it true about a lens?
5. For a thin glass prism the angle of minimum deviation is 20% of the prism angle. Find the refractive index for the material of the prism.

6.When the object is at distances u_1& u_2 the images formed by the same lens are real and virtual respectively and of the same size. Calculate focal length of the lens?

7. what is the principle for endoscopic examination of patients in hospital?
8. Will the focal length of a lens for red light be more, same or less than that for blue light? Justify?
9. The focal length of an equiconvex lens is equal to the radius of curvature of either face. What is the value of refractive index of the material of the lens?
10. Write advantages of reflecting type telescope over refracting type telescope.

Answers

1. This occurs because the visual angle subtended by the tower at the eye decreases as distance increases, making it appear smaller.

2. Yes; it decreases as the viewing angle becomes more oblique due to greater refraction at the water-air interface.

3. An air bubble acts as a diverging lens because light travels from a denser medium (water) to a rarer medium (air), bending away from the normal upon entry and exit.

4. No; the relation $f = R/2$ applies only to spherical mirrors. For lenses, focal length depends on the refractive index and surface radii via the Lens Maker's Formula.

5. The refractive index is $n = 1.20$, calculated using the thin prism formula $\delta = (n - 1) A$ with $\delta = 0.20A$.

6. The focal length is $f = -(u_1 + u_2) / 2$, derived by equating the magnifications for real and virtual images of the same size.

7. The operating principle is Total Internal Reflection (TIR), utilizing optical fibers to transit light through curved paths inside the body.

8. Focal length for red light is more because it has a longer wavelength and lower refractive index than blue light, and f is inversely proportional to $(n - 1)$.

9. The refractive index is $n = 1.5$, determined by the Lens Maker's Formula for an equiconvex lens where $f = R$.

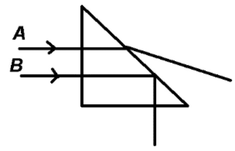
10. Key advantages include the absence of chromatic aberration, easier structural support for large mirrors, correction of spherical aberration with parabolic shapes, and lower manufacturing costs.

Practice questions

Q1 How come sunglasses are claimed as powerless though they are made of curved spherical surfaces of transparent nature (finite refractive index)?

Q2 if ${}_1^2n = 1.4\,,{}_2^3n = 1.5\; and\; {}_4^3n = 1.6$ find refractive index of 4th medium w.r.t. 1st medium. Out of these four media in which the light will travel fastest?

(Note : here ${}_1^2n\; means\; refractive\; index\; of\; 2nd\; medium\; w.r.t.\, 1st\; medium$)



Q3 Two light beams A and B are incident on a triangular prism as shown. Based on the ray diagram shown explain which of the two (A or B) has a greater wavelength.

4. Show that for a material with refractive index $\mu \geq \sqrt{2}$, light incident at any angle shall be guided along a length perpendicular to the incident face.
5. A ray of light is incident on a parallel slab of thickness *t* and refractive index *n*. If the angle of incidence θ is small, Express the displacement in the incident and emergent ray?

Answers

Ans 1 . Sunglasses are considered 'powerless' because both the front and back surfaces of the lens have the same radius of curvature ($R_1 = R_2$). According to the Lens Maker's Formula: $P = (n - 1)\,(1/R_1 - 1/R_2)$.Since the surfaces are parallel and curved in the same direction, $R_1 = R_2$. This makes the term $(1/R_1 - 1/R_2)$ equal to zero, resulting in a net optical power (P) of zero.

Ans2: Given:${}_1n_2 = 1.4$, ${}_2n_3 = 1.5$, ${}_4n_3 = 1.6$, To find the refractive index of the 4th medium w.r.t. the 1st medium We know that ${}_1n_4 = {}_1n_2 \times {}_2n_3 \times {}_3n_4$ Since ${}_3n_4 = 1 / {}_4n_3 = 1 / 1.6$
${}_1n_4 = 1.4 \times 1.5 \times (1 / 1.6) = 2.1 / 1.6 = 1.3125$.Light travels fastest in the medium with the lowest absolute refractive index. So medium 4

Ans3: In the ray diagram, Beam A undergoes refraction at the hypotenuse, while Beam B undergoes Total Internal Reflection (TIR).TIR occurs when the angle of incidence is greater than the critical angle (θc). Since both beams have the same angle of incidence, Beam B must have a smaller critical angle than Beam A.Since $\sin\theta_c = 1/n$, a smaller critical angle implies a higher refractive index (n). Thus, $n_B > n_A$.According to Cauchy's formula, refractive index is inversely proportional to wavelength ($n \propto 1/\lambda^2$).Since $n_B > n_A$, then $\lambda_A > \lambda_B$. Therefore, Beam A has the greater wavelength.

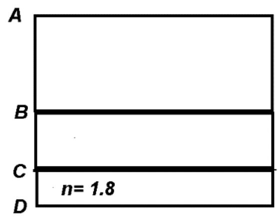
Ans 4:Consider a ray incident at the maximum possible angle (90°) on the end face of a rod.
By Snell's Law at entrance: $1 \cdot \sin(90°) = \mu \cdot \sin(r)$ => $\sin(r) = 1/\mu$
For the light to be guided (undergo TIR at the side wall), the angle of incidence at the wall (90° - r) must be ≥ Critical angle (θc).$\sin(90° - r) \geq \sin(\theta_c)$ => $\cos(r) \geq 1/\mu$ => Squaring both sides: $\cos^2(r) \geq 1/\mu^2$, so $1 - \sin^2(r) \geq 1/\mu^2$ => $\mu \geq \sqrt{2}$

Ans 5:The lateral displacement (d) of a ray passing through a slab is given by: $d = t \cdot \sin(\theta - r) / \cos(r)$. For small angles, $\sin(\theta - r) \approx \theta - r$ and $\cos(r) \approx 1$.
$d \approx t(\theta - r)$. From Snell's law for small angles: $\theta = n \cdot r$ => $r = \theta/n$. Substituting r: $d \approx t(\theta - \theta/n) = t \cdot \theta\,(1 - 1/n)$

Short answer Type II

Q1 Draw the u-v graph (cgs units) for a convex lens. if on this graph there is point having coordinates(50,50). What's the significance of this information? How can we locate that point on a given u-v graph?

Q2 Three slabs of height in the ratio 1:2:3 (lowest being 2cm) and Refractive indices in the ratio 6:5:4 (highest being 1.8) are placed One over the other respectively. Find the apparent shift in the Position of a spot on a paper kept below the slab at the bottom. (See figure, CD= 2cm)



Q3 Light From infinity falls on a globe of radius 40cm having refractive index 1.5. Find the point at which light will be focused.

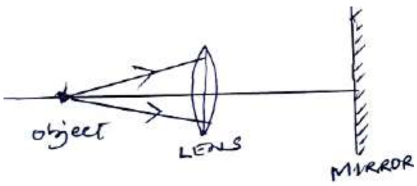
Q 4 A convex lens of focal length 5cm is used as a simple microscope. Find the minimum and maximum magnifying power that can be obtained from it. Discuss the case when the object is kept 3.5cm away from the lens.

Q5 A convergent light beam is focused at point P from left. A concave lens is placed at a fixed point 'Q' between light beam and 'P'. If a convex lens is kept in the path of emergent beam the distance between the final image and convex lens doesn't change irrespective of position of convex lens. Draw the ray diagram to explain the situation. What will be the focal length of concave lens?

Q6 How come sunglasses are claimed as powerless though they are made of curved spherical surfaces of transparent nature (finite refractive index)?

Q7 if ${}_{1}^{2}n = 1.4\,, {}_{2}^{3}n = 1.5\ and\ {}_{4}^{3}n = 1.6$ find refractive index of 4th medium w.r.t. 1st medium. Out of these four media in which the light will travel fastest? (Note : here ${}_{1}^{2}n\ means\ refractive\ index\ of\ 2nd\ medium\ w.r.t.\ 1st\ medium$)

Q8 A convex lens of focal length f is placed x metre apart from a plane mirror. As shown in figure an object is placed at x distance from the lens away from the mirror get a relation between x and f for following conditions



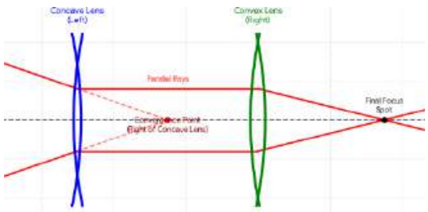
a) if final image is formed at x. (at the position of object itself)
b) if no images formed.
c) if virtual images are formed.

Q9. A convex lens and a concave lens have power in ratio 3:2 when placed in contact effective focal length of combination is found 30 cm. We get real image of an object which is placed at 15 cm in front of convex lens. This image is shifted by 20 cm when same concave lens is introduced between convex lens and image. Calculate the position of the lens introduced. Hence draw necessary ray diagram.

Q10.You have a concave mirror placed horizontally on a Floor. An all pin when placed at $d_1$meter above it, its real image coincide with itself'. This mirror is filled with a liquid of refractive index n_1 new image is found at D_2 if this liquid is replaced by another liquid of refractive index n_2 new image is found at D_3. If $n_1 > n_2$ give a relation between D_2 and D_3 with proper justification using a diagram.

Answers

Ans1. The u-v graph for a convex lens is a rectangular hyperbola in the second and fourth quadrants (if using Cartesian sign convention). In cgs units, the point (50, 50) signifies that when the object distance $u = -50$ cm, the image distance $v = 50$ cm.
Significance: At this point, $|u| = |v| = 2f$. Thus, $2f = 50$ cm, which gives the focal length $f = 25$ cm. The image is real, inverted, and of the same size as the object.
Locating the point: Draw a line $v = u$ (or a line at 45° to the axes passing through the origin). The intersection of this line with the hyperbola gives the point where $u = v = 2f$.
Ans2. Height ratio 1:2:3. Lowest (h_1) = 2 cm, so $h_2 = 4$ cm and $h_3 = 6$ cm.
Refractive index ratio 6:5:4. Highest (n_1) = 1.8, so $n_2 = (5/6)*1.8 = 1.5$ and $n_3 = (4/6)*1.8 = 1.2$. Total Apparent Shift (Δs) = $\Sigma h_i .(1 - 1/n_i)$. $\Delta s = 2(1 - 1/1.8) + 4(1 - 1/1.5) + 6(1 - 1/1.2)$
$\Delta s = 2(0.8/1.8) + 4(0.5/1.5) + 6(0.2/1.2) = 2(4/9) + 4(1/3) + 6(1/6)$. $\Delta s = 8/9 + 4/3 + 1 = (8 + 12 + 9)/9 = 29/9 \approx 3.22$ cm.
Ans3. First refraction: $n_1=1$, $n_2=1.5$, $u=\infty$, $R=40$cm. Using $(n_2/v) - (n_1/u) = (n_2-n_1)/R$
$(1.5/v_1) - 0 = (1.5-1)/40 \Rightarrow 1.5/v_1 = 0.5/40 \Rightarrow v_1 = 120$ cm from the first surface. Second refraction: $u_2 = v_1$ - Diameter = 120 - 80 = 40 cm (inside globe, directed towards second surface). $n_1=1.5$, $n_2=1$, $R=-40$cm. $(1/v_2) - (1.5/40) = (1-1.5)/(-40) \Rightarrow 1/v_2 = 0.5/40 + 1.5/40 = 2/40 = 1/20$. $v_2 = 20$ cm from the second surface (60 cm from the center).
Ans 4 Minimum Magnifying Power (at infinity): $M_{min} = D/f = 25/5 = 5$.
Maximum Magnifying Power (at D): $M_{max} = 1 + D/f = 1 + 25/5 = 6$.
Case $u = 3.5$ cm: $m = D/u = 25/3.5 = 7.13$
This is more tham maximum m but not useful as in this case $v<D = 25$cm so blurred image will be formed
Ans 5 If the position of the final image after a convex lens doesn't change regardless of the lens's position, the emergent beam from the concave lens must be parallel (at infinity). This happens if the convergent beam (meeting at P) is incident on the concave lens such that point P acts as its virtual focus (F). Thus, Focal length of concave lens = Distance QP.



Ans 6 Sunglasses have curved surfaces where the radii of curvature of the front and back surfaces are equal ($R_1 = R_2$).
Using Lens Maker's Formula: $P = (n - 1)(1/R_1 - 1/R_2)$. Since $R_1 = R_2$, $P = 0$. Thus, they are powerless.
Ans 7 1n4 = n_43 * n_32 * n_21. Given $n_{12} = 1.4$, $n_{23} = 1.5$, $n_{43} = 1.6$. $n_{21} = 1/n_{12} = 1/1.4$; $n_{32} = 1/n_{23} = 1/1.5$. $n_{41} = 1.6 * (1/1.5) * (1/1.4) = 1.6 / 2.1 \approx 0.76$.
Velocity $v = c/n$. Light travels fastest in the medium with the lowest absolute refractive index. Based on the ratios, medium 4 is the rarest w.r.t others, so light travels fastest in medium 4.
Ans 8 a) Image at x: The rays must retraces their path. This occurs if light falls normally on the mirror. The image from the lens must be at infinity, so $x = f$.
b) No image: If the virtual image by the lens coincides with the plane mirror's surface or if light never converges. Practically, if the object is at f, rays are parallel and no real image forms.
c) Virtual image: If the object is placed within the focal length, i.e., $x < f$.
Ans 9 Power ratio 3:2, focal length ratio 2:3. Let $f1 = 2k$, $f2 = -3k$. $1/F = 1/f1 + 1/f2 \Rightarrow 1/30 = 1/2k - 1/3k = 1/6k \Rightarrow 6k = 30 \Rightarrow k = 5$. $f_{convex} = 10$ cm, $f_{concave} = -15$ cm.
Object at 15 cm from convex lens: $1/v - 1/(-15) = 1/10 \Rightarrow 1/v = 1/10 - 1/15 = 1/30 \Rightarrow v = 30$ cm. When concave lens is introduced, image shifts by 20 cm (moves to 30 + 20 = 50 cm).

For concave lens: Object is the virtual image at 30cm. Let lens be at distance 'd' from convex lens. u_concave = 30 - d. v_concave = 50 - d. 1/(50-d) - 1/(30-d) = 1/(-15). Solving for d gives the position.

Ans 10 For a mirror filled with liquid, the effective focal length decreases. Since n1 > n2, the liquid with n1 is denser. D2 and D3 are related to the apparent depth and the radius of curvature. D2 < D3 because the denser liquid (n1) causes a greater shift/refraction, bringing the coincidence point closer.

Practice Problems

1.In case of a concave mirror magnification is found to be - 0.5 for a certain position of object, when object is displaced by 5 cm from its position, magnification becomes 0.25.What will be the focal length of the mirror? Draw ray diagram to support your answer.

2.You have two mirrors one is concave other is convex focal of each mirror is 30 cm are placed D m apart such that their principal axis are common to each other. An object is placed between them at a point P which is 45 cm from concave mirror. It is found that final images formed on object itself Draw probable ray diagram and calculate value of D?

3.When we use an astronomical telescope, we say there must be a certain minimum and maximum length of the Telescopic tube, which means distance between objective lens and eye lens should not have a value beyond a minimum value and a maximum value. Justify? Draw appropriate diagram where necessary.

4.(a)A right angle isosceles prism bands a ray of light by 90° when the ray incidents normal to its one smaller face. What may be the maximum or maximum possible values of refractive index of the medium of the prism?

(b) If this prism is taken to analyze bending of different colors it is observed that when yellow colour incidents perpendicular to its one small phase emergent ray shows angle of deviation 45˚ Draw a diagram showing refraction of green, red, blue and yellow colors.

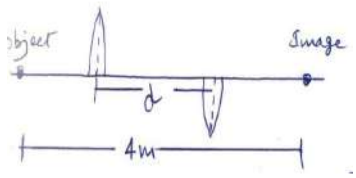
----5.A convex lens has focal length f in air. How its focal length would change in following cases:

a) surrounding medium is made slightly optical denser than it

b) surrounding medium is made slightly optical denser than air

c) surrounding medium is made slightly optical rarer than air

6. A convex lens with focal length f is cut into two equal parts horizontally as shown in figure. These two parts are shifted away along principal axis up to a separation of d m. An object and its image formed by this combination has separation of 4m. If magnification produced by one part is - 3.0. Calculate F & d, draw probable Ray diagram.



7.There is a concave mirror of radius of curvature 30 cm. A U-shaped wire of dimensions 15 cm, 15 cm and 15 cm is placed vertically in front of it along its axis such that its minimum distance from the pole of the mirror is 45 cm. Find total length of the image formed? Draw ray diagram to support your answer.

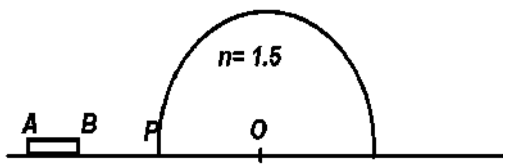
8.There is a plano convex lens whose radius of curvature is 2.5 cm and maximum thickness is 9 cm and object are placed at certain distance from the convex surface then its images formed at plane surface. If refractive index of the medium is 1.5, calculate magnification produced?

Q9 A student performs the experiment to find refractive index of material of a an equilateral glass prism. The readings obtained by him are given below. Now he claims that the minimum deviation shown by the prism is 37^0. Support (or criticize) his claim by suitable mathematical calculations.

Angle of incidence	35^0	40^0	45^0	50^0	55^0	60^0
Angle of deviation	41^0	39^0	37.5^0	37^0	38^0	39^0

Find the refractive index of the material of the prism based on his readings.

Q10 A bar AB of length 10cm is placed along the principal axis 20cm away from a transparent hemispherical glass sphere of radius 30cm (see figure) Find the length of image of the bar so formed.



Answers

Ans 1 Formula: m = f / (f - u), **Final Answer:** f = 5/6 cm (or 0.83 cm)

Ans 2 Formula: 1/v + 1/u = 1/f and D = v_1 - R_2 **Final Answer:** D = 30 cm

Ans 3 Formula: Lmax = fo + fe; Lmin = fo + (fe * D) / (fe + D)

Final Answer: Length ranges from fo + (fe*D)/(fe+D) to fo + fe

Ans 4 Formula: n = 1 / sin(c); deviation = (n-1)A

Final Answer: n_{min} = 1.414; Blue deviates most, Red deviates least

Ans 5 Formula: 1/f = (n_lens / n_medium - 1)(1/R_1 - 1/R2)

Final Answer: f increases as n_medium increases (if n_medium < n_lens)

Ans 6 Formula: 1/v - 1/u = 1/f; m = v/u **Final Answer:** f = 0.75 m

Ans 7 Formula: 1/v + 1/u = 1/f; m = -v/u **Final Answer:** Total length = 15 cm

Ans 8 Formula: n2/v - n1/u = (n2-n1)/R; m = (n1*v)/(n2*u).Magnification = -0.2

Ans 9 Formula: n = sin((A + Dm)/2) / sin(A/2). n = 1.50 (Claim for Dm = 37° is supported)

Ans 10 Formula: n2/v - n1/u = (n2-n1)/R **Final Answer:** Length of image = 45 cm

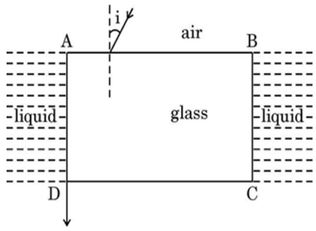
LONG ANSWER TYPE QUESTIONS

1. a)Draw a labeled ray diagram of a simple microscope in normal adjustment.
   b) A thin pencil of length (f/4) is placed coinciding with the principal axis of a mirror of focal length f. The image of the pencil is real and enlarged, just touches the pencil. Calculate the magnification produced by the mirror.
2. a)A convex lens is placed in contact with a plane mirror. A point object at a distance of 20 cm on the axis of this combination has its image coinciding with itself. What is the focal length of the lens?
   b) Calculate the angle of minimum deviation of an equilateral prism. The refractive index of the prism is $\sqrt{3}$.Calculate the angle of incidence for this case of minimum deviation also.
3. a) Draw a schematic arrangement of a reflecting telescope (Cassegrain) showing how rays coming from a distant object are received at the eyepiece.

b) A ray of light is incident on a refracting face AB of a prism ABC at an angle of 45^0.The ray emerges from face AC and the angle of deviation is 15^0.The angle of prism is 30^0.Show that the emergent ray is normal to the face AC from which it emerges out. Find the refractive index of the material of the prism.

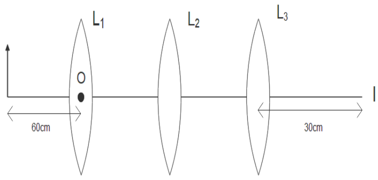
4. a) For the same value of angle of incidence, the angles of refraction in three media A, B and C are 15°, 25° and 35° respectively. In which medium would the velocity of light be minimum?

b) A rectangular glass slab ABCD ($n_1 = 1.5$) is surrounded by a transparent liquid ($n_2 = 1.25$)as shown in the figure. A ray of light is incident on face AB at an angle i such that it is refracted out grazing the face AD. Find the value of angle i.



5. a)An optical instrument uses eye-lens of power 20 D and the objective lens of power 50 D. Name the optical instrument and calculate its magnifying power if it forms the final image at infinity.

b)Three lenses L_1 L_2, L_3 each of focal length 30 cm are placed co-axially as shown in the figure. An object is held at 60 cm from the optic centre of Lens L_1. The final real image is formed at the focus of L_3. Calculate the separation between (i) (L_1 and L_3) and (ii) (L_2 and L_3).



6 Derive Lens maker's formula. Use it to show that a lens disappears in a medium of refractive index same as its own material

7 Draw a ray diagram to show refraction through a prism. Give prism formula. How it is modified for a thin prism? Draw graph to show variation of i with δ

8 Draw a ray diagram to show refraction at a convex spherical surface forming a virtual image. Write the refraction formula relating u, v and R if the light is going from (i) denser to rarer (ii) rarer to denser

9 A thin convex lens is made of material of refractive index 'n'. on the left side of lens medium has refractive index n_1 and to its right refractive index is n_3. If $n_1<n<n_3$ Draw a ray diagram to show image formation by it if object forms a real image. Hence establish relation among object distance(u), image distance (v) and radius of curvature (R)

10 For a glass prism, write the prism formula. In an astronomical telescope objective lens of focal length 150 cm and an eyepiece of focal length 6 cm are used.

(a) Calculate the magnifying power of the telescope in "normal adjustment."

(b) What is the length of the telescopic tube in this case?

A telescope has an objective lens of focal length 150 cm and an eyepiece of focal length 5 cm.

1. What is the magnifying power of the telescope?
2. If this telescope is used to view the moon, what is the diameter of the image of the moon formed by the objective lens?
   (Given: The diameter of the moon is 3.6 X 10^6m and radius of lunar orbit is 4 X 10^8m).

Answers

1. a) refer to the gist b) position of the other end $u = \frac{-7f}{4}$, $m = \frac{f}{f-u} = -4/3$

2. a) light rays from the object must fall on plane mirror normally. For this $f = u = 20\ cm$

b) use prism formula to find $\delta = 60^0$ $and\ then\ i + e = A + \delta$ $(i = 60^{\circ})$

3. a) refer to the gist b)$i + e = A + \delta$ =>$e = 0^0$=>$r_2 = 0^0$

4.a)Use snell's law and the relation, $n = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ th\ medium}$ (Ans: Medium A)

b) Use the relation $sin\ sin\ i_c = \frac{1}{n_{12}} = \frac{5}{6}$, $sin\ sin\ r\ = \frac{\sqrt{11}}{6}$ Use Snell's law to find $i = \frac{\sqrt{11}}{4}$

5. a) Compound microscope, $calculate\ f_0$.For image is at infinity, $m = \frac{D}{f_0}$

b) Use lens law to find the image distance at first place, $v_1 = 60\ cm$, then the light rays must be parallel between $L_2\ and\ L_3$.Use this concept to find the answer. (i) > 90 cm (ii) any value6 6 Formula: 1/f = (n2/n1 - 1)(1/R1 - 1/R2)

Condition: When n1 = n2, (n2/n1 - 1) = 0, so 1/f = 0 and f = infinity.

Final Result: The lens disappears as it behaves like a plane sheet of glass.

7 Prism Formula: n = sin[(A + Dm)/2] / sin(A/2)

Thin Prism: delta = (n - 1)A

Graph: The i-delta curve shows deviation decreasing to a minimum (Dm) and then increasing.

8 (i) Denser to Rarer: n1/v - n2/u = (n1 - n2)/R

(ii) Rarer to Denser: n2/v - n1/u = (n2 - n1)/R

9 Formula: n/v1 - n1/u = (n - n1)/R1

Second Surface: n3/v - n/v1 = (n3 - n)/R2

General Relation: n3/v - n1/u = (n - n1)/R1 + (n3 - n)/R2

10 1. Case 1 (fo=150, fe=6): m = fo/fe = 150/6 = 25; L = fo + fe = 156 cm

2. Case 2 (fo=150, fe=5): m = fo/fe = 150/5 = 30

3. Moon Image: Angular size α = (3.6 x 10^6) / (4 x 10^8) = 0.009 rad l

Answer: Diameter of image = α * fo = 0.009 * 150 = 1.35 cm

LONG ANSWER TYPE QUESTIONS-PRACTICE QUESTIONS

1. An object is placed at a distance of 40 cm on the principal axis of a concave mirror of radius of curvature 30 cm. By how much distances do the images may move if the object is shifted through 15 cm?
2. If you sit in a parked car, you glance in the rear-view mirror R= 2m and notice a jogger approaching. If the jogger is running at a speed of 5 ms^{-1}, how fast is the image of jogger moving when the jogger is 39 m away.
3. Four double convex lenses with following specification are available.

Lens	Focal length	Aperture	Lens	Focal length	Aperture
A	100 cm	10 cm	C	10 cm	2 cm
B	100cm	5 cm	D	5cm	2 cm

Which of the given four lenses should be selected as objective and eyepiece to construct an astronomical telescope and why? What will be the magnifying power and length of the tube of this telescope?

4. Draw ray diagram to show the working of a compound microscope. Deduce an expression for

magnifying power when the final image is formed at the near point. A compound microscope with an objective of 1.0cm focal length and an eye-piece of 2.0cm focal length has a tube of length of 20cm. Calculate the magnifying power of the microscope, if the final image is formed at the near point of the eye.

5. Draw a ray diagram to show the working of an astronomical telescope. Deduce an expression for magnifying power when the final image is formed at the near point. The magnifying power of an astronomical telescope in the normal adjustment is 20. If the length of the telescope is 105cm in this adjustment, find the focal lengths of the two lenses

ANSWERS

1. 13.5 cm 2. $\frac{1}{280}\ m/s$ 3. Eye lens-D, Objective lens- A, 20, 105 cm

4. m = 270 5. 5 cm ,100 cm

CASE STUDY/PASSAGE-BASED QUESTIONS

1. A prism is a portion of a transparent medium bounded by two plane faces inclined to each other at a suitable angle. A ray of light suffers two refractions on passing through a prism and hence deviates through a certain angle from its original path. The angle of deviation of a prism is, $\delta = (\mu - 1) A$,

Through which a ray deviates on passing through a thin prism of small refracting angle A. If μ is refractive index of the material of the prism, then prism formula is, $\mu = \frac{sinsin\left(\frac{A+\delta m}{2}\right)}{sinsin\left(\frac{A}{2}\right)}$

(i) For which color, angle of deviation is maximum?

a) Red b) Yellow c)Violet d)Blue

(ii) When white light moves in gravity free region

a) all colors have same speed b) different colors have different speeds

c) violet has more speed than red d) red has more speed than violet.

(iii) The deviation through a prism is maximum when angle of incidence is

a) 45^0 b)70^0 c)90^0 d)60^0

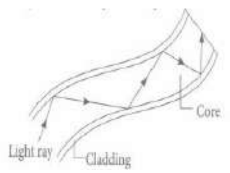
(iv) What is the deviation produced by a prism of angle 6°? (Refractive index of the material of the prism is 1.644).

a) 3.864° b)4.595° c)7.259° d)1.252°

(v) A ray of light falling at an angle of 50° is refracted through a prism and suffers minimum deviation. If the angle of prism is 60°, then the angle of minimum deviation is

a) 45° b)75° c)50° d)40°

2. An optical fibre is a thin tube of transparent material that allows light to pass through, without being refracted into the air or another external medium. It make use of total internal reflection. These fibres are fabricated in such a way that light reflected at one side of the inner surface strikes the other at an angle larger than critical angle. Even, if fibre is bent, light can easily travel along the length.



(i) Which of the following is based on the phenomenon of total internal reflection of light?

a)Sparkling of diamond b) Optical fibre communication

c)instrument used by doctors for endoscopy d)All of these

(ii) A ray of light will undergo rotal internal reflection inside the optical fibre, if it

a) goes from rarer medium to denser medium
b) is incident at an angle less than the critical angle
c) strikes the interface normally
d) is incident at an angle greater than the critical angle

(iii) If in core, angle of incidence is equal to critical angle, then angle of refraction will be
a) 0° b) 45° c) 90° d) 180°

(iv) In an optical fibre correct relation for refractive indices of core (n_1) and cladding (n_2) is
a) $n_1 = n_2$ b) $n_1 > n_2$ c) $n_1 < n_2$ d) $n_2 = 2$

(v) If the value of critical angle is 30° for total internal reflection from given optical fibre, then speed of light in that fibre is
a) 10^8 m s^{-1} b) 1.5×10^8 m s^{-1} c) 6×10^8 m s^{-1} d) 4.5×10^8 m s^{-1}

3. The lens maker's formula relates the focal length of a lens to the refractive index of the lens material and the radii of curvature of its two surfaces. This formula is called so because it is used by manufacturers to design lenses of required focal length from a glass of given refractive index. If the object is placed at infinity, the image will be formed at focus for both double convex lens and double concave lens

Therefore, lens maker's formula is $\frac{\mu_1}{f} = (\mu_2 - \mu_1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

(i) The radius of curvature of each face of biconcave lens with refractive index 1.5 is 30 cm. The focal length of the lens in air is
a) 12cm b) 10cm c) 20 cm d) 30 cm

(ii) The radii of curvature of the faces of a double convex lens are 10 cm and 15 cm. If focal length is 12 cm, then refractive index of glass is
a) 1.5 b) 1.78 c) 2.0 d) 2.52

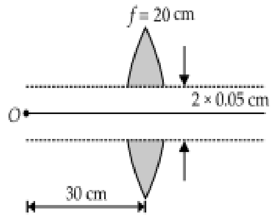
(iii) An under-water swimmer cannot see very clearly even in absolutely clear water because of
a) absorption of light in water b) scattering of light in water
c) reduction of speed of light in water d) change in the focal length of eye-lens

(iv) A thin lens of glass ($\mu = 1.5$) of focal length 10 cm is immersed in water ($\mu = 1.33$). The new focal length is
a) 20cm b) 40cm c) 48cm d) 12cm

(v) An object is immersed in a fluid. In order that the object becomes invisible, it should
a) behave as a perfect reflector
b) absorb all light falling on it
c) have refractive index one
d) have refractive index exactly matching with that of the surrounding fluid.

4. A convex or converging lens is thicker at the center than at the edges. It converges a parallel beam of light on refraction through it. It has a real focus. A convex lens is of three types :
(i) Double convex lens (ii) Plano-convex lens
(iii) Concavo-convex lens. The concave lens is thinner at the center than at the edges. It diverges a parallel beam of light on refraction through it. It has a virtual focus.

(i): A point object O is placed at a distance of 0.3 m from a convex lens (focal length 0.2 m) cut into two halves each of which is displaced by 0.05 m as shown in the figure.



What will be the location of the image?

a) 30 cm right of lens b)60 cm right of lens

c) 70 cm left of lens d)40 cm left of lens

(ii)Two thin lenses are in contact and the focal length of the combination is 80 cm. If the focal length of one lens is 20 cm, the focal length of the other would be.

a) –26.7 cm b)60 cm c)- 80 cm d)20 cm

(iii)A spherical air bubble is embedded in a piece of glass. For a ray of light passing through the bubble, it behaves like a

a) converging lens b)diverging lens c) plano-converging lens d)plano-diverging lens

(iv) Lens used in magnifying glass is

a) Concave lens b) Convex lens

c) Both (a) and (b) d) Neither concave lens nor convex lens

(v)The magnification of an image by a convex lens is positive only when the object is placed

a) at its focus F b)between F and 2F c) at 2F d)between F and optical center

Answers

1. i. c)$Deviation \propto \frac{1}{wavelength}$ ii. a)a gravity-free region is essentially a vacuum for the purpose of light propagation

iii. c)The deviation is maximum when the ray either just enters the prism (grazing incidence) or just exits the prism (grazing emergence).iv.a) use formula $\delta = (\mu - 1) A$

v) d) use formula $i + e = \delta + A$

2. i. d) ii. d) iii. c) iv. c) For TIR, light must travel from a denser medium to a rarer medium v. b) Using formula $sin\ sin\ i_c = \frac{1}{n_{21}}$ $and\ then\ use\ Snell's formula$

3. i. d) use lens formula to calculate focal length

ii. a) use lens formula to calculate refractive index

iii. d) The difference in refractive index between the water and the cornea is very small. This significantly reduces the refractive power of the cornea, making it difficult for the eye to converge light rays sufficiently to form a clear image on the retina.

iv. b) use lens maker's formula to calculate new focal length v. d)

4. i. b)use lens formula to calculate image distance ii. a)us the formula $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$

iii. b) A spherical air bubble within glass acts as a diverging lens because the light rays moving from glass to air bend away from the normal, and then when moving from air to glass, they bend towards the normal again, resulting in an overall divergence of the light rays.

iv. b) convex lens produce a magnified, virtual, and erect image of an object

v. d) Ray diagrams may be drawn to locate the position of object

CASE STUDY/PASSAGE-BASED PRACTICE QUESTIONS

1 On a bright sunny day a student burns a paper by using a convex lens (refractive index 1.5) by keeping it 40cm m away from the lens. Now he dips the lens in a glass filled with a liquid. He repeates the act by bringing it closer to the paper time and again but could not succeed. His teacher was observing him and suggested that he must move away from the paper rather than coming closer to it. He follows his teacher and performs the activity. for a particular distance 'd' he could burn the paper again.

(i)The focal length of the lens in air is

(a) 20cm (b) 40cm (c) 60cm (d) 80cm

(ii) if the value of 'd' is 2m the refractive index of the liquid is nearly

(a) 1.36 (b) 1.45 (c) 1.5 (d) 1.68

(iii) The behaviour of the lens in the liquid is like a

(a) prism (b) concave lens (c) glass slab (d) convex lens

(iv) If he uses a lens of bigger aperture but same material and same radii of curvature the value of 'd' for which he could burn the paper will be

(a) d >2m (b) d< 2m (c) d=2m (d) depending on size of aperture

2 A compound microscope is an optical instrument used for observing highly resolved and magnified images of tiny objects which are placed very close to it. Magnifying power of a compound microscope is defined as the ratio of the angle subtended at the eye by the final image to the angle subtended at the eye by the object, when both the final image and the objects are situated at the least distance of distinct vision from the eye. It can be given that: $m=m_e \times m_o$, where m_e is the magnification produced by the eye lens and m_o is the magnification produced by the objective lens. Consider a compound microscope that consists of an objective lens of focal length 2.0 cm and an eyepiece of focal length 6.25 cm separated by a distance of 15 cm.

(i) The object distance for eye-piece, so that final image is formed at the least distance of distinct vision, will be

(a) 3.45 cm (b) 5 cm (c)1.29 cm (d)2.59 cm

(ii) How far from the objective should an object be placed in order to obtain the condition described in part (i)?

(a) 4.5 cm (b)2.5 cm (c)1.5 cm (d) 3.0 cm

(iii) What is the magnifying power of the microscope in case of least distinct vision?

(a) 20 (b)30 (c)40 (d)50

(iv) The intermediate image formed by the objective of a compound microscope is

(a) real, inverted and magnified(b) real, erect and magnified

(c) virtual, erect and magnified(d) virtual, inverted and magnified

OR

The magnifying power of a compound microscope increases with

(a) the focal length of objective lens is increased and that of eye lens is decreased.

(b) the focal length of eye lens is increased and that of objective lens is decreased.

(c) focal length of both objects and eye-piece are increased.

(d) focal length of both objects and eye-piece are decreased.

3. As we know, when light ray travels from one medium to another changes its direction of path due to the change in optical density of the medium. When light ray travels from optically denser medium to the optically rarer medium then some of the light get reflected back in the same medium and remaining light get refracted in the second medium and such a phenomenon of light is called as internal reflector light. We know that when a ray of light travels from denser medium to rarer medium then it get bent away from the normal. If we increase the angle of incidence slowly then angle of refraction also get increased and at one stage, the angle of refraction is 90° for some angle of incidence. And further if we increase the angle of incidence then there will be no refraction of light, and the ray will be totally internally reflected. Such phenomenon of reflection of light is called as total internal reflection of light. And the angle of incidence in denser medium for which the angle of refraction in rarer medium is 90°, that angle of incidence is called as critical angle. So we define total internal reflection as if the angle of incidence exceeds the critical angle, then the total light get internally reflected. Mirage is the best real-life example of total internal reflection of light. The high brilliance of diamonds is only due to the total internal reflection of light through them which is get total internally reflected many times and causes brilliance of diamonds. Prisms are also made by using total internal reflection of light. We all know that, optics is the vast branch of physics which has vast application in our daily life such as optical fibre. Optical fibre are used for long distance transmission of audio and video signal also. And they are mainly constructed on the basis of total internal reflection of light to reduce the decrease in amplitude of the sending signal.

i) For critical angle the value of corresponding angle of refraction is____

a) 180° b) less than 90° c) greater than 90° d) 90°

ii) As the refractive index of the medium increases the corresponding value of critical angle for that medium ____

a) decreases b) increases

c) remains same d) independent of refractive index of the medium

iii) In case of total internal reflection, for angle of incidence greater than critical angle the refraction of light is not possible because____

a) Snell's law of refraction get satisfied b) Snell's law of refraction cannot be satisfied

c) laws of refraction cannot be satisfied d) can't say

iv) What is mean by optically denser and optically rarer medium?

OR

How would total internal reflection of light be possible in case of optical fibres?

Answers

1	i) b	ii) a	iii) d	iv) c	
2	i) b	ii) b	iii) b	iv) a	**OR** d
3	i) d) 90°	ii) a) decreases	iii) b) Snell's law of refraction cannot be satisfied		

CHAPTER- 10

WAVE OPTICS

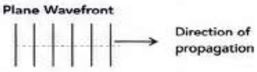
CBSE CLASS XII PHYSICS

1 WAVEFRONT & HUYGENS PRINCIPLE

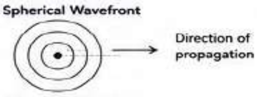
Wavefront: The locus of points in a medium which are in the same phase of vibration is called a wavefront.

Types of Wavefronts

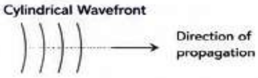
- Plane Wavefront



- Spherical Wavefront



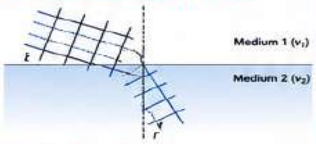
- Cylindrical Wavefront



Huygens Principle

Every point on a wavefront acts as a source of secondary spherical wavelets which spread out in the medium with the same speed as the wave.

Refraction Using Huygens Principle



Relation between i and r

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \mu_{21}$$

where $\mu_{21} = \frac{\text{Refractive index of medium 2}}{\text{Refractive index of medium 1}}$

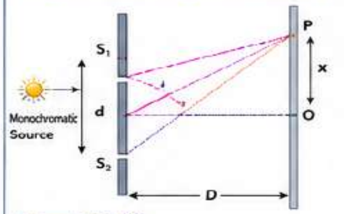
PYQ

Define wavefront. Draw different types of wavefronts. Derive Snell's law using Huygens principle.

2 INTERFERENCE & YOUNG'S DOUBLE SLIT EXPERIMENT

When two coherent light waves superpose, a stable interference pattern is produced.

Young's Double Slit Experiment (YDSE)



Fringe Width (β)

$$\beta = \frac{\lambda D}{d}$$

(Distance between two consecutive bright or dark fringes)

Position of n^{th} Bright Fringe

$$x_n = \frac{n\lambda D}{d} \quad (n = 0, \pm1, \pm2, \ldots)$$

Path Difference

- For Bright fringes (Maxima): $\Delta x = n\lambda$ $(n = 0, \pm1, \pm2, \ldots)$
- For Dark fringes (Minima): $\Delta x = (2n+1)\frac{\lambda}{2}$ $(n = 0, \pm1, \pm2, \ldots)$

Intensity of Resultant Fringe

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

Maximum Intensity (Bright Fringe)

$$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$$

Minimum Intensity (Dark Fringe)

$$I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$$

Fringe Pattern

PYQ

Derive the expression for fringe width in YDSE. What are the conditions for maxima and minima?

3 COHERENT SOURCES & SUSTAINED INTERFERENCE

Conditions for Two Sources to be Coherent

- Same frequency (monochromatic)
- Constant phase difference
- Same state of polarization
- Same amplitude (or nearly same)

Coherent Sources

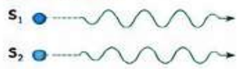
Sources which satisfy the above conditions are called coherent sources.

Sustained Interference

When two coherent sources of same frequency superpose, the resultant interference pattern is stable and constant in time. This is called sustained interference.

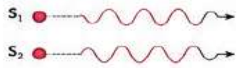
Coherent vs Incoherent Sources

Coherent Sources



- Same frequency
- Constant phase difference
- Resultant pattern is stable (sustained interference)

Incoherent Sources



- Same or different frequency
- Random phase difference
- Resultant pattern is unstable (no sustained interference)

PYQ

Focus the conditions for two sources to be coherent. What is sustained interference?

Coherent sources are: "Same Frequency, Constant Phase, Same Polarization."

4 SINGLE SLIT DIFFRACTION

When monochromatic light passes through a single narrow slit, the light spreads out and a diffraction pattern is obtained on the screen.

Theory

Minima (dark bands) occur when path difference from the edges of the slit is an integral multiple of wavelength.

Condition for Minima

$$a\sin\theta = n\lambda$$
$$(n = \pm1, \pm2, \pm3 \ldots$$

where, a = width of slit

Angular Width of Central Maximum

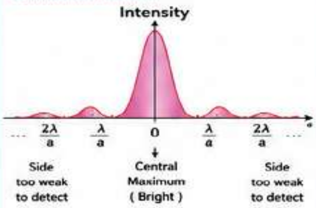
$$\theta_{angular} = \frac{2\lambda}{a} \text{ (radians)}$$

Linear Width of Central Maximum

$$\beta = \frac{2\lambda D}{a}$$

(where D = distance of screen)

Diffraction Pattern



PYQ

Derive the expression for angular width of the central maximum in single slit diffraction.

QUICK REVISION

- Wavefront: Locus of same phase points.
- Huygens Principle: Each point on the wavefront acts as a source of secondary wavelets.
- YDSE: Interference of two coherent sources gives alternate bright and dark fringes.
- Fringe width: $\beta = \frac{\lambda D}{d}$
- Bright: $\Delta x = n\lambda$ Dark: $\Delta x = (2n+1)\frac{\lambda}{2}$
- Coherent sources → Sustained interference.
- Diffraction: Bending/spreading of light around edges; pattern of maxima & minima.

FORMULA SUMMARY

- Final relation (Huygens/Snell) : $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \mu_{21}$
- Fringe width : $\beta = \frac{\lambda D}{d}$
- Position of n^{th} bright fringe : $x_n = \frac{n\lambda D}{d}$
- Path difference (bright) : $\Delta x = n\lambda$
- Path difference (dark) : $\Delta x = (2n+1)\frac{\lambda}{2}$
- Intensity : $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$
- Max intensity : $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$
- Min intensity : $I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$
- Diffraction minima : $a\sin\theta = n\lambda$
- Angular width : $\theta = \frac{2\lambda}{a}$
- Linear width : $\beta = \frac{2\lambda D}{a}$
- Wavelength in medium : $\lambda_{medium} = \frac{\lambda}{\mu}$

PYQ TIPS

- Derivations are important:
  - Snell's law using Huygens principle
  - Fringe width in YDSE
  - Condition for minima in diffraction
- Learn diagrams neatly.
- Write conditions for maxima/minima clearly.
- Understand the difference between interference and diffraction.
- Numericals are mostly formula based.

PYQ

Focus on NCERT end-of-chapter questions and previous 10 years board questions.

COMMON MISTAKES

- Confusing interference with diffraction.
- Using $\beta = \frac{\lambda D}{d}$ in single slit diffraction.
- Forgetting $(2n+1)\frac{\lambda}{2}$ condition for dark fringes.
- Not distinguishing coherent and incoherent sources.
- Wrong units in formula application.
- Not drawing proper labelled diagrams.

REMEMBER THIS

Bright fringes are wider in YDSE as we move away from the center only in case of unequal intensities of sources.

INTERFERENCE vs DIFFRACTION

INTERFERENCE (YDSE)	BASIS	DIFFRACTION (Single Slit)
Superposition of waves from two coherent sources	Cause	Bending of waves around edges of a slit
Two coherent sources	Sources	Single slit (one source)
Bright and dark fringes of nearly equal intensity	Pattern	Central maximum is bright and broad; side maxima are weak
All fringes have same width ($\beta = \frac{\lambda D}{d}$)	Fringe Width	Central maximum is widest ($\beta = \frac{2\lambda D}{a}$)
Maxima: $n\lambda$ Minima: $(2n+1)\frac{\lambda}{2}$	Conditions	Minima: $n\lambda$ (where $a\sin\theta = n\lambda$)
Depends on d, D, λ	Dependence	Depends on a, D, λ
Almost uniform in all fringes	Energy Distribution	Most energy in central maximum

BOARD EXAM TIPS

- Learn definitions word-for-word.
- Know all formulas with symbols.
- Practice derivations regularly.
- Draw neat, labelled diagrams.
- Write logical steps in derivations.
- Use correct units.
- Attempt NCERT in-text, examples and exercise thoroughly.
- Revise PYQs before the exam.

Concept Clear ✦ Diagrams Neat
Formulas Perfect ✦ Score High!

SYMBOLS & UNITS

Symbol	Meaning	SI Unit
λ	Wavelength	metre (m)
d	Separation between slits	metre (m)
D	Distance between slits & screen	metre (m)
x_n	Position of n^{th} fringe	metre (m)
β	Fringe width	metre (m)
a	Width of slit	metre (m)
θ	Angle	radian (rad)
v	Speed of light in medium	$m\ s^{-1}$
μ	Refractive index	Dimensionless

WAVELENGTH IN MEDIUM

$$\lambda_{medium} = \frac{\lambda}{\mu}$$

Where, λ = wavelength in vacuum (air)
μ = Refractive index of medium

KEY TAKEAWAY

Wave optics explains the behaviour of light as a wave — through wavefronts, interference and diffraction — using superposition principle.

LEGEND

Maxima (Bright) · Minima (Dark) · Wavefront · Direction of Propagation · Angle

MULTIPLE CHOICE QUESTIONS(1-20)

1. In Young's double slit experiment, the two slits act as coherent sources of equal amplitude 'a' and of wavelength λ. In other experiment with the same set up, the two slits are sources of equal amplitude 'a' and wavelength λ , but are incoherent. The ratio of intensity of light at the mid point of the screen in the first case to that in the second case is

(a) 2:1 (b) 1:2 (c) 3:4 (d) 4:3

2. The maximum number of possible interference maxima for slit separation equal to twice the wavelength in Young's double slit experiment is

(a) infinite (b) five (c) three (d) zero

3. Young's double slit experiment is first performed in air and then in a medium other than air. It is found that 8th bright fringe in the medium lies where 5th dark fringe lies in air. The refractive index of the medium is nearly.

(a) 1.25 (b) 1.59 (c) 1.69 (d) 1.78

4. In a Young's double-slit experiment, the source is white light. One of the holes is covered by a red filter and another by a blue fil ter. In this case,

(a) there shall be a interference patterns of red and blue

(b) there shall be an interference pattern for red distinct from that for blue

(c) there shall be no interference fringes

(d) there shall be an interference pattern for red mixing with one for blue

5. Huygen's concept of secondary waves

(a) is used to explain absorption of light by a medium

(b) is a geometrical method to find the position of a new wavefront

(c) is used to determine the velocity of light

(d) is used to explain rectilinear propagation of light

6. Diffraction pattern is observed using green light. When green light is replaced by red light

(a) no change is observed

(b) bands become narrower and crowded

(c) bands become broader and well separated

(d) bands disappear

7. A wavefront is defined as a surface where all points have:

(a) Different frequencies (b) The same phase

(c) Different amplitude (d) Zero displacement

8. Two independent sodium lamps do not produce an interference pattern because:

(a) They have different intensities. (b) Their phase difference changes randomly

(c) They are too far apart (d) Sodium emits white light

9. A single slit of width 0.1 mm is illuminated by light of wavelength 600 nm. The screen is 2 m away. The width of the central maximum is:

(a) 12 mm (b) 24 mm (c) 6 mm (d) 3 mm

10. Light of wavelength 6328 Å is incident on a single slit of width 0.2 mm. The angular width of the central maximum on a screen kept at a distance 9 m from the slit is

(a) 1.5×10^{-3} rad (b) 3.142×10^{-3} rad (c) 6.328×10^{-3} rad (d) 14.3×10^{-3} rad

11. The resultant amplitude of a vibrating particle by the superposition of the two waves $y_1 = a \sin(\omega t + \pi / 3)$ and $y_2 = a \sin \omega t$ is :-

(a) a (b) $\sqrt{2}$ a (c) 2a (d) $\sqrt{3}$ a

12. Which of following is a true statement, if in Young's experiment, separation between the slits is gradually increased :

(a) fringe width increases and fringes disappear (b)fringe width decreases and fringes disappear

(c) fringes become blurred. (d) fringe width remains constant and fringes are more bright

13. In an interference of yellow light derived from two slit apertures, if at some point on the screen, yellow light has a path difference of $3\lambda / 2$, then the fringe at that point will be :

(a)yellow in colour (b) white in colour (c)dark (d)bright

14. Two beams of light having intensities I and 4I interfere to produce a fringe pattern on a screen. The phase difference between the beam is $\pi/2$ at point A and 2π at point B. Then find out the difference between the resultant intensities at A and B.

(a)2I (b)5I (c) I (d) 4I

15. In an interference pattern of two waves fringe width is β . If the frequency of source is doubled then fringe width will become :

(a) (1/2) β (b)β (c)2β (d) (3/2) β

16. In Young's double-slit experiment, distance between slits in kept 1mm and a screen is kept 1m apart from slits. If wavelength of light used is 500nm, then fringe spacing is

(a) 0.5mm (b) 0.5cm (c) 0.25mm (d) 0.25cm

17. A light source of 5000Å wave length produces a single slit diffraction. The first minima in diffraction pattern is seen, at a distance of 5mm from central maxima. The distance between screen and slit is 2 metre. The width of slit in mm will be :

(a) 0.1 (b) 0.4 (c) 0.2 (d) 2

18. Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12×10^{-5} cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.

(a) 40° (b) 45° (c)30° (d)60°

19. What happens if one of the slits, say S_1 in Young's double, slit experiment-is covered with a glass plate which absorbs half the intensity of light from it?

(a) The bright fringes become less-bright and the dark fringes have a finite light intensity
(b) The bright fringes become brighter and the dark fringes become darker
(c) The fringe width decreases
(d) No fringes will be observed

20. In a double slit experiment instead of taking slits of equal widths, one slit is made twice as wide as the other. Then, in the interference pattern

(a) the intensities of both the maxima and the minima increase

(b) the intensities of the maxima increases and minima has zero intensity

(c) the intensity of the maxima decreases and that of the minima increases

(d) the intensity of the maxima decreases and the minima has zero intensity.

ANSWERS (1-20)

1.	If I_0 is intension of light from each slit then $I_c= 4\ I_o$. $I_{in}= 2Io$, $I_c/I_{in}=2$	a
2.	Maximum possible maxima $\sin\theta = 1 \Rightarrow n = 2$. No. of maxima $N = (2n + 1) = (2 \times 2 + 1) = 5$	b
3.	X_5 dark= X_8 bright. Equating we get μ =1.78	d
4.	In this case there shall be no interference fringes.	c
5.	is a geometrical method to find the position of a new wavefront	b
6.	This occurs because red light has a longer wavelength than green light, and diffraction fringe width is directly proportional to the wavelength.	c
7.	A wavefront is a locus of all particles vibrating in the same phase. It is a surface of constant phase.	b

8.	Independent sources undergo abrupt phase changes every ~10^{-10} s (temporal incoherence). The pattern averages out, producing uniform illumination.	**b**
9.	Linear width = 2λD/a = 2 × 600×10^{-9} × 2 / (0.1×10^{-3}) = 2.4×10^{-2} m = 24 mm.	**b**
10.	2 θ= 2λ/a = 6.328 X 10^{-3} rad	**c**
11	use the formula $A^2 = A_1^2 + A_2^2 + 2A_1A_2 cos\ \phi$	**d**
12	Use formula, β=λD/d, As the fringes become narrower, they become harder to distinguish, and eventually, they will disappear	**b**
13	path difference,3λ/2 as $(1 + \frac{1}{2})\lambda$-condition for dark fringe	**c**
14	Use the formula $I = I_1 + I_2 + 2\sqrt{I_1I_2} cos\ \phi$	**d**
15	use the formula $\beta = \frac{\lambda D}{d} = \frac{cD}{\nu d}$	**a**
16	use the formula $\beta = \frac{\lambda D}{d}$	**a**
17	use the formula $y = \frac{\lambda D}{a}$	**c**
18	condition for the first minimum is $a\ sin\ \theta = \lambda$	**c**
19	The bright fringes become less-bright and the dark fringes have a finite light intensity	**a**
20	because the increased light through the wider slit prevents perfect cancellation at the minima while adding total energy to the maxima.	**a**

EXERCISE QUESTIONS

1. Two coherent light beams of intensity I and 4I are superposed. The maximum and minimum possible intensities in the resulting beam are:
(a) 5I and 3I (b) 5I and I (c) 9I and 3I (d) 9I and I

2. In an interference experiment, third bright fringe is obtained at a point on the screen with a light of 700 nm. What should be the wavelength of the light in order to obtain 5th bright fringe at the same point?
(a) 500 nm (b) 630 nm (c) 750 nm (d) 420 nm

3. In Young's double slit experiment, the two slits act as coherent sources of equal amplitude A and wavelength λ. In another experiment with the same set up the two slits are sources of equal amplitude A and wavelength λ but are incoherent. The ratio of the intensity of light at the mid-point of the screen in the first case to that in the second case is
(a)4 : 1 (b)2 : 1 (c)1 : 1 (d)1 : 2

4. In Young's double slit experiment maximum intensity of each source is I . At angular position θ the intensity becomes 4I where Sin θ is:

(a) λ/d (b) λ/2d (c) λ/3d (d) λ/4d

5. Which of following is a true statement, if in Young's experiment, separation between the slits and screen is gradually decreased :

(a)fringe width increases and fringes disappear. (b)fringe width decreases and fringes disappear. (c)fringes become blurred (d)fringe width remains constant and fringes are more bright

ANSWERS- 1. d 2. d 3. b 4. a 5. b

ASSERTION-REASON QUESTION

For these Questions two statements are given one labelled **Assertion (A)** and other labelled **Reason (R).** Select the correct answer to these questions from the options as given below

(a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.
(b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
(c) If Assertion is true but Reason is false.
(d) If both Assertion and Reason are false.

1. Assertion (A): The fringe width in Young's experiment decreases when the experiment is performed in a medium with refractive index greater than 1.
Reason (R): The effective wavelength of light in a medium becomes λ/μ, where μ is the refractive index.

2. Assertion (A): Two equal wavelengths meet at point when coming from opposite direction may give brightest spot at the point of meeting.
Reason(R) : Two waves moving in opposite directions meet in opposite phase.

3.Assertion (A): The two slits in YDSE are illuminated by two different sodium lamps emitting light of same wavelength. No interference pattern will be observed.
Reason (R): Two independent light sources (except LASER) cannot be coherent.

4. Assertion (A): In calculating the disturbance produced by a pair of superimposed incoherent wave trains, you can add their intensities.
Reason (R): $I = I_1 + I_2 + 2(I_1 I_2)^{1/2}\cos\theta$. The average value of $\cos\theta = 0$, for incoherent waves.

5. Assertion (A): Thin films such as soap bubble or thin layer of oil spread on water show beautiful colors when illuminated by white light.
Reason (R): It is due to interference of Sun's light reflected from upper and lower surfaces of the film.

6. Assertion (A): In YDSE central fringe may not be a bright fringe.
Reason (R): If path difference at central fringe is zero then it will be a bright fringe.

7. Assertion (A): Fringe width in single slit experiment depends upon refractive index of the medium.
Reason (R): Refractive index changes optical path of ray of light forming fringe pattern also changes.

8. Assertion (A): Diffraction of light is more pronounced through a narrower slit.

Reason (R): The amount of diffraction is inversely proportional to the slit width relative to the wavelength.

9. Assertion (A): We cannot get diffraction pattern from a wide slit illuminated by monochromatic light.

Reason (R): In diffraction pattern, all the bright bands are not of the same intensity.

10. Assertion (A): In Young's experiment, the fringe width for dark fringes is different from that for white fringes.

Reason (R): In Young's double slit experiment the fringes are performed with a source of white light then only black and bright fringes are observed.

ANSWERS

1. a. 2.c. 3. a. 4. a 5. a 6. b 7. a 8. a 9. b 10. d

EXERCISE QUESTIONS

1. Assertion (A): In Young's double slit experiment if intensity of each source is I_0 than minimum and maximum intensities will be zero and $4I_0$ respectively.

Reason (R): In Young's double slit experiment energy conservation is not followed.

2. Assertion (A): Two monochromatic sources of light originated from same source with intensities I and 4I are placed in front of two slits in interference pattern in front of both the slits intensity of fringes shall be different.

Reason (R): Central band of interference pattern shall be the brightest.

3. Assertion (A): The angular fringe width in YDSE is independent of the distance D of the screen.

Reason (R): Angular fringe width $\theta = \beta/D = \lambda/d$; it depends only on λ and d.

4. Assertion (A): Wavefronts are always perpendicular to rays of light.

Reason (R): A ray is defined as the direction of energy propagation and is always perpendicular to the wavefront.

5. Assertion (A): Interference obeys the law of conservation of energy.

Reason (R): The energy is redistributed in case of interference

SHORT ANSWER TYPE -I

1. How does the fringe width in Young's double-slit experiment change when the distance of separation between the slits and screen is doubled?

2.When white light is used in YDSE we say Central band is white surrounded by colored bands with inner edge as violet and outer edge as red. justify it, as well as explain pattern of width of fringes obtained.

3. In a Young's double-slit experimental set-up with slit separation 0.6 mm a beam of light consisting of two wavelengths 440 nm and 660 nm is used to obtain interference pattern on a screen kept 1.5 m in front of the slits. Find the least distance of the point from the central maximum where the bright fringes due to both the wavelengths coincide.

4.Answer the following questions:

(i) In what way is diffraction from each slit related to the interference pattern in a double slit experiment?

(ii) When a tiny circular obstacle is placed in the path of light from a distance source, a bright spot is seen at the center of the shadow of the obstacle. Explain, why.

5. (a) The ratio of the widths of two slits in Young's double slit experiment is 4: 1. Evaluate the ratio of intensities at maxima and minima in the interference pattern. (b) Does the appearance of bright and dark fringes in the interference pattern violate, in any way, conservation of energy?

6. Two plane monochromatic waves propagating in the same direction with amplitudes A and 2A and differing in phase by $\pi/3$ superimpose. Calculate the amplitude of resulting wave.

7. (a) Write the conditions under which light sources can be said to be coherent. (b) Why is it necessary to have coherent sources in order to produce an interference pattern?

8.Draw the shape of the wavefront coming out of a concave mirror and a convex lens when a plane wave is incident on it.

9. How will the interference pattern in Young's double slit experiment gets affected when

(i) distance between the slits S1 and S2 is reduced and

(ii) the entire set up is immersed in water. Justify your answer in each case.

10. How will the angular separation and visibility of fringes in Young's double slit experiment change when (i) screen is moved away from the plane of slits, and (ii) width of source slit is increased?

SOLUTIONS/HINTS

1. The fringe width is β = λD/d, D (distance between slits and screen) is doubled, then fringe width will be doubled.

2. Since white light is a combination of all visible colors, the superposition of all colors at the central maximum results in a bright white band. Also the position of bright fringe is directly proportional to the wavelength of light. Thus, the first order bright fringe will be a spectrum with violet light at the inner edge and red light at the outer edge.

3. n=2 , y=n λ_2D/d , y=3.3 mm

4.(i) The observed double-slit interference pattern is actually the interference pattern modulated by the single-slit diffraction pattern.

(ii) Due to the symmetry of the circular obstacle, the diffracted wavelets from all points along the circumference of the obstacle's edge travel the *same optical path length* to the exact center of the shadow. Because they travel the same path length, they arrive in phase at the center of the shadow. This in-phase superposition leads to constructive interference at the exact center of the shadow, resulting in a bright spot.

5. $(a) Intensity \propto width\ of\ slit$ and use the correct formula Ans. 9:1

(b) No, the appearance of bright and dark fringes does not violate the law of conservation of energy.

6. Use the formula $A^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos \cos \phi$ Ans $A\sqrt{7}$

7. (a) Conditions for Coherent Sources: Same Frequency/Wavelength: The light sources must emit light of the same frequency or monochromatic light. Constant Phase Difference: The phase difference between the waves must remain constant with time. Same Amplitude (Optional but preferred): For high-contrast interference, amplitudes should be nearly equal. Origin: They should be derived from a single source to maintain phase consistency.

(b) Necessity of Coherent Sources: Coherent sources are necessary to produce a sustained (stable) interference pattern. If the phase relationship changes randomly (incoherent), the bright and dark fringes will shift positions constantly, averaging out to uniform illumination, and no interference pattern will be observable

8. Concave Mirror: When a plane wavefront is incident normally, the reflected wavefront converges at the focus. Therefore, it is a converging spherical wavefront.

Convex Lens: When a plane wavefront passes through a convex lens, it converges towards the focal point. The refracted wavefront is a converging spherical wavefront.

9. : (i) fringe width increases As β=λD/d

(ii) fringe width decreases

10. $\beta = \frac{\lambda D}{d}$ Angular separation $\theta = \frac{\lambda}{d}$ (i) unchanged (ii) the interference pattern becomes less and less sharp. When the source slit becomes so wide that the condition s/S < λ/D is not satisfied, the interference pattern disappears, but the angular width remains unchanged.

EXERCISE QUESTIONS

1. In YDSE with D = 1m, d = 1mm, light of wavelength 500 nm is incident at an angle of 0.57° w.r.t. the axis of symmetry of the two slits in the experimental set up. If centre of symmetry of screen is O . (**Competitive Corner)**

(i) find the position of central maxima

(ii) Intensity at point O in terms of intensity of central maxima I_0.

2. In Young's double slit experiment using mono-chromatic light of wavelength X, the intensity of light at a point on the screen where path difference is X, is K units. Find out the intensity of light at a point where path difference is 2λ/3.

3. In young's double slit experiment how is the fringe width change when

(a) Light of smaller frequency is used

(b) Distance between the slits is decreased?

4. What type of wavefront will emerge from a (i) point source (ii) distant light source (iii) A spherical wave front after reflection from a plane mirror. (iv) A spherical wave front after reflection from a concave mirror.

5. Two wavelengths of light 600 nm and 610 nm are used in turn, to study the diffraction at a single slit of size 2 mm. The distance between the slits and screen is 2 m. Calculate the separation between the positions of the second order maximum of the diffraction pattern obtained in the two cases.

ANSWERS

1. (i) 9.949 mm (ii) $0.90I_0$ **2.** K/4 **3.** (a) increase (b) increase

4. (i) spherical wavefronts (ii) plane wavefronts (iii) spherical wavefronts (diverging) (iv) is spherical (either converging or diverging) or plane wavefronts, depending on the source's position **5.** 0.025 mm.

SHORT ANSWER TYPE- II

1. (a)What is the effect on the interference fringes if the monochromatic source is replaced by a source of polychromatic light.

(b) In Young's double slit experiment, the two slits 0.15 mm apart are illuminated by monochromatic light of wavelength 450 nm. The screen is 1.0 m away from the slits.

Find the distance of the second (i) bright fringe, (ii) dark fringe from the central Maximum.

2. How will the interference pattern in Young's double slit experiment gets affected when

(i) distance between the slits S1 and S2 is reduced and

(ii) the entire set up is immersed in water. Justify your answer in each case.

3.A parallel beam of monochromatic light falls normally on a narrow slit of width 'a' to produce a diffraction pattern on the screen placed parallel to the plane of the slit. Use Huygens' principle to explain that

(i) the central bright maxima is twice as wide as the other maxima.

(ii) the intensity falls as we move to successive maxima away from the centre on either side.

4.(a) Why are coherent sources necessary to produce a sustained interference pattern?

(b) In Young's double slit experiment using mono-chromatic light of wavelength λ , the intensity of light at a point on the screen where path difference is λ, is K units. Find out the intensity of light at a point where path difference is 2λ.

5. (a) Define the term wave front.

(b) State Huygen's principle.

(c) Consider a plane wave front incident on a thin convex lens. Draw a proper diagram to show how the incident wave front traverses through the lens and after refraction focuses on the focal point of the lens, giving the shape of the emergent wave front.

6. (a) Draw a graph showing the variation of intensity of light with the position on the screen in Young's double- slit experiment.

(b) Find the intensity of light at a point on the screen when two interfering waves of the same intensity (I_0) have a path difference of (i) λ/4 and (ii) λ/3.

7.Which of the following statements does not correctly comply with Huygens' Principle of constructing a secondary wavefront from a primary wavefront? Justify each case?

(a)After some time interval, the new position of the wave front is the forward envelope to the secondary wavelets.

(b) Secondary wavelets propagate outward through a medium with speed characteristic of waves in that medium.

(c) A secondary wavefront is always a plane wavefront irrespective of whether the primary wavefront is planar or spherical.

8. (a) In a Young's double slit experiment, the two slits are illuminated by two different lamps having same wavelength of light. Explain with reason, whether interference pattern will be observed on the screen or not.

(b) Light waves of intensities I_o each from two coherent sources arrive at two points on a screen with path differences of 5λ/2 and 5λ. Find the intensities at the points.

9.Two monochromatic sources of light originated from same source with intensities I and 4I are placed in front of two slits in YDSE. Prove that in interference pattern in front of both the slits intensity of fringes shall be same irrespective of the fact that sources are coherent or not. Justify?

10. Why we need coherent sources to get sustained interference of light? Someone says that two identical independent light sources can be coherent for a very short time period. It is called temporal coherency. Explain the statement.

SOLUTIONS/HINTS

1. (a) fringes will become coloured near to edge of central band lower wavelength will be seen.

(b) (i) Distance of second bright fringe is $= \frac{2\lambda D}{d}$ =6mm

(ii) Distance of second dark from central maxima , = $3\frac{\lambda D}{2d}$ =4.5mm

2. i) fringe width increases As β=λD/d

ii) fringe width decreases $\beta \propto \lambda$

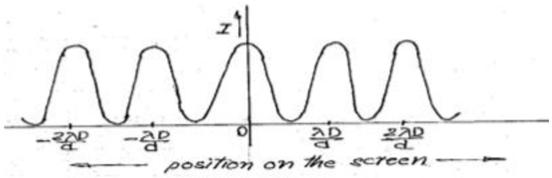
3. i) Describe single slit exp using wave theory ii) This is because the waves diffracting from different parts of the slit interfere with each other, and the interference pattern creates both bright and dark fringes (minima). The central bright fringe is the brightest and widest, and the intensity of the secondary maxima (bright fringes) decreases as you move further away from the center.

4. (a) if sources are not coherent then phase difference will be time varying.

(b) phase difference=ϕ=2π/λ x 2λ= 4 π intensity $I=I_0 \cos^2(\frac{\phi}{2})$, I_o=K . so I=K

5. (a)Wavefront is the continuous locus of all points (such as wave crests or troughs) that oscillate in phase, meaning they are at the same distance from the source.

(b)Correct principle (c)proper diagram with explanation

6. (a) 

(b) Correct formula application (i) 2 Io (ii) Io

7. (a) correct, The forward envelope tangent to all secondary wavelets forms the new wavefront.

(b) correct, Wavelets always travel at the medium's characteristic wave speed.

(c) incorrect, Secondary wavefronts mimic the primary shape; spherical wavefronts produce spherical secondary wavefronts, not planar ones.

8. (a) no interference pattern will be observed as the sources are two independent sources.

(b) use direct formula and values will be 0 and $4I_o$ respectively.

9. Justify using formula of intensity

10. Coherent sources give constant phase difference and stable fringes. Independent light sources can maintain a steady phase relationship only for a fleeting duration. This brief phase stability is called temporal coherence.

EXERCISE QUESTIONS

1. A beam of light consisting of two wavelengths, 650 nm and 520 nm, is used to obtain interference fringes in a Young's double-slit experiment.(a)Find the distance of the third bright fringe on the screen from the central maximum for wavelength 650 nm.(b)What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide?

2. In a double-slit experiment the angular width of a fringe is found to be 0.2° on a screen placed 1 m away. The wavelength of light used is 600 nm. What will be the angular width of the fringe if the entire experimental apparatus is immersed in water? Take refractive index of water to be 4/3.

3. A narrow monochromatic beam of light of intensity I is incident a glass plate. Another identical glass plate is kept close to the first one and parallel to it. Each plate reflects 25% of the incident light and transmits the reaming. Calculate the ratio of minimum and maximum intensity in the interference pattern formed by the two beams obtained after reflection from each plate.

4. What are coherent sources? Why are coherent sources required to produce interference of light? Give an example of interference of light in everyday life. In Young's double slit experiment, the two slits are 0.03 cm apart and the screen is placed at a distance of 1.5 m away from the slits. The distance between the central bright fringe and fourth bright fringe is 1 cm. Calculate the wavelength of light used.

5. (i)What is the difference between a ray and a wavefront ?

(ii) A plane wave is incident on a reflecting surface. Using Huygens principle, show how it is reflected from the surface. Hence, verify the law of reflection.

ANSWERS/HINTS

1. $\frac{1950D}{d}nm$, $\frac{2600D}{d}nm$

2. 0.15 degrees **3.** 0.008 **4.** Definition ,500 nm

5.(i)Correct difference (ii)Verification using Huygens principle

LONG ANSWER TYPE QUESTIONS

1. (a) State the essential condition for diffraction of light to take place.
(b) Use Huygen's principle to explain diffraction of light due to a narrow single slit and the formation of a pattern of fringes obtained on the screen.
(c) Sketch the pattern of fringes formed due to diffraction at a single slit showing variation of intensity with angle θ.

2. Red colour of light of wavelength λ is passed from two narrow slits which are distance *d* apart and interference pattern is obtained on the screen distance *D* apart from the plane of two slits. Then find the answer to following parts assuming that slit widths are equal to produce intensity I_0 from each slit.
(a) Intensity at a point on the screen, situated at a distance 1/4 th of fringe separation from centre.
(b) Intensity in the screen, if the sources become incoherent by using two different lamps behind lamps *S*1 and *S*2.
(c) Angular position of 10th maxima, and the angular width of that fringe.
(d) Find the distance between 5th maxima and 3rd minima, at same side of central maxima.

3. (a) In a diffraction experiment, the slit is illuminated by light of wavelength 600 nm. The first minimum of the pattern falls at $\theta = 30^o$ .Calculate the width of the slit.
(b) Show that the angular width of the first diffraction fringe is half of that of the central fringe.
(c) If a monochromatic source of light is replaced by white light, what change would you observe in the diffraction pattern?

4. (a) In Young's double slit experiment, derive the condition for (i) constructive interference and (ii) destructive interference at a point on the screen.
(b) A beam of light consisting of two wavelengths, 800 nm and 600 nm is used to obtain the interference fringes in a Young's double slit experiment on a screen placed 1.4 m away. If the two slits are separated by 0.28 mm, calculate the least distance from the central bright maximum where the bright fringes of the two wavelengths coincide.

5. Explain Huygen's principle. Name the types of wavefronts that corresponds to a beam of light
(a) coming from a convex lens when point source placed at focus.
(b) coming from very far off source.

(c) coming from a convex lens (μ for lens = 1.1) when point source placed at its focus inside water μ= 1.33.

(d) wave front from a distant source fall perpendicular to an equilateral hollow prism placed in side water.

6. (a)Prove the laws of reflection by using a basic principle in wave optics. Name the principle.

(b) Laser light of wavelength 640 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 7.2 mm. Calculate the wavelength of another source of light which produces interference fringes separated by 8.1 mm using same arrangement. Also find the minimum value of the order 'n' of bright fringe of shorter wavelength which coincides with that of the longer wavelength

7. (a) In a single slit diffraction pattern, how is the angular width of central maximum affected when (i) slit width is increased (ii) the distance between the slit and the screen is increased.

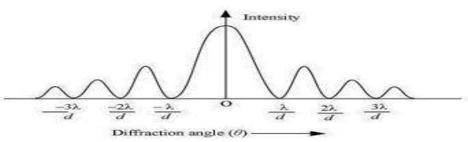
(iii) light of smaller wavelength is used. Justify your answer.

(b) A slit of width d is illuminated by light of wavelength 700 nm. Find the value of d for which the first minimum falls at an angle of 30°

SOLUTIONS/HINTS

1. (a)Essential condition for diffraction: the size of the obstacle or aperture (slit) must be comparable to the wavelength of the light being used.

(b) Correct explanation

(c) 

2. (a) $\Delta x = \frac{yd}{D} = \frac{\lambda}{4}$; $\Phi = \frac{\Pi}{2}$; $I = 4I_0 \cos\cos \frac{\Phi}{2}^2 = 2I_0$

(b) No interference pattern observed, $I_{total} = 2I_0$

(c) $d\sin\theta = 10\lambda$, find θ using this formula ; Angular width, $\Delta\theta = \frac{\lambda}{d}$

(d) distance = $|y_5 - y_3|$ Ans - $\frac{5\lambda D}{2d}$

3. a) Condition for minima; a sin $\theta = n\lambda$ use this formula to find a = 1.2 μm

b) Condition for first minimum, a$\theta = \lambda$; $\theta_1 = \frac{\lambda}{a}$ $\theta_2 = -\frac{\lambda}{a}$

Angular width=$2\theta_1 = \frac{2\lambda}{a}$

c) The central maximum will remain white, secondary maxima will become colored fringes and the overlapping of different colored secondary maxima will increase.

4. a) correct derivation for (i) constructive interference and (ii) destructive interference at a point on the screen.

b)Here $y_1 = y_2$ to find the order of the bright fringes. Then calculate the position of this coinciding fringe using both pair of values. Ans:12 mm

5. The principle is based on two primary postulates:

Secondary Sources: Every point on a given wavefront acts as a source of new secondary spherical wavelets.

Forward Propagation: The new position of the wavefront at any later time is the forward envelope (the common tangent surface) of all these secondary wavelets

a) plane wavefronts b) plane wavefronts c) Using lens maker's formula, we will find that lens will behave diverging. So we get diverging wavefront d) Plane wavefront

6. (a) Correct prove and name of principle

(b)Distance between two bright fringes = Fringe width

$\beta = \frac{\lambda D}{d}$ using $\beta_1 / \beta_2 = \lambda_1 / \lambda_2$

λ_2=720 nm, minimum order n=9

7. (a) (i) decrease, $\theta = \frac{\lambda}{d}$, justification

(ii) independent

(iii) decrease, $\theta = \frac{\lambda}{d}$

(b) d sin $\theta = \lambda$, d= 1.4 μm

EXERCISE QUESTIONS

1. (a) In a YDSE, two light waves, each of intensity I_0,interfere at a point, having a path difference $\frac{\lambda}{8}$ on the screen. Find the intensity at this point.

(b) In a double-slit experiment,6th dark fringe is observed at a certain pint of the screen. A transparent sheet of thickness t and refractive index n is now introduced in the path of one of the two interfering waves to increase its phase by $\frac{2\pi(n-1)t}{\lambda}$.The pattern is shifted and 8thbright fringe is observed at the same point. Find the relation for thickness t in terms of n and λ. (**Competitive Corner)**

2.(a) Draw the variation of intensity with angle of diffraction in single slit diffraction pattern. Write the expression for value of angle corresponding to zero intensity locations.

(b) In what way diffraction of light waves differs from diffraction of sound waves?

(c) A parallel beam of light of wavelength 650 nm passes through a slit of width 0.6 mm. The diffraction pattern is obtained on a screen kept 60 cm away from the slit. Find the distance between first order minima on both sides of the central maximum.

3. A physics teacher wants to demonstrate interference with the help of double slit experiment using a laser beam of 633 nm wavelength. Since the hall is large enough, interference pattern is formed on the wall 5 m from the slits. For clear and comfortable view by all the students they want the fringe width 5 mm.

(a) Find the slit separation for obtaining the desired interference pattern.

(b) How far will the first minimum be from the central maximum?

(c)Light waves from two pinholes illuminated by two sodium lamps do not produce interference patterns. Give reason

4. A double slit set-up was initially placed in a tank filled with water and the interference pattern was obtained using a laser light. When water is replaced by a transparent liquid of refractive index $n > n_{water}$, what will be the effect on the following:

(a) Speed, frequency, and wavelength of the light of laser beam

(b) The fringe width, shape of interference fringes and shift in the position of central maximum.

5. Using Huygen's principle draw a ray diagram showing the propagation of a plane wave refracting at a plane surface separating two media. Also verify Snell's law of refraction.

ANSWERS

1.(a) $3.414\ I_0$ (b) $\frac{5\lambda}{2(n-1)}$

2.(a) Correct graph (b) light waves have low wavelength. (c) 1.3 mm

3.(a) 633μm (b) 2.5 mm (c) they are **not coherent**, meaning they do not maintain a constant phase relationship

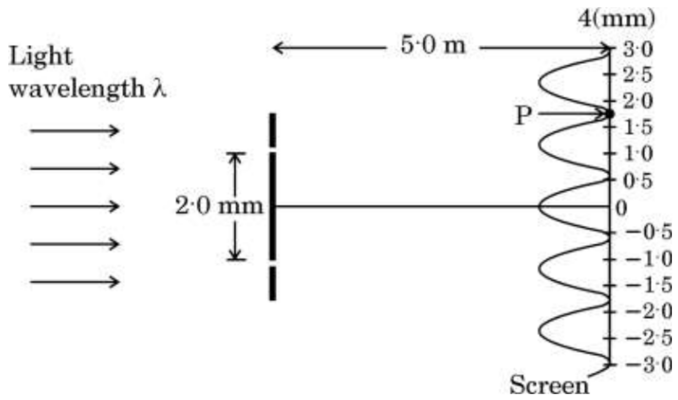
4.(a) speed of light and wavelength will decrease and frequency remains unaffected.

(b) Fringe width decreases, shapes and position of central maxima will not change

5.(a) Correct ray diagram and correct derivation.

CASE STUDY/PASSAGE-BASED QUESTIONS

(C.S.-1). In a Young's double-slit experiment, the two slits behave as coherent sources. When coherent light waves superpose over each other they create an interference pattern of successive bright and dark regions due to constructive and destructive interference. Two slits 2 mm apart are illuminated by a source of monochromatic light and the interference pattern is observed on a screen 5·0 m away from the slits as shown in the figure.



(i) What property of light does this interference experiment demonstrate ?

(A) Wave nature of light (B) Particle nature of light (C) Transverse nature of light

(D) Both wave nature and transverse nature of light

(ii) The wavelength of light used in this experiment is :

(A) 720 nm (B) 590 nm (C) 480 nm (D) 364 nm

(iii) The fringe width in the interference pattern formed on the screen is : (A) 1·2 mm. (B) 0·2 mm. (C) 4·2 mm. (D) 6·8 mm

(iv) The path difference between the two waves meeting at point P, where there is a minimum in the interference pattern is :

(A) $8{\cdot}1 \times 10^{-7}$ m (B) $7{\cdot}2 \times 10^{-7}$ m (C) $6{\cdot}5 \times 10^{-7}$ m (D) $6{\cdot}0 \times 10^{-7}$ m

(v) When the experiment is performed in a liquid of refractive index greater than 1, then fringe pattern will :

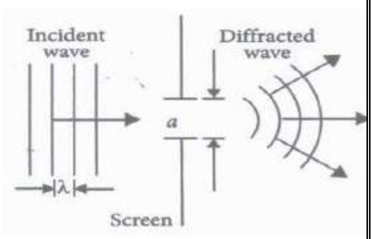
(A) disappear. (B) become blurred. (C) be widened. (D) be compressed

<u>Answer (C.S.-1).</u>

(i) (A) wave nature of light **(ii)** (C) 480 nm **(iii)** (A) 1.2 mm.

(iv) (B) 7.2 X 10^{-7} m. **(v)** (D) be compressed

<u>(C.S.-2)</u>.



The phenomenon of bending of light around the sharp corners and the spreading of light within the geometrical shadow of the opaque obstacles is called diffraction of light. The light thus deviates from its linear path. The deviation becomes much more pronounced, when the dimensions of the aperture or the obstacle are comparable to the wavelength of light.

(i) Light seems to propagate in rectilinear path because

(A)its spread is very large. (B)its wavelength is very small

(C)reflected from the upper surface of atmosphere (D)it is not absorbed by atmosphere

(ii) In diffraction from a single slit the angular width of the central maxima does not depends on $(A)\lambda$ of light used. (B)width of slit (C) distance of slits from the screen (D) ratio of λ and slit width

(iii) For a diffraction from a single slit, the intensity of the central point is

(A) infinite. (B) finite and same magnitude as the surrounding maxima

(C) finite but much larger than the surrounding maxima

(D) finite and substantially smaller than the surrounding maxima

(iv) In a single diffraction pattern observed on a screen placed at D metre distance from the slit of width d metre, the ratio of the width of the central maxima to the width of other secondary maxima is (approx.)

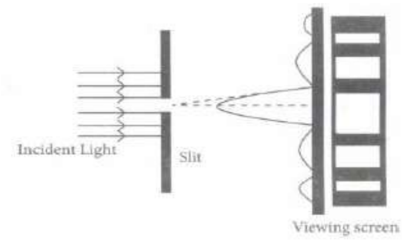
(A) 2: 1 (B) 1: 2 (C)1: 1 (D)3: 1

<u>Answer (C.S.-2).</u>

(i) B (ii) C (iii) C (iv) A

(C.S.-3)

When light from a monochromatic source is incident on a single narrow slit, it gets diffracted and a pattern of alternate bright and dark fringes is obtained on screen, called "Diffraction Pattern" of single slit. In diffraction pattern of single slit, it is found that



(I) Central bright fringe is ·of maximum intensity and the intensity of any secondary bright fringe decreases with increase in its order.

(II) Central bright fringe is twice as wide as any other secondary bright or dark fringe .

Read the following case/passage and answer the following questions:

(i) A single slit of width 0.1 mm is illuminated by a parallel beam of light of wavelength 6000 A and diffraction bands are observed on a screen 0.5 m from the slit. The distance of the third dark band from the first dark band of opposite side is

(A) 6 mm (B)15 mm (C)9 mm (D)12 mm

(ii) In Fraunhofer diffraction pattern, slit width is 0.2 mm and screen is at 2 m away from the lens. If wavelength of light used is 5000 A then the distance between the first minimum on either side the central maximum is

(A) 10^{-1} m (B)10^{-2} m (C)2×10^{-2} m (D)2×10^{-1} m

(iii) Light of wavelength 600 nm is incident normally on a slit of width 0.2 mm. The angular width of central maxima in the diffraction pattern is

(A) 6×10^{-3} rad (B)4×10^{-3} rad (C)2.4×10^{-3} rad (D)4.5×10^{-3} rad

(iv) A diffraction pattern is obtained by using a beam of red light. What will happen, if the red light is replaced by the blue light?

(v) To observe diffraction, the size of the obstacle

(A) should be A/2, where A is the wavelength.

(B) should be of the order of wavelength.

(C) has no relation to wavelength.

(d) should be much larger than the wavelength.

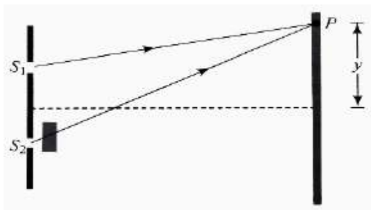
Answer (C.S.-3).

(i) D (ii) B (iii) A (iv) Explanation (v) B

EXERCISE QUESTIONS

(EQ-1)

Interference of light:- If double slit apparatus is immersed in a liquid of refractive index μ, the wavelength of light reduces to λ/μ and fringe width also reduces to β'=β/μ. The given figure shows a double-slit experiment in which coherent monochromatic light of wavelength A from a distant source



is incident upon the two slits, each of width w ($w >> \lambda$) and the interference pattern is viewed on a distant screen. A thin piece of glass of thickness t and refractive index n is placed between one of the slit and the screen, perpendicular to the light path.

(i) In Young's double slit interference pattern, the angular fringe width

(A) can be changed only by changing the wavelength of incident light

(B) can be changed only by changing the separation between the two slits

(C) can be changed either by changing the wavelength or by changing the separation between two slits

(D) is a universal constant and hence cannot be changed

(ii) If the width w of one of the slits is increased to 2w , the wave amplitude emerging from the slit will change from a to:

(A) 1.5a (B)2a (C)$\sqrt{2}a$ (D)no change

(iii) In YDSE, let A and B be two slits. Films of thicknesses t_A and t_B and refractive indices μ_A and μ_B are placed in front of A and B, respectively. If $\mu_A t_A = \mu_B t_B$ then the central maxima will

(A) not shift (B) shift towards A (C) shift towards B

(D) shift towards A if $t_B > t_A$ and shift towards B if $t_B < t_A$

(iv) In Young's double slit experiment, a third slit is made in between the double slits. Then

(A) fringes of unequal width are formed.

(B) contrast between bright and dark fringes is reduced

(C) intensity of fringes totally disappears

(D) only bright light is observed on the screen

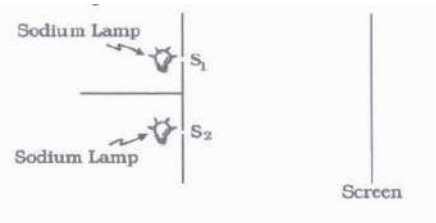
(v) In Young's double slit experiment, if one of the slits is covered with a microscope cover slip, then

(A) fringe pattern disappears

(B) the screen just gets illuminated

(C) in the fringe pattern, the brightness of the bright fringes will decreases and the dark fringes will become more dark

(D) bright fringes will be more bright and dark fringes will become more dark.



(EQ-2) Interference is based on the superposition principle of waves from coherent sources. According to this principle, at a particular point in the medium, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each of the waves. If two isolated sodium lamps illuminate two pin holes S_1 and S_2. The intensities will add up and no interference fringes will be observed on the screen. Here the source undergoes abrupt phase change in times of the order of 10^{-10} seconds called temporal coherency.

(i) Two coherent sources of intensity 100 W/m^2 and 25 W/m^2 interfere to form fringes. Find the ratio of maximum intensity to minimum intensity

(a) 5:3 (b)9:1 (c)4:1 (d)None of the all

(ii) Which of the following does not show interference?

(a) Soap bubble (b)Excessively thin film of oil

(c)A thick film of oil (d) Wedge shaped film

(iii) In a Young's double-slit experiment, the slit separation is doubled. To maintain the same fringe spacing on the screen, the screen-to-slit distance D must be changed by

(a) 2D (b)4D (c)D/2 (d)D

(iv) The maximum number of possible interference maxima for slit separation equal to twice the wavelength in Young's double-slit experiment, is

(a) Infinite (b)Five (c)Three (d)zero

(v) The resultant amplitude of a vibrating particle by the superposition of the two waves are

y_1=a sin [ωt + π/3] and y_2=a sin ωt is

(a) a (b)√2a (c)2a (d)√3a

(EQ-3)

Diffraction and interference are closely related phenomena that occur together. Diffraction is the phenomenon of bending of light around the edges of the obstacle, while interference is the combination of waves that results in a new wave pattern. In order to get interference, there must be at least two waves that are diffracting. So while diffraction can occur without interference, interference cannot occur without diffraction. Two slits of width 2 μm each in an opaque material are separated by a distance of 6 μm. Monochromatic light of wavelength 450 nm is incident normally on the slits. One finds a combined interference and diffraction pattern on the screen.

(i). The number of peaks of the interference fringes formed without the central peak of the envelope of the diffraction pattern will be

(a) 2 (b) 3 (c) 4 (d) 6

(ii). The number of peaks of the interference formed if the slit width is doubled while keeping the distance between the slits same will be

(a) 1 (b)2 (c) 3 (d) 4

(iii). If instead of 450 nm light, another light of wavelength 680 nm is used, number of peaks of the interference formed in the central peak of the envelope of the diffraction pattern will be

(a) 2 (b) 4 (c) 6 (d) 9

(iv). The number of bright fringes formed due to interference on 1 m of screen placed at 4/3 m away from the slits is

(a) 2 (b) 3 (c) 6 (d) 10

****

FORMULA SHEET

CBSE CLASS XII PHYSICS • WAVE OPTICS

PREMIUM SMART-STUDY REVISION POSTER & FORMULA SHEET

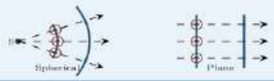
NEP 2020 Aligned — Highly Visual — Short Tricks & PYQ Tips — Quick Revision

1. WAVEFRONT & HUYGENS PRINCIPLE

Wavefront: The continuous locus of all adjacent particles of a medium vibrating in the same phase.

- **Plane Wavefront:** Originates from a source at infinity (parallel rays).
- **Spherical Wavefront:** Originates from a point source at finite distance.
- **Cylindrical Wavefront:** Originates from a linear source (e.g., narrow slit).

Huygens Principle: 1. Every point on a wavefront acts as a fresh source of secondary wavelets moving with the speed of light.
2. The forward envelope (tangential surface) of these secondary wavelets at any instant gives the new wavefront.



2. REFLECTION & REFRACTION VIA WAVE THEORY

Key Concept: Rays are always perpendicular to the wavefront (Ray $\perp$ Wavefront). Time taken by light along any ray path from one wavefront to another is identical.

- **Law of Reflection:** Proved by showing triangles formed by incident and reflected wavefronts are congruent $\implies \angle i = \angle r$.
- **Law of Refraction (Snell's Law):**

$$\mu = \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

- **CRITICAL NOTE:** When light travels from a rarer to a denser medium, speed (v) and wavelength (λ) decrease:

$$\lambda_{medium} = \frac{\lambda_{vacuum}}{\mu}$$

But **Frequency (ν) remains absolutely constant** (depends only on the source).

3. COHERENT SOURCES & SUPERPOSITION

Coherent Sources: Two sources emitting light waves of the **same frequency/wavelength** with a **constant phase difference**.

Note: Two independent light bulbs can never be coherent because atoms emit light bursts with random phase changes every $\sim 10^{-10}$ s.

Resultant Intensity Formula: For two interfering waves of intensities I_1, I_2 and phase difference ϕ:

$$\boxed{I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi}$$

Phase Diff (ϕ) vs Path Diff (Δx):

$$\phi = \frac{2\pi}{\lambda}\cdot\Delta x$$

Intensity Extrema:

- **Maximum Intensity (Constructive):** $\cos\phi = 1 \implies I_{max} = \left(\sqrt{I_1}+\sqrt{I_2}\right)^2$
- **Minimum Intensity (Destructive):** $\cos\phi = -1 \implies I_{min} = \left(\sqrt{I_1}-\sqrt{I_2}\right)^2$

Identical Slits ($I_1 = I_2 = I_0$):

$$I = 4I_0\cos^2\left(\frac{\phi}{2}\right) \implies I_{max} = 4I_0, \quad I_{min} = 0$$

Slit Width & Amplitude Relations:

$$\frac{w_1}{w_2} = \frac{I_1}{I_2} = \frac{A_1^2}{A_2^2} \implies \frac{I_{max}}{I_{min}} = \left(\frac{A_1+A_2}{A_1-A_2}\right)^2 = \left(\frac{\sqrt{w_1}+\sqrt{w_2}}{\sqrt{w_1}-\sqrt{w_2}}\right)^2$$

4. YOUNG'S DOUBLE SLIT EXPERIMENT (YDSE)

Setup: Slit separation $= d$, Slit-to-Screen distance $= D$.
Path Difference at point P on screen at distance y from center:

$$\Delta x = S_2P - S_1P \approx d\sin\theta \approx \frac{y\cdot d}{D}$$

1. Bright Fringes (Constructive Interference):

- Path difference: $\Delta x = n\lambda \quad (n = 0, 1, 2, \dots)$
- Position from central max: $y_n = \frac{n\lambda D}{d}$

2. Dark Fringes (Destructive Interference):

- Path difference: $\Delta x = (2n+1)\frac{\lambda}{2} \quad (n = 0, 1, 2, \dots)$
- Position from central max: $y_n = \frac{(2n+1)\lambda D}{2d}$

Fringe Width (β): Distance between two successive bright or dark fringes:

$$\boxed{\beta = \frac{\lambda D}{d}}$$

- **Angular Fringe Width:** $\theta_0 = \frac{\beta}{D} = \frac{\lambda}{d}$ (Independent of screen distance D).
- **Immersion in Medium:** Entire setup immersed in liquid of ref. index $\mu \implies \beta_{medium} = \frac{\beta_{air}}{\mu}$ (Fringes shrink).

5. DIFFRACTION DUE TO SINGLE SLIT

Bending of light around corners of an obstacle/aperture of size comparable to λ. Slit width $= a$.

Condition for Minima (Dark Fringes):

$$a\sin\theta = n\lambda \implies y_n = \frac{n\lambda D}{a} \quad (n = \pm1, \pm2, \dots)$$

Warning: $n = 0$ corresponds to the central maximum, not a minimum!

Condition for Secondary Maxima (Bright Fringes):

$$a\sin\theta = (2n+1)\frac{\lambda}{2} \implies y_n = \frac{(2n+1)\lambda D}{2a}$$

Central Maximum Dimensions:

- **Angular Width:** $2\theta = \frac{2\lambda}{a}$
- **Linear Width:** $W_0 = \frac{2\lambda D}{a} = 2\beta_{diff}$

Key Takeaway: The central maximum in single-slit diffraction is **twice as wide** as any secondary maximum, and holds most of the total intensity.

6. INTERFERENCE VS DIFFRACTION

Feature	Interference (YDSE)	Diffraction (Single Slit)
Origin	Superposition of waves from **two distinct** coherent slits.	Superposition of wavelets from **different parts of same** slit.
Fringe Width	All fringes have **equal width** ($\beta = \lambda D/d$).	Central maximum is **double** the width of secondary maxima.
Intensity	All bright fringes have **uniform maximum intensity**.	Intensity falls off rapidly for higher-order secondary maxima.

7. QUICK RECALL & PYQ TIPS (MANDATORY)

- **Optical Path:** Distance light travels in vacuum in the same time it travels distance x in medium: $x_{optical} = \mu x$.
- **Insertion of Thin Plate:** Placing a glass slab of thickness t and ref. index μ in front of one slit introduces path diff $\Delta x = (\mu - 1)t$.
  Fringe Shift: Pattern shifts towards covered slit by:

$$\Delta y = \frac{D}{d}(\mu-1)t = \frac{\beta}{\lambda}(\mu-1)t$$

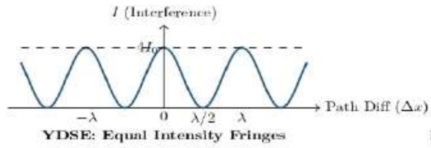
- **Sustained Interference:** Coherent, monochromatic, narrow slits, small separation d, large screen distance D.
- **White Light Source:** Central fringe is **white**. Closest side fringe is **violet** (λ min), outermost is **red**.

8. TRICKS & COMMON MISTAKES

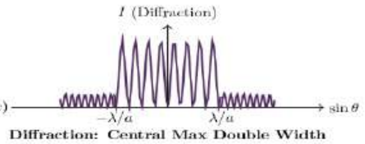
COMMON MISTAKE ALERT:

- **Formula Reversal:** In YDSE, $n\lambda$ gives **BRIGHT** fringes. In Single Slit Diffraction, $n\lambda$ gives **DARK** minima. Never mix them up!
- **Intensity Ratio Error:** Remember intensity $I \propto A^2$, so finding I_{max}/I_{min} requires taking square roots of individual intensities first.

Symbols: λ: Wavelength (m), β: Fringe width (m), D: Distance to screen (m), d, a: Slit sizes (m), μ: Refractive index.



YDSE: Equal Intensity Fringes



Diffraction: Central Max Double Width

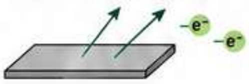
CHAPTER 11

Dual Nature of Radiation and Matter

1. ELECTRON EMISSION

Emission of electron from a metal surface.

1. Thermionic emission (when metal is heated)
2. Field emission (very strong electric field)
3. Photoelectric emission (light of suitable frequency)



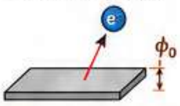
2. WORK FUNCTION (ϕ_0)

Minimum energy required to escape from metal surface.

$$\boxed{1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}}$$

Work function of:

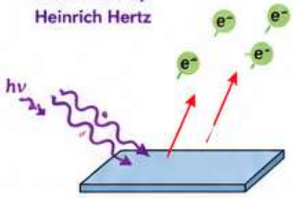
- Platinum = 5.65 eV (highest)
- Caesium = 2.14 eV (lowest)



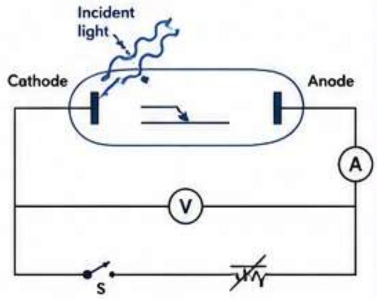
3. PHOTOELECTRIC EFFECT

Emission of electrons from metal surface when light of suitable frequency illuminates it.

Discovered by Heinrich Hertz



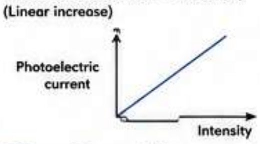
4. LENARD'S EXPERIMENTAL SETUP



5. EFFECTS ON PHOTOELECTRIC CURRENT

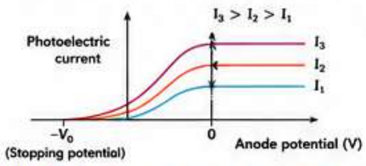
(i) Effect of Intensity (ν, V constant)

Photoelectric current ∝ Intensity
(Linear increase)



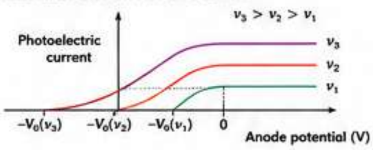
(ii) Effect of Potential (ν constant)

- Increasing positive potential → current increases until saturation.
- Negative potential → current decreases.
- At stopping potential (V_0), current becomes zero.



(iii) Effect of Frequency (Intensity constant)

- Greater frequency → greater stopping potential → greater K_{max}
- Saturation current remains same.



6. LAWS OF PHOTOELECTRIC EFFECT

1. Photoelectric current ∝ intensity of radiation (for fixed frequency).
2. Saturation current ∝ intensity; stopping potential is independent of intensity.
3. No emission occurs below threshold frequency (ν_0).
4. K_{max} ∝ frequency of incident radiation (ν); independent of intensity.
5. Photoelectric emission is instantaneous (delay $\asymp 10^{-9}$ s).

7. FAILURE OF CLASSICAL THEORY

Wave theory predicts electron absorbs energy continuously.

Contradictions:

a. K_{max} should depend on intensity (Observed: depends on frequency)
b. Any frequency should cause emission (Observed: only above threshold freq.)
c. Should be delayed process (Observed: instantaneous)

8. EINSTEIN'S PHOTOELECTRIC EQUATION

Photon energy $= h\nu = K_{max} + \phi_0$

$$\boxed{K_{max} = h(\nu - \nu_0)}$$

where, ν_0 = threshold frequency $= \dfrac{\phi_0}{h}$

Explanation of Laws

- Intensity ↑ → photon number ↑ → current ↑
- If $\nu < \nu_0$ → K_{max} negative (impossible) → no emission
- Photon–electron interaction is instantaneous → no time lag

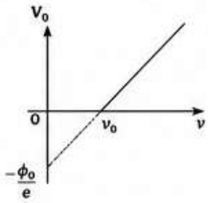
9. GRAPH (ν vs STOPPING POTENTIAL)

$$V_0 = \left(\frac{h}{e}\right)\nu - \frac{\phi_0}{e}$$

Straight line

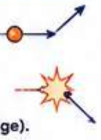
Slope $= \dfrac{h}{e}$

y–intercept $= -\dfrac{\phi_0}{e}$



10. PARTICLE NATURE OF LIGHT

- Light interacts with matter as photons. Photon energy: $h\nu$; Photon momentum: $\frac{h\nu}{c}$
- Photons have no charge → not deflected by E or B fields.
- Photon collisions conserve energy & momentum (number of photons may change).
- Compton scattering confirmed particle nature of light.



11. DUAL NATURE OF RADIATION

Wave Nature	Particle Nature
• Interference	• Photoelectric effect
• Diffraction	• Compton scattering
• Polarisation	

⇒ Light shows wave–particle duality

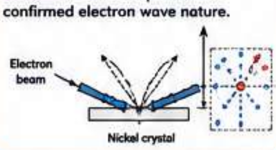
12. DUAL NATURE OF MATTER

Louis de Broglie (1924) proposed partiicles have wave nature.

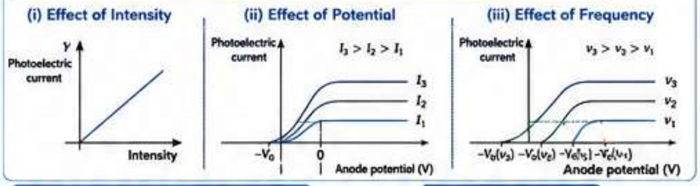
de-Broglie Equation

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2meV}}$$

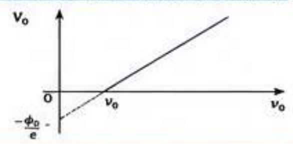
Davisson–Germer experiment confirmed electron wave nature.



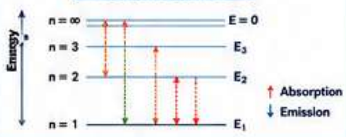
13. PHOTOELECTRIC EFFECT – ALL GRAPHS



14. PHOTOELECTRIC EQUATION GRAPH (V_0 vs ν)

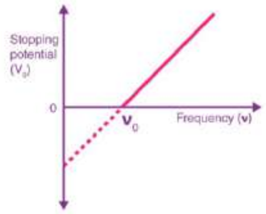


15. ENERGY DIAGRAM



MULTIPLE CHOICE QUESTIONS

1. A graph is plotted between the stopping potential (on y-axis) and the frequency of incident radiation (on x-axis) for a metal. The product of the slope of the straight line obtained and the magnitude of charge on an electron is equal to:



(a)h (b) h/c (c) h/2c (d)2h/c

2. A metal surface ejects electrons when hit by green light but none when hit by yellow light. The electrons will b e ejected when the surface is hit by:
(a). blue light (b). heat rays (c). infrared light (d). red light

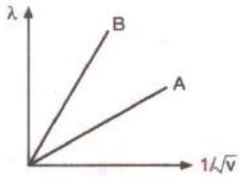
3. The work- function of a substance is 4.0 eV. The longest wavelength of light that can cause photoelectron emission from this substance is approximately: -
(a) 540 nm (b) 400 nm (c) 310 nm (d) 220 nm

4. Photoelectric effect takes place in element A. Its work function is 2.5 eV and threshold wavelength is λ. An other element B is having work function of 5 eV. Then find out the maximum wavelength that can produce photoelectric effect in B: -
(a) λ/2 (b) 2λ (c) λ (d) 3λ

5. The de-Broglie wavelength of a neutron in thermal equilibrium with heavy water at a temperature T (Kelvin) and mass m, is
(a)$\frac{h}{\sqrt{mkT}}$ (b) $\frac{h}{\sqrt{3mkT}}$ (c) $\frac{2h}{\sqrt{3mkT}}$ (d) $\frac{2h}{\sqrt{mkT}}$

6. The photoelectric threshold wavelength of silver is 3250×10^{-10} m. The velocity of the electron ejected from a silver surface by ultraviolet light of wavelength 2536×10^{-10} m is: (Given: $h = 4.14 \times 10^{-15}$ eV s and $c = 3 \times 10^{8}$ m s^{-1})
(a) $\approx 6 \times 10^5$ m s^{-1} (b) $\approx 0.6 \times 10^4$ m s^{-1} (c) $\approx 61 \times 10^3$ m s^{-1} (d) $\approx 0.3 \times 10^6$ m s^{-1}

7. The two lines A and B shown in figure are the graphs of the de Broglie wavelength λ as a function of $1/\sqrt{V}$ (V is the accelerating potential) for two particles having the same charge.
Which of the two represents the particle of heavier mass ?



(a) A (b) B
(c) Both A and B (d) Insufficient Data

8. When the light of frequency $2\nu_0$ (where ν_0 is threshold frequency), is incident on a metal plate, the maximum velocity of electrons emitted is v_1 When the frequency of the incident radiation is increased to $5\nu_0$, the maximum velocity of electrons emitted from the same plate is v_2.The ratio of v_1 to v_2 is
(a) 4 : 1 (b) 1 : 4 (c) 1 : 2 (d) 2 : 1

9. Photons with energy 5 eV are incident on a cathode C in a photoelectric cell. The maximum energy of emitted photoelectrons is 2 eV. When photons of energy 6 eV are incident on C, no photoelectrons will reach the anode A, if the stopping potential of A relative to C is
(a) +3 V (b) +4 V (c) -1 V (d) -3 V

10. An electron of mass m and a photon have same energy E. the ratio of de-Broglie wavelengths associated with them is:
(a)$\frac{1}{c}\left[\frac{E}{2m}\right]^{\frac{1}{2}}$ (b) $\left[\frac{E}{2m}\right]^{\frac{1}{2}}$ (c) $c[2mE]^{\frac{1}{2}}$ (d) $\frac{1}{c}\left[\frac{2m}{E}\right]^{\frac{1}{2}}$

11. When the mass of an electron becomes equal to thrice its rest mass, its speed is

(a) $\frac{2\sqrt{2}}{3}$c (b) $\frac{2}{3}$c (c) $\frac{1}{3}$c (d) $\frac{1}{4}$c

12. Which of the following cannot be observed by an increase in the intensity of light alone?

(a) Increase in photocurrent (b) Increase in stopping potential

(c) Increase in number of emitted electrons (d) Increase in rate of emission

13. In an experiment, intensity of light is increased but photoelectric current remains constant after sometime. This is due to:

(a) saturation current has been reached

(b) frequency of light is below threshold

(c) work function is larger than incident photon energy

(d) electrons are absorbed back

14. The photoelectric current becomes zero when:

(a) The intensity of light is zero (b) Frequency is below the threshold

(c) Work function is very high (d) Any of the above

15. In a photoelectric experiment with light of intensity I, the current is I_0. When light is filtered to allow only 50% photons through, the current becomes:

(a) $2\ I_0$ (b) $\frac{I_0}{2}$ (c) $\sqrt{2}\ I_0$ (d) Remains same

16. Consider a photoelectric tube where magnitude of negative anode potential is gradually increased. The photoelectric current decreases to zero because:

(a) Kinetic energy of electrons is reduced (b) All photons are absorbed

(c) Potential suppresses even fastest electrons (d) Frequency becomes less than threshold

17. In an experiment, when frequency is increased, the stopping potential increases linearly. This verifies:

(a) Planck's quantization (b) de Broglie relation

(c) Einstein's photoelectric equation (d) Wave-particle duality

18. Which observation supports the quantum nature of light?

(a) Instantaneous emission (b) KE ∝ frequency

(c) Threshold frequency exists (d) All of the above

19. In photoelectric emission, a radiation whose frequency is 2 times threshold frequency of a certain metal is incident on the metal. Then the maximum possible velocity of the emitted electron will be:

(a) $\sqrt{\frac{h\nu_0}{m}}$ (b) $\sqrt{\frac{2h\nu_0}{m}}$ (c) $2\sqrt{\frac{h\nu_0}{m}}$ (d) $\sqrt{\frac{6h\nu_0}{m}}$

20. For two particles with equal momenta, which of the following is true regarding their de Broglie wavelengths?

(a) The heavier particle has smaller wavelength (b) Both have same wavelength

(c) The faster particle has smaller wavelength (d) Depends on nature of the particles

Answers

1. a, 2. a, 3. c, 4. a, 5. b, 6. a, 7. a, 8. c, 9. d, 10. a,

11. a, 12. b, 13. a, 14. d, 15. b, 16. c, 17. c, 18. d, 19. b, 20. b

Assertion- Reason Type Questions

(A) Both (A) & (R) are true and the (R) is the correct explanation of the (A)
(B) Both (A) & (R) are true but the (R) is not the correct explanation of the (A)
(C) (A) is true but (R) is false
(D) Both (A) and (R) are false

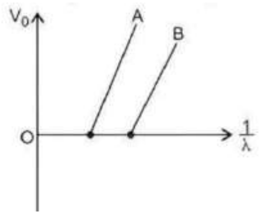
1. **Assertion:** At a fixed frequency above the threshold, doubling the intensity of light doubles the stopping potential.
   Reason: Stopping potential is proportional to the energy of the photoelectrons, which increases with intensity.
2. **Assertion**: Even when monochromatic light falls on a metal surface, the emitted photoelectrons have varying kinetic energies.
   Reason: Electrons originating from within the metal lose part of their energy due to collisions with other atoms before escaping the surface.
3. **Assertion:** A time delay is observed before photoelectrons are emitted from a metallic surface under light exposure.
   Reason: According to Einstein's theory, electrons take time to absorb sufficient energy from the incoming wavefront.
4. **Assertion:** A heavier particle moving slowly can have a longer de Broglie wavelength than a lighter particle.
   Reason: The de Broglie wavelength is independent of the particle's mass and velocity.
5. **Assertion:** An infinite time delay is observed when light of frequency less than the threshold is incident on a metal surface.
   Reason: According to Einstein's theory, electrons need to accumulate energy over time from multiple photons to be emitted.
6. **Assertion (A):** A beam of electrons with energy of 150 eV is incident on a crystal, and a diffraction pattern is observed. If the energy is increased to 600 eV, the fringe spacing in the diffraction pattern will decrease.
   Reason (R): The de Broglie wavelength of a particle is inversely proportional to the square root of its kinetic energy.
7. A photon and an electron both have energy 50 eV.
   Assertion (A): Both have different wavelengths.
   Reason (R): Wavelength depends on energy and not on mass.
8. **Assertion (A):** The relative velocity of two photons travelling in opposite directions is c.
   Reason (R): The rest mass of a photon is infinite.
9. **Assertion (A):** An electron microscope is based on de Broglie's hypothesis of matter waves.
   Reason (R): Higher the accelerating potential, smaller is the de Broglie wavelength of the electron.
10. **Assertion (A):** Photoelectric effect demonstrates the wave nature of light.
    Reason (R): The number of photoelectrons is proportional to the frequency of light.

Answers

1. D, 2. A, 3. D, 4. C, 5. C, 6. A, 7. C, 8. D, 9. A, 10. D

Short Answer Questions (2 marks each)

1. How will the de-Broglie wavelength associate with an electron be affected when the (i) velocity of the electron decreases? (i) accelerating potential is increased? Justify your answer.
2. (I) Define the terms, (a) threshold frequency and (b) stopping potential in photoelectric effect. (ii) Plot a graph of photocurrent versus anode potential for a radiation of frequency v and intensities I_1 and I_2 ($I_1 > I_2$).
3. Plot a graph showing variation of de-Broglie wavelength (λ) associated with a charged particle of mass m, versus $1/\sqrt{V}$, where V is the potential difference through which the particle is accelerated. How does this graph give information regarding the magnitude of charge of the particle?
4. An α-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de- Broglie wavelengths.
5. An electron and alpha particle have the same de-Broglie wavelength associated with them. How are their kinetic energies related to each other?
6. Figure shows the stopping potential (V_0) for the photoelectron versus 1/λ graph, for two metals A and B, λ being the wavelength of incident light. (i) How is the value of Planck's constant determined from the graph? (ii) If the distance between the light source and the surface of metal A is increased, how will the stopping potential from electrons emitted from it be effected?



7. If light of wavelength 412.5 nm is incident on each of the metals given below, which one will show photoelectric emission and why?

Metal	Work Function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

8. An electron is accelerated through a potential difference of 100 volts. What is the de-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond?
9. If an electron has a wavelength, does it also have a colour?
10. A parallel beam of monochromatic light of wavelength 663 nm is incident on a totally reflecting plane mirror. The angle of incidence is 60° and the number of photons striking the mirror per second is 1.0×10^{19}. Calculate the force exerted by the light beam on the mirror.

Answers

Ans – 1 -(i) According to the de-Broglie wavelength formula. the wavelength i s inversely proportional to the momentum of the electron. As momentum is the product of mass and velocity, when the velocity of the electron decreases. its momentum also decreases. Therefore, the de-Broglie wavelength of the electron will increase.

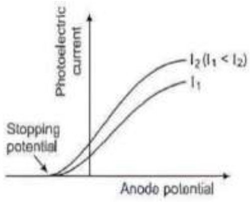
(ii) When the accelerating potential is increased the velocity of the electron also Increases. As a result, the momentum of the electron increases. and according to the de-Broglie wavelength formula, the wavelength decreases. Therefore, the de-Broglie wavelength of the electron will decrease.

Justification: According to de-Broglie wavelength $\lambda = \frac{h}{p}$, if the velocity of the electron decreases. The momentum of the electron also decreases. Resulting in an increase in the de-

Broglie wavelength. Similarly. if the accelerating potential is increased. the velocity of the electron increases. leading to an increase in the momentum of the electron and a decrease in the de-Broglie wavelength.

Ans – (2)- 1(a) Threshold frequency: The minimum value of frequency of incident radiation that can cause photoemission from a given photo sensitive surface is called threshold frequency.

(b) Stopping potential: The minimum negative retarding potential given to the anode i.e. collector plate with respect to cathode for which the photocurrent stops or becomes zero is called stopping potential

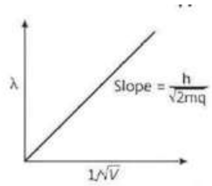


(ii) Graph of photocurrent versus anode potential.

3. The de-Broglie wavelength is $\lambda_1 = \frac{h}{p} = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2mqV}} => \lambda \, \alpha \, \frac{1}{\sqrt{V}}$

So. the graph between λ & $\frac{1}{\sqrt{V}}$

Thus. it gives a straight line graph. Knowing the mass of particle (m). and slope of graph. we can calculate charge (q) on a particle.



4. The ratio of the de Broglie wavelength of an α particle (λ_α) to that of a proton (λ_p) accelerated from rest by the same potential is

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h/\sqrt{2m_\alpha q_\alpha V}}{h/\sqrt{2m_p q_p V}} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}} => \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p \cdot e}{4m_p \cdot 2e}} = \sqrt{\frac{1}{8}} = \frac{1}{2\sqrt{2}}$$

5. $E_K = \frac{p^2}{2m}$ where, E_K = Kinetic Energy, p = momentum and m = mass

de-Broglie wavelength, $\lambda = \frac{h}{p}$, where, h = Planck's constant Therefore, $\lambda = \frac{h}{\sqrt{2mE_K}}$

Both the particles have the same de-Broglie wavelength. (Given) $\therefore \frac{h}{\sqrt{2m_e E_{Ke}}} = \frac{h}{\sqrt{2m_\alpha E_{K\alpha}}}$

or, $\frac{m_e}{m_\alpha} = \frac{E_{K\alpha}}{E_{Ke}}$ As, $m_\alpha > m_e \therefore E_{Ke} > E_{K\alpha}$

6.(i) We can determine Planck's constant by calculating the slope of the graph.

Since we know that Slope of the graph $= \frac{hc}{e}$, where, h = Planck's constant, c = velocity of light in vacuum and e = charge of electron

(ii) If distance between source of light and surface of metal A is increased, the intensity of incident light decreases, but stopping potential does not depend on the intensity of the incident light. So, the stopping potential will not be affected.

7. Given, $\lambda = 412.5$ nm $= 412.5 \times 10^{-9}$ m

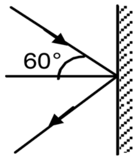
$E = hc/\lambda = (6.62\times10^{-34} \times 3\times10^{8}) / (412.5\times10^{-9} \times 1.6\times10^{-19})$ eV $= 3.01$ eV

This energy of the incident radiation is greater than the work function of Na and K but less than those of Ca and Mo, so photoelectric emission will occur only in Na and K metals and not in Mo and Ca.

8. $\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{100}} = 1.227\ A°$. This wavelength corresponds to X-rays.

9. Colour is a characteristic of electromagnetic waves. Electrons behave as a de- Broglie wave because of their velocity. A de-Broglie wave is not an electromagnetic wave and is one dimensional. Hence, no colour is shown by an electron.

10. $\lambda = 663 \times 10^{-9}$ m, $\theta = 60°$, n = 1×10^{19}, $\lambda = \frac{h}{p} \Rightarrow p = \frac{h}{\lambda} = 10^{-27}$



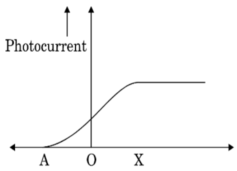
Force exerted on the wall = n(mvcos θ − (−mvcos θ))

=2n mvcos θ = 2n pcos θ

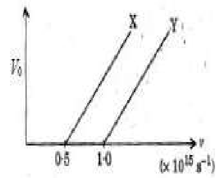
= $2 \times 1 \times 10^{19} \times 10^{-27} \times$ ½ = 1×10^{-8} N.

Short Answer type Questions (3 Marks each)

1. The following graph shows the variation of photocurrent for a photosensitive metal:



   a) Identify the variable X on the horizontal axis.
   b) What does the point A on the horizontal axis represent?
   c) Draw this graph for three different values of frequencies of incident radiation ν_1, ν_2 and ν_3 ($\nu_1 > \nu_2 > \nu_3$) for same intensity.
   d) Draw this graph for three different values of intensities of incident radiation I_1, I_2, and I_3 ($I_1 > I_2 > I_3$) having same frequency.
2. In a plot of photoelectric current versus anode potential, how does?
   a) The saturation current vary with anode potential for incident radiations of different frequencies but same intensity?
   b) The stopping potential vary for incident radiations of different intensities but same frequency?
   c) Photoelectric current vary for different intensities but same frequency of incident radiations? Justify your answer in each case.
3. The following graph shows the variation of stopping potential V_0 with the frequency ν of the incident radiation for two photosensitive metals X & Y:



   a) Which of the metals has larger threshold wavelength? Give reason.
   b) Explain, giving reason, which metal gives out electrons, having larger kinetic energy, for the same wavelength of the incident radiation.
   c) If the distance between the light source and metal X is halved, how will the kinetic energy of electrons emitted from it change? Give reason.
4. Two neutral particles are kept 1m apart. Suppose by some mechanism some charge is transferred from one particle to the other and the electric potential energy lost is completely converted into a photon. Calculate the longest and the next smaller wavelength of the photon possible.
5. Why do different metals emit electrons only when exposed to light of certain minimum frequencies? The threshold frequency of a metal is f_0. When the light of frequency $2f_0$ is incident on the metal plate, the maximum velocity of electrons emitted is v_1 . When the frequency of the incident radiation is increased to $5f_0$ the maximum velocity of electrons emitted is v_2. Find the ratio of v_1 to v_2.
6. An electron and a photon each have a wavelength 1.00 nm. Find:
   a) Their momenta, b) The energy of the photon and, c) The kinetic energy of electron
7. Explain by giving reasons for the following:
   a) Photoelectric current in a photocell increases with the increase in the intensity of the incident radiation.
   b) The stopping potential (V_0) varies linearly with the frequency (ν) of the incident radiation for a given photosensitive surface with the slope remaining the same for

different surfaces.

c) Maximum kinetic energy of the photoelectrons is independent of the intensity of incident radiation.

8. A photoelectric cell has two plates 2 cm apart with no external battery connected. Light of wavelength 310 nm is incident on a metal surface of work function 2.3 eV. An electric field of 2×10^{2} N/C exists between the plates, directed such that it opposes the motion of emitted electrons. (a) Calculate the maximum kinetic energy of emitted photoelectrons. (b) Calculate the work done by the electric field against the electrons. (c) Will any photoelectrons reach the collector plate? Justify.

9. An electron is accelerated through a potential of 100 V and directed toward a thin metal foil with atomic spacing 0.2 nm.

(a) Calculate the de Broglie wavelength of the electron.

(b) Will diffraction be observed?

(c) What happens to the wavelength if the voltage increases to 400 V?

10. A particle of mass m and charge q is accelerated through a potential difference V. Plot a graph of de-Broglie wavelength λ associated with it as a function of V. (ii) Calculate the energy acquired by and de-Broglie wavelength associated with, an electron accelerated through a potential difference of 400V.

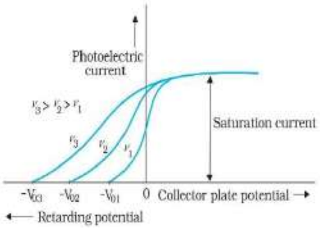
ANSWERS

1.

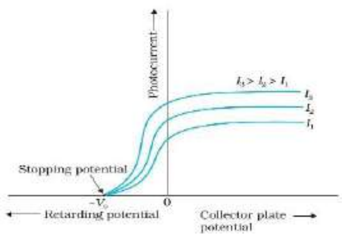
a. X is collector plate potential.

b. A is stopping potential.

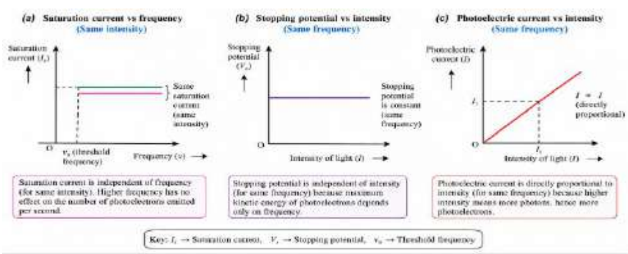
c. Graph for different frequencies.



Graph for three different Intensities



2. i. Saturation current does not change.
ii. Stopping potential does not change.
iii. Photoelectric current increases with increase in intensity.



3. 'X' as it has smaller threshold frequency.

a) $KE_{max} = h\nu - \phi_0$

Since $\phi_y > \phi_x \Rightarrow K_y < K_x$ therefore 'X' gives out electrons with larger KE.

b) No change as KE of photoelectron does not depend on the intensity of incident radiations.

4. r = 1m

Potential Energy= $\frac{kq^2}{r} = \frac{kq^2}{1}$, Energy of photon= $\frac{hc}{\lambda} = \frac{kq^2}{1} \Rightarrow \lambda = \frac{hc}{kq^2}$

For max λ , 'q' should be min, i.e q = e = 1.6×10^{-19} C

Substituting we get, $\lambda_{max} = 863\ m$

For next smaller wavelength, $q = 2e$ and $\lambda = \frac{863}{4} = 215.74\ m.$

5. There is minimum energy required to free an electron from its surface binding called work function.

Einstein's photoelectric equation is hν = hν_0 + $\frac{1}{2}$ mv^2

In first case ν = $2f_0$, $\nu_0 = f_0$, ν = v_1 , hence **h(2f_0)= hf_0 +** $\frac{1}{2}$ $\boldsymbol{m}\ v_1{}^2 \Rightarrow \frac{1}{2}\boldsymbol{m}\ v_1{}^2 = \mathbf{h}f_0$

Similarly in second case we get, $\frac{1}{2}m\ v_2{}^2 = 4\mathrm{h}f_0$, Dividing both we get, $\frac{v_1}{v_2} = \sqrt{\frac{hf_0}{4hf_0}} = \frac{1}{2}$

6. $\lambda_e = \lambda$ photon = 1.00nm = 10^{-9}m.

a) For electron or photon, momentum p = $\frac{h}{\lambda} = \frac{6.63\times10^{-34}}{10^{-9}} = 6.63 \times 10^{-25}$ kg m/s

b) Energy= $\frac{hc}{\lambda}$ = 19.89 × 10^{-17} J (≈ 124 eV)

c) Kinetic energy of electron= $\frac{p^2}{2m} = 2.42 \times 10^{-19}J = 1.51\ eV$

7. a) The collision of a photon can cause emission of a photoelectron (above the threshold frequency). As intensity increases, number of photons increases. Hence the current increases.

b) We have, $eV_s = h(\nu - \nu_o)$, $\quad V_s = \frac{h}{e}\nu + (-\frac{h}{e})\nu_o$

∴ Graph of V_s with ν is a straight line and slope (h/e) is a constant.

c) According to Einstein's photoelectric equation ($KE_{max} = h\nu - \phi_0$), KE is independent of intensity.

8. a) $KE_{max} = h\nu - \phi_0 = \frac{hc}{e\lambda} - \phi_0 = \frac{6.4\times10^{-19}}{1.6\times10^{-19}} - 2.3 = 1.7\ eV$

b) $W = eEd = 1.6 \times 10^{-19} \times 2 \times 10^2 \times 0.02 = 4\ eV$

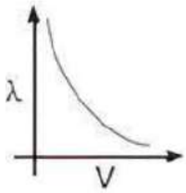
c) $KE_{max} < W$, No, photoelectrons will not reach the collector plate. The electric field does more work than the electrons' available kinetic energy, so they are stopped before reaching the collector.

9. a) $\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{100}} = 1.227\ A°$

b) Yes, diffraction will be observed if the wavelength is comparable to the atomic spacing of the target material.

Calculated wavelength: 0.123 nm Atomic spacing: 0.2 nm

Since λ~d, diffraction will occur.



d) When voltage is increased to four times, the wavelength is reduced to half and hence fringe width decreases.

10. (i) Graph showing de-Broglie wavelength & associated with as a function of V

(ii) Given, Potential difference V = 400V

∴ Energy = q · V = $1.6\times10^{-19} \times 400 = 640\times10^{-19}$ J = 6.40×10^{-17} Joule.

de-Broglie wavelength λ = 12.27/√V = 12.27/√400 = 12.27/20 = 0.6135 Å = 6.135×10^{-11} m

CASE STUDY BASED QUESTIONS (4 MARKS)

Case Study: Smart Door Lock with Fingerprint Scanner

1. In modern homes and offices, smart biometric door locks that use fingerprint scanning have become popular. These devices work based on the photoelectric effect, a concept that demonstrates the dual nature of radiation. When you place your finger on the scanner, a beam of light, usually from a laser or LED source, illuminates your fingerprint. The light consists of photons (particles of light) that strike the surface of the finger. The ridges and valleys of the fingerprint reflect this light differently. Some parts absorb the photons, while others reflect them back to a sensor.

i. Why can't the wave theory of light alone explain the working of fingerprint scanners based on the photoelectric effect?

(A) The wave theory fails to explain reflection of light.
(B) The wave theory does not account for the threshold frequency required to emit electrons.
(C) The wave theory suggests light can't interact with electrons.
(D) The wave theory explains the continuous emission of light, not its speed.

ii. What would happen if the intensity of light increased but its frequency remains below the threshold frequency in a fingerprint scanner?

(A) More electrons would be emitted with higher energy.
(B) The fingerprint image would become clearer.
(C) Electrons would emit with the same energy as before.
(D) The emission of electrons would not occur.

iii. How does the concept of de Broglie wavelength support the miniaturization and efficiency of the fingerprint scanner's electronic components?

(A) By allowing light to be diffracted and focused more accurately.
(B) By explaining how heat is dissipated in semiconductors.
(C) By enabling high-resolution imaging using wave properties of electrons.
(D) By reducing the speed of electron movement in circuits.

iv. Which technological limitation would most directly challenge the use of wave nature of electrons in fingerprint sensor development?

(A) Requirement for extremely small de Broglie wavelengths for high resolution
(B) Slow scanning speed
(C) Difficulty in focusing particle beams
(D) Interference from ambient light

OR

Suppose a new fingerprint scanner is designed using blue light instead of red light. What would be the most likely outcome regarding the photoelectric effect?

(A) The emitted electrons would have lower kinetic energy.
(B) The emission of electrons would decrease due to lower intensity.
(C) The emitted electrons would have higher kinetic energy due to higher photon frequency.
(D) The resolution of the scanner would decrease.

Case Study: Automatic Sliding Doors

2. Automatic sliding doors are now a common feature at the entrances of supermarkets and malls. These doors open when a person approaches. One common mechanism used in such systems is an infrared motion sensor, which detects changes in infrared radiation emitted or reflected by a human body. These sensors rely on the particle nature of light (photons) to detect motion. The human body emits infrared radiation, and when this radiation is incident on a photodiode or sensor, it gets absorbed, causing electron excitation and the generation of a signal.

i. Why is infrared radiation suitable for motion detection in automatic doors, considering the concept of dual nature of light?
(A) Because it consists of photons that can be detected by a photoelectric sensor
(B) Because it is not absorbed by human skin
(C) Because it reflects better than visible light
(D) Because it has the highest frequency among radiations

ii. How does the photoelectric effect contribute to the function of motion sensors in automatic doors?
(A) It enables light waves to diffract around the human body
(B) It measures temperature differences
(C) It causes infrared photons to trigger electron emission in the sensor
(D) It allows the human body to reflect visible light better

iii. If the frequency of infrared radiation emitted by the human body were lower than the threshold frequency of the sensor's material, what would happen?
(A) The sensor would detect motion faster
(B) The door would open before the person arrived
(C) No electrons would be emitted, so the door wouldn't open
(D) More current would be generated

iv. Which property of electrons is exploited when using electron beam microscopes to design sensor components for automatic doors?
(A) Their energy levels (B) Their mass (C) Their wave-like nature (D) Their charge only

OR

A new sensor is developed with a material having a higher work function. What change must be made to ensure continued efficient operation using the same infrared radiation?
A. Reduce the ambient temperature B. Increase the intensity of radiation
C. Decrease the distance from the sensor. D. Increase the frequency of incident photons

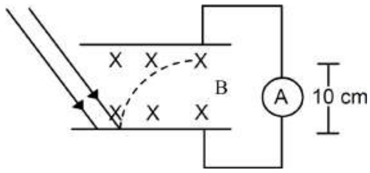
ANSWERS

1.	i) B	ii) D	iii) C	iv) A or C
2.	i) A	ii) C	iii) C	iv) C or D

LONG ANSWER TYPE QUESTIONS (5 Marks)

1. a) Light of a particular wavelength does not eject electrons from the surface of a given metal. Should the wavelength of the light be increased or decreased in order make ejection of electrons possible? Justify.

b) In an experiment on photoelectric effect, the emitter and the collector plates are placed at a separation of 10 cm and are connected through an ammeter without any cell. A magnetic field B exists parallel to the plates. The work function of the emitter is 2.39 eV and the light incident on it has wavelengths between 400 nm and 600 nm. Find the minimum value of B for which the current registered by the ammeter is zero. Neglect any effect of space charge.



2. a) A particle of mass M at rest decays into two particles of masses m_1 and m_2 having non-zero velocities. What is the ratio of de Broglie wavelengths of the two particles?

   b) Determine the value of the de Broglie wavelength associated with the electron orbiting in the ground state of hydrogen atom. How will the de Broglie wavelength change when it is in the first excited state?

3. a) A beam of monochromatic radiation is incident on a photosensitive surface. Answer the following questions giving reasons:

   (i) Do the emitted photoelectrons have the same kinetic energy?

   (ii) Does the kinetic energy of the emitted electrons depend on the intensity of incident radiation?

   (iii) On what factors does the number of emitted photoelectrons depend?

b) A satellite in space is fitted with a photoelectric sensor to detect solar flares. The sensor uses a metal surface with a work function of 2.2 eV & is exposed to solar radiation of wavelength 330 nm. The emitted electrons are collected in a spherical metal shell of radius 10 cm that surrounds the sensor plate. Due to limited power on the satellite, no external electric field is used to collect the electrons. Instead, the sensor relies on the natural motion of photoelectrons. As electrons accumulate on the shell, they develop a negative potential that begins to repel further photoelectrons. Calculate the maximum charge that can accumulate on the spherical shell before photoemission stops.

ANSWERS

1. a) The wavelength should be decreased because photon energy is inversely proportional to wavelength (E=hc/λ). Decreasing the wavelength increases the energy of incident photons, making it possible to overcome the metal's work function and eject electrons.

b) $\phi_0 = 2.39$ev $\lambda_1 = 400$ nm, $\lambda_2 = 600$ nm

for B to be minimum, energy should be maximum $\therefore \lambda$ should be minimum (i.e. λ_1)

$$K = \frac{hc}{\lambda} - \phi_0 = 3.105 - 2.39 = 0.715\ eV = 1.144 \times 10^{-19} J$$

The presence of magnetic field will bend the beam and there will be no current if the electron does not reach the other plate.

$$r = \frac{mv}{qB} = \frac{\sqrt{2mK}}{qB} \Rightarrow B = \frac{\sqrt{2mK}}{qr} = \frac{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.144 \times 10^{-19}}}{1.6 \times 10^{-19} \times 0.1} = 2.85 \times 10^{-5}\, T$$

2. a) According to the law of conservation of momentum, the momentum of a system remains conserved.

$$Mv = m_1v_1 + m_2v_2 \Rightarrow 0 = m_1v_1 + m_2v_2 \Rightarrow m_1v_1 = -m_2v_2$$

So, we can write, $p_1 = p_2 \Rightarrow \frac{hc}{\lambda_1} = \frac{hc}{\lambda_2} \Rightarrow \frac{\lambda_1}{\lambda_2} = 1$

b) In ground state, the kinetic energy of the electron is, $K = 13.6\ eV = 2.18 \times 10^{-18}\ J$

$$\lambda_0 = \frac{h}{\sqrt{2mK}} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 2.18 \times 10^{-18}}} = 3.32 \times 10^{-10}\ m$$

In the first excited state, $K = \frac{13.6}{2^2} = \frac{13.6}{4}$ so we get $\lambda_1 = 2 \times \lambda_0 = 6.64 \times 10^{-10}\ m$

3. a) (i) No, the emitted photoelectrons do not have the same kinetic energy because some electrons lose part of their energy overcoming the surface barrier inside the material.

(ii) No, the kinetic energy of the emitted electrons depends only on the frequency of the incident radiation, not on its intensity.

(iii) The number of emitted photoelectrons depends on the intensity of the incident radiation and the area exposed.

b) $E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{330\times10^{-9}} = 6.03 \times 10^{-19} J$

$\phi = 2.2\ eV = 2.2\ \times 1.6 \times 10^{-19} = 3.52 \times 10^{-19}$

$$KE_{max} = E - \phi = 6.03 \times 10^{-19} - 3.52 \times 10^{-19} = 2.51 \times 10^{-19} J$$

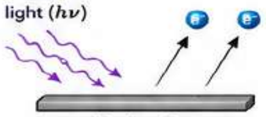
Stopping potential, $V_0 = \frac{KE_{max}}{e} = \frac{2.51\times10^{-19}}{1.6\times10^{-19}} = 1.57\ V$

$$V = \frac{kq}{r} \Rightarrow q = \frac{Vr}{k} = \frac{1.57 \times 0.1}{9 \times 10^{9}} = 1.75 \times 10^{-11} C$$

DUAL NATURE OF RADIATION AND MATTER

CBSE Class XII Physics | NCERT Quick Revision Infographic

1. PHOTOELECTRIC EFFECT



When light of suitable frequency falls on a metal surface, electrons are emitted from the surface. These emitted electrons are called photoelectrons.

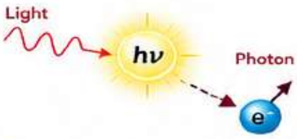
KEY FORMULAE

- $K_{max} = h\nu - \phi_0$
- $eV_0 = h\nu - \phi_0$
- $\nu_0 = \dfrac{\phi_0}{h}$
- $\lambda_0 = \dfrac{hc}{\phi_0}$
- $K_{max} = \dfrac{1}{2}mv^2$

ϕ_0 = Work function (eV)
V_0 = Stopping potential (V)
ν_0 = Threshold frequency
λ_0 = Threshold wavelength

2. EINSTEIN PHOTON THEORY

Light consists of tiny packets of energy called photons.



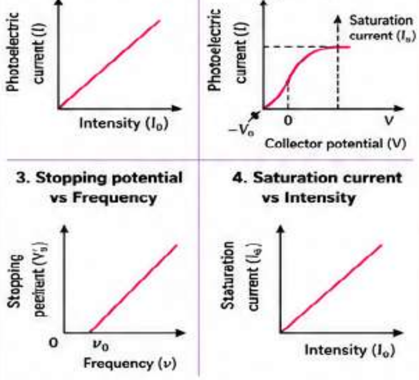
- One photon of energy $h\nu$ interacts with one electron.
- Entire energy is transferred.
- If $h\nu > \phi_0$, electron is emitted with kinetic energy K_{max}.

PHOTON & RADIATION

- $E = h\nu$ (Energy of photon)
- $E = \dfrac{hc}{\lambda}$
- $p = \dfrac{h\nu}{c}$ (Momentum)
- $p = \dfrac{h}{\lambda}$

$h = 6.626 \times 10^{-34}$ J s (Planck's constant)
$c = 3 \times 10^8$ m s^{-1} (Speed of light)

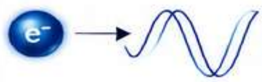
3. EXPERIMENTAL GRAPHS



- I_s (Saturation current) increases with intensity.
- V_0 (Stopping potential) increases with frequency.
- Photoelectric current becomes zero at $V = -V_0$.

4. de BROGLIE MATTER WAVES

Particles like electrons show wave nature. Proposed by Louis de Broglie.



de BROGLIE RELATION

- $\lambda = \dfrac{h}{p}$ (Wavelength)
- $\lambda = \dfrac{h}{mv}$ (For non-relativistic particles)

λ = de Broglie wavelength
p = Momentum of particle
m = Mass of particle
v = Velocity of particle

★ Matter exhibits dual nature: Particles at one scale and waves at microscopic scale.

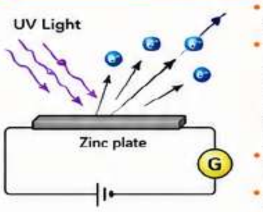
OBSERVATIONS IN PHOTOELECTRIC EFFECT

A. HERTZ' OBSERVATIONS (1887)

During electromagnetic wave experiments, Hertz observed that sparks across the detector were strengthened when the metal plate was illuminated by ultraviolet light.

Conclusion: Ultraviolet light enhances the electric discharge. (First observation of photoelectric effect)

B. HALLWACHS & LENARD OBSERVATIONS (1888 – 1902)



- Electrons are emitted from the zinc plate.
- For a given metal, there is a minimum frequency (Threshold frequency ν_0) below which no electrons are emitted, no matter how intense the light.
- Emission is instantaneous ($\sim 10^{-9}$ s).
- Depends on nature of material and frequency, not on intensity.

Conclusion: Existence of threshold frequency and instantaneous emission.

C. EXPERIMENTAL OBSERVATIONS (GENERAL)

1. Photoelectric current is directly proportional to intensity of incident light (for $\nu > \nu_0$).
2. Maximum kinetic energy (K_{max}) depends on frequency of light, not on intensity.
3. Stopping potential is independent of intensity but depends on frequency.
4. There exists a threshold frequency (ν_0) for each metal below which no photoelectrons are emitted.
5. Photoelectric emission is instantaneous ($\sim 10^{-9}$ s or less).
6. Current rises with collector potential and becomes constant (saturation current).

EINSTEIN'S PHOTOELECTRIC EQUATION

According to Einstein,

Incident photon of energy $h\nu$ → interacts with → One electron in metal surface

Energy used in: Overcoming work function (ϕ_0) | Kinetic energy of electron (K_{max})

$$h\nu = \phi_0 + K_{max}$$

(Einstein's Photoelectric Equation)

- If $h\nu < \phi_0$ ⟶ No emission
- If $h\nu = \phi_0$ ⟶ $K_{max} = 0$ (threshold condition)
- If $h\nu > \phi_0$ ⟶ $K_{max} > 0$

PARTICLE NATURE OF LIGHT (PHOTON)

- Light behaves as particles called photons.
- A photon has zero rest mass and travels at speed c in vacuum.
- Energy of photon: $E = h\nu$
- Momentum of photon: $p = \dfrac{h\nu}{c} = \dfrac{h}{\lambda}$
- Intensity of light depends on number of photons (more photons → more intensity).

WAVE–PARTICLE DUALITY

$E \propto \nu$ (Photon energy)
$I \propto$ Number of photons
$\nu > \nu_0$ for emission

MATTER WAVES

- Louis de Broglie proposed that every moving particle is associated with a wavelength.
- These waves are called matter waves.
- These waves are different from electromagnetic waves and are important at microscopic scale.

de Broglie Relation

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

where, $h = 6.626 \times 10^{-34}$ J s
p = momentum, m = mass, v = velocity

Key Points about Matter Waves

★ As momentum increases, λ decreases.
★ As mass increases, λ decreases.
★ Matter waves are significant for electrons, protons, neutrons at microscopic scale.

IMPORTANT POINTS

- Light has dual nature – wave nature (interference, diffraction) and particle nature (photoelectric effect).
- Photoelectric effect can be explained only by particle nature of light (photon theory).
- Matter also shows wave nature (de Broglie hypothesis).
- Dual nature is a fundamental concept of quantum physics.

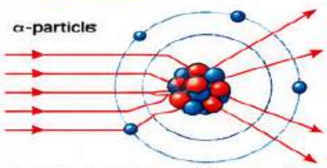
" Light is both a wave and a particle. Matter is also both a particle and a wave.

CHAPTER 12

ATOMS

1. RUTHERFORD'S ATOMIC MODEL

α-particle scattering experiment



On the basis of the α-particle scattering experiment, Rutherford made the following observations:

1. The entire positive charge and almost entire mass of the atom is concentrated at its centre in a very tiny region of the order of 10^{-15} m, called nucleus.
2. The negatively charged electrons revolve around the nucleus in different orbits.
3. The total positive charge on nucleus is equal to the total negative charge on electrons. Therefore, atom as a whole is neutral.
4. The centripetal force required by electron for revolution is provided by the electrostatic force of attraction between the electron and the nucleus.

2. SCATTERING GEOMETRY & RUTHERFORD FORMULA

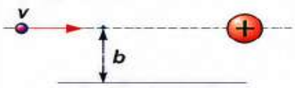
Distance of Closest Approach

$$r_0 = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E_K}$$

where, E_K = kinetic energy of the α-particle.

Impact Parameter

The perpendicular distance of the velocity vector of α-particle from the central line of the nucleus, when the particle is far away from the nucleus is called impact parameter.



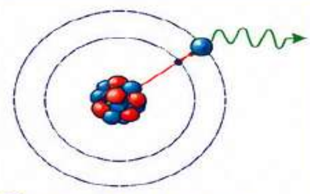
b = impact parameter

Rutherford's Scattering Formula

$$\frac{N(\theta)}{N_i} = \frac{nZ^2e^4t}{16\pi^2\varepsilon_0^2E^2}\frac{1}{\sin^4(\theta/2)}$$

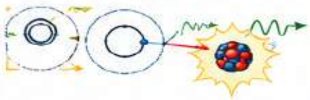
where, $N(\theta)$ = number of α-particles scattered at angle θ
N_i = total number of α-particles reaching the screen
n = number of atoms per unit volume in the foil
Z = atomic number
E = kinetic energy of the α-particles
t = foil thickness

3. LIMITATIONS OF RUTHERFORD MODEL



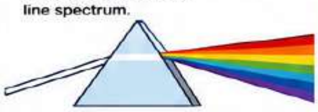
1 About the Stability of Atom

According to Maxwell's electromagnetic wave theory, electron should emit energy in the form of electromagnetic wave during its orbital motion. Therefore, radius of orbit of electron will decrease gradually and ultimately it will fall in the nucleus.

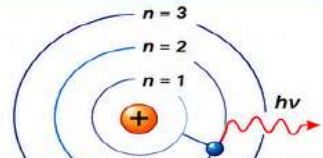


2 About the Line Spectrum

Rutherford atomic model cannot explain atomic line spectrum.



4. BOHR'S ATOMIC MODEL



- Electron can revolve in certain non-radiating orbits called stationary orbits for which the angular momentum of electron is an integer multiple of $\frac{h}{2\pi}$.

$$mvr = \frac{nh}{2\pi}$$

where n = 1, 2, 3, ... called principal quantum number.

- Radiation of energy occurs only when electron jumps from one permitted orbit to another permitted orbit.

$$h\nu = E_2 - E_1$$

where E_1 and E_2 are energies of electron in orbits.

5. QUANTITIES IN BOHR MODEL

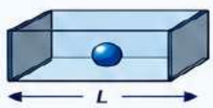
Radius of orbit	$r = \dfrac{n^2h^2}{4\pi^2mKZe^2}$	$\Rightarrow r \propto \dfrac{n^2}{Z}$
Velocity of electron	$v = \dfrac{2\pi KZe^2}{nh}$	$\Rightarrow v \propto \dfrac{Z}{n}$
Frequency of electron	$v = \dfrac{KZe^2}{nhr} = \dfrac{4\pi^2Z^2e^4mK^2}{n^3h^3}$	
Kinetic energy (E_K)	$E_K = \dfrac{2\pi^2me^4Z^2K^2}{n^2h^2} = \dfrac{13.6Z^2}{n^2}$ eV	
Potential energy (E_P)	$E_P = -\dfrac{4\pi^2me^4Z^2K^2}{n^2h^2} = -\dfrac{27.2Z^2}{n^2}$ eV	
Total energy (E)	$E = -\dfrac{2\pi^2me^4Z^2K^2}{n^2h^2} = -\dfrac{13.6Z^2}{n^2}$ eV	$\Rightarrow E \propto -\dfrac{Z^2}{n^2}$

where,
n = principal quantum number
h = Planck's constant
m = mass of electron
$K = \dfrac{1}{4\pi\varepsilon_0}$,
Z = atomic number
e = electronic charge

Quantization of Energy (Particle in a Box)

In quantum mechanics, the energies of a system are discrete or quantized. The energy of a particle of mass m confined to a box of length L can have discrete values of energy given by the relation

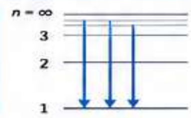
$$E_n = \frac{n^2h^2}{8mL^2}\ ;\ n = 1, 2, 3, \ldots$$



6. HYDROGEN SPECTRUM SERIES

Each element emits a spectrum of radiation, which is characteristic of the element itself. The spectrum consists of a set of isolated parallel lines and is called the line spectrum.

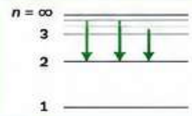
1 Lyman Series (UV region)



When electron jumps from n = 2, 3, 4, ... orbit to n = 1 orbit, then a line of Lyman series is obtained.

Region: Ultra violet

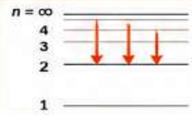
2 Balmer Series (Visible region)



When electron jumps from n = 3, 4, 5, ... orbit to n = 2 orbit, then a line of Balmer series is obtained.

Region: Visible

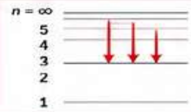
3 Paschen Series (IR region)



When electron jumps from n = 4, 5, 6, ... orbit to n = 3 orbit, then a line of Paschen series is obtained.

Region: Infrared

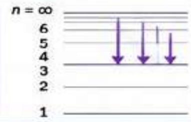
4 Brackett Series (IR region)



When electron jumps from n = 5, 6, 7, ... orbit to n = 4 orbit, then a line of Brackett series is obtained.

Region: Infrared

5 Pfund Series (IR region)



When electron jumps from n = 6, 7, 8, ... orbit to n = 5 orbit, then a line of Pfund series is obtained.

Region: Infrared

QUICK REFERENCE CONSTANTS

- $e = 1.6 \times 10^{-19}$ C (Electronic charge)
- $m_e = 9.11 \times 10^{-31}$ kg (Mass of electron)
- $h = 6.626 \times 10^{-34}$ J s (Planck's constant)
- $\varepsilon_0 = 8.854 \times 10^{-12}$ F m^{-1} (Permittivity of free space)
- 1 eV = 1.602×10^{-19} J

MCQ's WITH SOLUTION - ATOMS

1. When alpha particles are sent through a thin gold foil, most of them go straight through the foil, because

(a) α is +ve charged (b) $M_\alpha > M_e$

(c) Most part of an atom is empty space (d) α moves with high velocity

2. In an experiment of scattering of alpha particle showed for the first time that the atom has,

(a) Electron (b) Proton (c) Neutron (d) Nucleus

3. In Geiger Marsden experiment, expression of distance of closest approach to the nucleus of an α particle with KE 'K' before it comes to momentarily at rest & reverse its direction is,

(a) $\frac{Ze^2}{4\pi\varepsilon_0 K}$ (b) $\frac{Ze^2}{2\pi\varepsilon_0 K}$ (c) $\frac{Ze^2}{2\varepsilon_0 K}$ (d) $\frac{Ze^2}{4\varepsilon_0 K}$

4. The angular momentum of the electron in the nth allowed orbit is;

(a) $\frac{Ph}{2\pi}$ (b) $\frac{h}{2\pi}$ (c) $\frac{2h}{\pi}$ (d) $\frac{nh}{2\pi}$

5. In equation, what does this $E_n = -\frac{13.6}{n^2}\ eV$, negative sign indicates.

(a) Electrons are free to move (b) Electron is bound with nucleus.

(c) Kinetic energy is equal to potential energy (d) Atom is radiating energy

6. Kinetic energy of electron in hydrogen atom is

(a) $\frac{e^2}{4\pi\varepsilon_0 r}$ (b) $\frac{e^2}{8\pi\varepsilon_0 r}$ (c) $\frac{e^3}{8\pi\varepsilon_0 r}$ (d) $\frac{e^2}{3\pi\varepsilon_0 r}$

7. Energy required to excite an electron in hydrogen atom to its ground state to its first excited state is .

(a) 6.2 eV (b) 3.40 eV (c) 10.2 eV (d) -13.6 eV

8. What is the angular momentum of an electron revolving in the 3rd orbit of an atom?

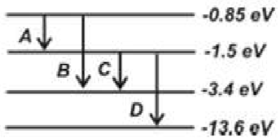
(a) 31.5×10^{-34} J-sec (b) 3.15×10^{-34} J-sec

(c) 315×10^{-34} J-sec (d) 0.315×10^{-34} J-sec

9. If the electron in hydrogen atoms is excited to n = 5 state, the number of different frequencies of radiation which may be emitted is:

(a) 4 (b) 10 (c) 8 (d) 5

10. Energy level diagram of an element is given:- Which transition corresponds to the emission of a spectral line of wave length 102.7 nm



(a) A (b) B (c) C (d) D

11. In Geiger-Marsden scattering experiment, the trajectory traced by an α-particle depends on

(a) number of collisions (b) number of scattered α-particles

(c) impact parameter (d) none of these

12. The first model of the atom was proposed in 1898 by

(a) Ernst Rutherford (b) Albert Einstein (c) J. J. Thomson (d) Niels Bohr

13. In Bohr's model of the hydrogen atom, the radius of the n^{th} orbit r_n is related to the principal quantum number n as

(a) $r_n \propto n$ (b) $r_n \propto 1/n$ (c) $r_n \propto n^2$ (d) $r_n \propto 1/n^2$

14. Which of the following spectral series of hydrogen atom lies in the visible region of the electromagnetic spectrum?

(a) Lyman series (b) Balmer series (c) Paschen series (d) Brackett series

15. Ground state energy of H- atom is −13.6 eV. Energy required to remove an electron from n = 2 is

(a) 10.2 eV (b) 3.4 eV (c) 6.8 eV (d) 0 eV

ANSWERS

1.c, 2. d, 3. b, 4. d, 5. b, 6. b, 7. c, 8. b, 9. b, 10. d,
11. c, 12. c, 13. c, 14. b, 15. b

ASSERTION AND REASON TYPE QUESTIONS

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) If the Assertion is correct but Reason is incorrect.

(d) If both the Assertion and Reason are incorrect.

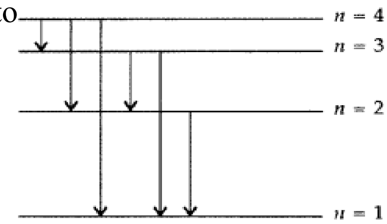
1. **Assertion (A):** According to Bohr's theory in the hydrogen atom, the electron revolves in circular orbits.
   Reason (R): The centripetal force is provided by the electrostatic attraction between the proton and the neutron.
2. **Assertion (A):** The frequency of radiation emitted or absorbed by an atom is related to the difference in energy between two energy levels.
   Reason (R): The energy of the photon emitted or absorbed is equal to the difference in energy between the two levels.
3. **Assertion (A):** The ground state of an atom is its highest energy state.
   Reason (R): In the ground state, the electron occupies the farthest possible orbit to the nucleus.
4. **Assertion (A):** The Bohr model of the atom explains the line spectra of hydrogen atom.
   Reason (R): The energy levels of the electron in the hydrogen atom are quantized, leading to discrete spectral lines.
5. **Assertion (A):** The angular momentum of an electron in a Bohr orbit is quantized.
   Reason (R): The angular momentum of the electron is an integral multiple of $h/4\pi$.
6. **Assertion (A):** The emission spectrum of an element is characteristic of the element.
   Reason (R): The energy levels of electrons in an atom are unique to each element.
7. **Assertion (A):** The ionization energy of an atom is the energy required to remove an electron from the atom in its ground state.
   Reason (R): Ionization energy is a measure of the binding energy of the protons in the ground state.
8. **Assertion (A):** The wavelength of light emitted in an electronic transition is inversely proportional to the energy difference between the initial and final states.
   Reason (R): The energy of a photon is inversely proportional to its wavelength.
9. **Assertion (A):** The energy levels in an atom are quantized due to the wave nature of electrons.
   Reason (R): Electrons exhibit both particle and wave properties
10. **Assertion (A):** Distance of closest approach of α-particle to the nucleus is always greater than the size of the nucleus.
    Reason (R): Strong nuclear repulsion does not allow α-particle to reach the surface of nucleus.

ANSWERS

1. c, 2. a, 3. d, 4. a, 5. c, 6. a, 7. c, 8. a, 9. b, 10. d

SHORT ANSWER QUESTIONS: (02 MARKS)

1. What is the shortest wavelength present in Paschen series and Balmer series of H-spectrum?
2. In the Rutherford's scattering experiment the distance of closest approach for an α −particle is d_0. If α −particle is replaced by a proton, how much kinetic energy in comparison to α particle will it require to have the same distance of closest approach d_0?
3. Find the ratio of Bohr's radius in ground state and 1st excited state of H-atom?
4. The value of ground state energy of hydrogen atom is -13.6 eV. (i) what does the negative sign signify? (ii). How much energy is required to take an electron in this atom from the ground state to the first excited state?
5. Use Rydberg formula to determine the wavelength of H_α & H_β line. R =1.03 X 10^7 m^2)
6. Calculate the shortest wavelength of the spectral lines emitted in Balmer series.
7. When an electron in hydrogen atom jumps from the third excited state to the ground state, how would the de Broglie wavelength associated with the electron change? Justify your answer.
8. Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom.
9. Using Bohr's postulates, obtain the expression for the total energy of the electron in the stationary states of the hydrogen atom. Hence draw the energy level diagram showing how the line spectra corresponding to Balmer series occur due to transition between energy levels.



10. The figure shows energy level diagram of hydrogen atom
(a) Find out the transition which results in the emission of a photon of wavelength 496 nm.
(b) Which transition corresponds to the emission of radiation of max wavelength ? Justify.

SOLUTIONS FOR SHORT ANSWER QUESTIONS: (02 MARKS)

1. Using the Rydberg formula: $\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$,

for Balmer Series n_f=2 & n_i=∞,

$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right)$ => $\lambda = \frac{4}{R}$ => 364.6 nm

Similary for Paschen Series n_f=3 & n_i=∞,

$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{\infty^2}\right)$ => $\lambda = \frac{9}{R}$ => 820 nm

2. $K_\alpha = \frac{1}{4\pi\varepsilon_0} . \frac{(Ze)(2e)}{d_0}$, $K_p = \frac{1}{4\pi\varepsilon_0} . \frac{(Ze)(e)}{d_0}$ => $K_p = \frac{1}{2} K_\alpha$

3. Ratio of Bohr's Radius in Ground State and First Excited State

Radius of nth orbit: $r_n = a_0 n^2$ For ground state: $n = 1, r_1 = a_0$

For first excited state: $n = 2, r_2 = 4a_0$ Therefore, $\frac{r_2}{r_1} = \frac{4a_0}{a_0} = 4$, $\boxed{r_2 : r_1 = 4:1}$

4. Ground State Energy of Hydrogen Atom = -13.6 eV

(i) Meaning of Negative Sign - The negative sign shows that the electron is bound to the nucleus by electrostatic force.

(ii) Energy Required for First Excited State

Ground state: $E_1 = -13.6$ eV => First excited state: $E_2 = \frac{-13.6}{2^2} = -3.4$ eV

Required energy: $\Delta E = E_2 - E_1 = (-3.4) - (-13.6) = 10.2$ eV=> $\boxed{10.2 \text{ eV}}$

5. Wavelength of H_α and H_β Using Rydberg formula: $\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

(i) H_α line Transition: $n_2 = 3, \quad n_1 = 2$

$\frac{1}{\lambda} = 1.03 \times 10^7 \left(\frac{1}{4} - \frac{1}{9}\right) = 1.03 \times 10^7 \times \frac{5}{36}$ => $\lambda \approx 6.56 \times 10^{-7}$ m. => $\boxed{\lambda_{H_\alpha} = 656\,\text{nm}}$

(ii) H_β line -Transition: $n_2 = 4, \quad n_1 = 2.$ $\frac{1}{\lambda} = 1.03 \times 10^7 \left(\frac{1}{4} - \frac{1}{16}\right) = 1.03 \times 10^7 \times \frac{3}{16}$

$\lambda \approx 4.86 \times 10^{-7}$ => $\boxed{\lambda_{H_\beta} = 486\,\text{nm}}$

6. Shortest Wavelength in Balmer Series

For shortest wavelength: $n_2 = \infty, \quad n_1 = 2$ => $\frac{1}{\lambda} = R\left(\frac{1}{4}\right)$

$\lambda = \frac{4}{R} = \frac{4}{10^7} = 4 \times 10^{-7}$ m => $\boxed{\lambda = 400\,\text{nm}}$

7. Change in de Broglie Wavelength

de Broglie relation: $2\pi r = n\lambda$ => $\lambda = \frac{2\pi r}{n}$ => Since: $r_n \propto n^2$ => therefore $\lambda \propto n$

When electron jumps from $n = 4$ to $n = 1$, the de Broglie wavelength decreases.

8. Show that Radius Varies as n^2

Electrostatic force provides centripetal force: $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$

Bohr quantization condition: $mvr = \frac{nh}{2\pi}$ => Squaring: $m^2v^2r^2 = \frac{n^2h^2}{4\pi^2}$

Using: $mv^2 = \frac{e^2}{4\pi\varepsilon_0 r}$ & Substituting, we get $r \propto n^2$

9. Expression for Total Energy of Electron

Electrostatic force: $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$ & *we know* Kinetic energy: $K = \frac{1}{2}mv^2$

Using force equation: $K = \frac{e^2}{8\pi\varepsilon_0 r}$, Potential energy: $U = -\frac{e^2}{4\pi\varepsilon_0 r}$

Total energy: $E = K + U$ => $E = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r}$ =>. $E = -\frac{e^2}{8\pi\varepsilon_0 r}$ & hence, $E_n = -\frac{13.6}{n^2}$ eV

Balmer Series Energy Level Diagram

n = ∞ ----------------

n = 5 ---------------- ↓

n = 4 ---------------- ↓

n = 3 ---------------- ↓

n = 2 ---------------- ← Balmer Series

n = 1 ----------------

10. Energy Level Diagram

(a) Transition for 496 nm : 496 nm belongs to Balmer series: $n_2 = 4, n_1 = 2$ $\quad i.e.$ $\boxed{4 \to 2}$

(b) Transition Corresponding to Maximum Wavelength Using: $E = \frac{hc}{\lambda}$

Maximum wavelength corresponds to minimum energy difference. Hence transition: $\boxed{4 \to 3}$ gives maximum wavelength.

Short Answer Type Questions: (03 MARKS)

1. Write two important limitations of Rutherford model which could not explain the observed features of atomic spectra. How were these explained in Bohr's model of hydrogen atom? Use the Rydberg formula to calculate the wavelength of the Hα line. (Take R = 1.1×10^7 m^{-1})

2. Calculate the shortest wavelength in the Balmer series of hydrogen atom. In which region (infra-red, visible, ultraviolet) of hydrogen spectrum does this wavelength lie?

3. Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom.

4. An α-particle moving with initial kinetic energy K towards a nucleus of atomic number z approaches a distance 'd' at which it reverses its direction. Obtain the expression for the distance of closest approach 'd' in terms of the kinetic energy of α-particle K.

5. Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron?

6. (i) A hydrogen atom initially in the ground state absorbs a photon which excites it to the n = 4 level. Determine the wavelength of the photon.

(ii) The radius of innermost electron orbit of a hydrogen atom is 5.3×10^{-11} m. Determine its radius in n = 4 orbit.

7. (i) In hydrogen atom, an electron undergoes transition from 2nd excited state to the first excited state and then to the ground state. Identify the spectral series to which these transitions belong.

(ii) Find out the ratio of the wavelengths of the emitted radiations in the two cases.

8. The ground state energy of hydrogen atom is – 13.6 eV. What are the kinetic and potential energies of electron in this state?

9. Find the ratio of energies of photons produced due to transition of an electron of hydrogen atom from its second permitted energy level to the first permitted level and the highest permitted energy level to the first permitted level.

10. Calculate the wave number, wavelength and frequency of the spectral line of hydrogen for the transition from $n_2 = 4$ to $n_1 = 2$ (given $R = 1.097 \times 10^7\ m^{-1}$)

ANSWERS

Q.1 Rutherford Model and H_α Line

Limitations of Rutherford Model

(i) Stability of Atom:- According to Maxwell's electromagnetic theory, an electron revolving around the nucleus should continuously radiate energy. Hence its orbit should shrink and finally the electron should fall into the nucleus. Therefore Rutherford model could not explain stability of atom.

(ii) Atomic Spectra :- Rutherford model could not explain discrete line spectra of hydrogen atom. According to classical theory, atom should emit continuous spectrum.

Explanation by Bohr's Model

(i) Stable Orbits- Electrons revolve only in certain permitted stationary orbits without radiating energy.

(ii) Quantized Energy Levels:- Radiation is emitted or absorbed only when electron jumps between two stationary orbits. Hence discrete spectral lines are obtained.

Calculation of H_α Line : Using Rydberg formula, $\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

For H_α line, $n_1 = 2, \quad n_2 = 3$ => $\frac{1}{\lambda} = 1.1 \times 10^7 \left(\frac{1}{4} - \frac{1}{9}\right) = 1.1 \times 10^7 \times \frac{5}{36} = 1.528 \times 10^6$

$$\lambda = \frac{1}{1.528\times10^6} \Rightarrow \boxed{\lambda \approx 6.54 \times 10^{-7}\ \text{m}} \text{ or } \boxed{\lambda \approx 654\ \text{nm}}$$

Q.2 Shortest Wavelength in Balmer Series : For shortest wavelength, $n_1 = 2, \quad n_2 = \infty$

Using Rydberg formula, $\frac{1}{\lambda} = R\left(\frac{1}{4}\right)$=> $\lambda = \frac{4}{R} = \frac{4}{1.097\times10^7}$

$\boxed{\lambda \approx 3.646 \times 10^{-7}\text{ m}}$ *or* $\boxed{\lambda \approx 364.6\text{ nm}}$ This wavelength lies in ultraviolet region.

Q.3 Radius of Orbit varies as n^2 => Electrostatic force provides centripetal force, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$

Bohr quantization condition, $mvr = \frac{nh}{2\pi}$, Squaring, $m^2v^2r^2 = \frac{n^2h^2}{4\pi^2}$ Using, $mv^2 = \frac{e^2}{4\pi\varepsilon_0 r}$

Substituting, $r = \frac{\varepsilon_0 n^2h^2}{\pi me^2}$ Thus, $\boxed{r_n \propto n^2}$ Hence proved.

Q.4 Distance of Closest Approach

At closest approach, entire kinetic energy converts into electrostatic potential energy.

Initial kinetic energy,K Potential energy at distance d, $U = \frac{1}{4\pi\varepsilon_0}\frac{(2e)(Ze)}{d}$

Equating energies, $K = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{d}$ => Therefore, $\boxed{d = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{K}}$

Q.5 Total Energy of Electron in Hydrogen Atom

Electrostatic force provides centripetal force, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$ Hence, $mv^2 = \frac{e^2}{4\pi\varepsilon_0 r}$

Kinetic Energy. $K = \frac{1}{2}mv^2$ =>. $K = \frac{e^2}{8\pi\varepsilon_0 r}$ &. Potential Energy $U = -\frac{e^2}{4\pi\varepsilon_0 r}$

Total Energy. $E = K + U$ => $E = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r}$ => $\boxed{E = -\frac{e^2}{8\pi\varepsilon_0 r}}$

Significance of Negative Energy

Negative sign shows that electron is bound to the nucleus. Energy must be supplied to remove the electron from atom.

Q.6 Wavelength of Photon absorbed Energy of electron in nth orbit, $E_n = -\frac{13.6}{n^2}$ eV

Ground state n=1, $E_1 = -13.6$ eV For $n = 4$, $E_4 = \frac{-13.6}{16} = -0.85$ eV

Energy absorbed, $\Delta E = E_4 - E_1 = (-0.85) - (-13.6) = 12.75$ eV

Using, $\lambda = \frac{hc}{E}$ => $\lambda = \frac{1240}{12.75}$ => $\boxed{\lambda \approx 97\text{ nm}}$

(i) Radius of $n = 4$ Orbit - Given, $r_1 = 5.3 \times 10^{-11}$ m

Using, $r_n = n^2r_1$ => $r_4 = 16 \times 5.3 \times 10^{-11}$ => $\boxed{r_4 = 8.48 \times 10^{-10}\text{ m}}$

Q.7 Spectral Series: (i) Spectral Series - Second excited state, $n = 3$, Transition, $3 \to 2$ belongs to Balmer series.

Transition, $2 \to 1$, belongs to Lyman series.

(ii) Ratio of Wavelengths. Using, $\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$ For $3 \to 2$, $\frac{1}{\lambda_1} = R\left(\frac{1}{4} - \frac{1}{9}\right) = \frac{5R}{36}$

For $2 \to 1$, $\frac{1}{\lambda_2} = R\left(1 - \frac{1}{4}\right) = \frac{3R}{4}$ => Thus, $\frac{\lambda_1}{\lambda_2} = \frac{27}{5}$, hence $\boxed{\lambda_1 : \lambda_2 = 27 : 5}$

Q.8 Kinetic and Potential Energies: Given, $E = -13.6$ eV

Relation, $K = -E$ => $K = 13.6$ eV Potential energy, $U = 2E$ => $U = 2(-13.6)$

=> $\boxed{U = -27.2\text{ eV}}$ Thus, $\boxed{K = 13.6\text{ eV}}$ &. $\boxed{U = -27.2\text{ eV}}$

Q.9 Ratio of Energies of Photons

For transition $2 \to 1$, $E_2 = -3.4$ eV &. $E_1 = -13.6$ eV

Photon energy,$\Delta E_1 = 10.2$ eV

For transition $\infty \to 1$, $E_\infty = 0$ & $\Delta E_2 = 13.6$ eV Therefore, $\frac{\Delta E_1}{\Delta E_2} = \frac{10.2}{13.6} = \frac{3}{4}$

Q.10 Wave Number, Wavelength and Frequency: Given, $n_2 = 4$, $n_1 = 2$

Using Rydberg formula, $\bar{\nu} = R\left(\frac{1}{4} - \frac{1}{16}\right) = 1.097 \times 10^7 \times \frac{3}{16}$ => $\boxed{\bar{\nu} = 2.057 \times 10^6 \text{ m}^{-1}}$

Wavelength -- $\lambda = \frac{1}{\bar{\nu}} = \frac{1}{2.057 \times 10^6}$ => $\boxed{\lambda = 4.86 \times 10^{-7} \text{ m}}$ or $\boxed{486 \text{ nm}}$

Frequency. Using, $\nu = c\bar{\nu} = 3 \times 10^8 \times 2.057 \times 10^6$ => $\boxed{\nu = 6.17 \times 10^{14} \text{ Hz}}$

CASE BASED QUESTIONS

(a) *The spectral series of hydrogen atom were accounted for by Bohr using the relation* $\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$, where, R=Rydberg constant = 1.097×10^7 m^{-1}. Lyman series is obtained when an electron jumps to first orbit from any subsequent orbit. Similarly, Balmer series is obtained when an electron jumps to 2nd orbit from any subsequent orbit. Paschen series is obtained when an electron jumps to 3rd orbit from any subsequent orbit. Whereas Lyman series in U.V. region, Balmer series is in visible region and Paschen series lies in infrared region. Series limit is obtained when n2=∞.

(i) What is the ratio of minimum to maximum wavelength in Balmer series?
(a) 5:2 (b) 5:9 (c) 5:8 (d) 9:5

(ii) Which series of hydrogen spectrum can we see through naked eye?
(a) Laymen (b) Balmer Series (c) paschan (d) none

(iii) What is the wavelength of first spectral line of Lyman series?
(a) 1215.4 (b) 5121.4 (c) 2115.4 (d) 4211.5

(iv) What is the frequency of first spectral line of Balmer series?
(a) 4.57×10^{14} Hz (b) 5.57×10^{14} Hz (c) 7.57×10^{14} Hz (d) 0.57×10^{14} Hz

(b) Lyman series is obtained when an electron jumps to first orbit from any subsequent orbit. Similarly, Balmer series is obtained when an electron jumps to 2nd orbit from any subsequent orbit. Paschen series is obtained when an electron jumps to 3rd orbit from any subsequent orbit. Whereas Lyman series in U.V. region, Balmer series is in visible region and Paschen series lies in infrared region. Series limit is obtained when n_2=∞.

(i) The wavelength of first spectral line of Lyman series is
(a) 1215.4 A^0 (b) 1215.4 cm (c) 1215.4 m (d)1215. 4 mm

(ii) The wavelength limit of Lyman series is
(a) 951.6 A^0 (b) 511.9 A^0 (c)1215.4 A^0 (d) 911.6 A^0

(iii) The frequency of first spectral line of Balmer series is
(a) 1.097×10^7 Hz (b) 4.57×10^{14} Hz (c) 4.57×10^{15} Hz (d) 4.57×10^{16} Hz

(iv) Which of the following transitions in hydrogen atom emit photon of highest frequency?
(a)n=1 to n=2 (b) n=2 to n=6 (c) n=6 to n=2 (d) n=2 to n=1

(c) Electrons are revolving around the nucleus in particular stable orbits. The energy of the electron is increasing as we go from the orbit closer to nucleus to outer side. The ground state energy is the lowest energy and it is -13.6 eV for hydrogen atom. Thus, the minimum amount of energy required to remove or free the electron from the ground state is the ionisation energy and it has value +13.6 eV. When electrons jumps from higher energy orbit to lower energy orbit emits energy in the form of photons which are in the form of spectral lines and called as emission lines. The light emitted by the ordinary source of light consist of different wavelength. But the laser light is the monochromatic one which emits light of single wavelength. In case of hydrogen atom, the ground state energy is that energy state for which n = 1. And the states for which n > 1, all are the excited states. Where n shows the principal quantum number.

(i) In hydrogen atom, the energy corresponding to principal quantum number n =2 is
(a) -13.6 eV (b) -3.4 eV (c) +13.6 eV (d) +3.4 eV

(ii) For ground state of hydrogen atom the value of principal quantum number is
(a) n = 2 (b) n = 0 (c) n = 1 (d) n = infinity

(iii) The minimum energy required to remove the electron from the ground state of the hydrogen atom is called as______
(a) excitation energy (b) ionisation energy
(c)ground state energy (d)excited state energy

(iv) The acronym LASER stands for?
(a) Light Amplification by Simplification Estimation and Radiation
(b) Light Amplification by Stimulated Emission of Radiation.
(c) Light Amplification by Simulated Emission and Radio
(d) Light Amplifier by Stimulated Emission of Radiation.

ANSWERS

Q.1 : (i) B (ii) B (iii) A (iv) A
Q.2:- (i) A (ii) C (iii) C (iv) D
Q.3:- (i) B (ii) C (iii) C (iv) B

Long Answer Questions

1. (a) Write two important limitations of Rutherford model, which could not explain the observed features of atomic spectra. How were these explained in Bohr's model of Hydrogen atom? Use the Rydberg formula to calculate the wavelength of Hα line of the Balmer Series.
   (b) Using Bohr's postulates, obtain the expression for the radius of n^{th} orbit in hydrogen atom.
2. (I) State Bohr's postulates. Using these postulates derive an expression for the total energy of an electron in n^{th} orbit of an atom. What does negative value of this energy signify? What is Bohr's radius?
3. (I)Using Bohr's postulates, derive the expression for the frequency of radiation emitted when electron in hydrogen atom undergoes transition from higher energy state (quantum number n_i) to the lower state (n_f).
   (II) When electron in hydrogen atom jumps from energy state n_i=4 to n_f=3, 2, 1. Identify the spectral series to which the emission lines belong.

ANSWERS

1(a) <u>Limitations of Rutherford Model</u>

1. Stability of Atom: According to Rutherford model, electrons revolve around the nucleus in circular orbits. Since a revolving electron is an accelerated charge, it should continuously radiate energy. Therefore: Electron would lose energy continuously, Radius of orbit would decrease, Electron would finally fall into the nucleus. Thus, Rutherford model could not explain the stability of atom.

2. Atomic Spectra

Rutherford model predicted continuous radiation from revolving electrons. Hence it should produce a continuous spectrum. But experimentally, hydrogen atom gives a line spectrum consisting of discrete lines. Therefore, Rutherford model failed to explain atomic spectra.

Bohr's Explanation

1. Stable Orbits: Bohr proposed that electrons revolve only in certain permitted circular orbits called stationary orbits. In these orbits, electrons do not radiate energy, thus atom remains stable.

2. Explanation of Line Spectrum: Radiation is emitted or absorbed only when electron jumps from one orbit to another. $h\nu = E_i - E_f$

Thus only specific frequencies are emitted, giving discrete spectral lines.

Calculation of Wavelength of H_α Line

For Balmer series: $n_f = 2$, For H_α line: $n_i = 3$, Using Rydberg formula: $\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

$\frac{1}{\lambda} = 1.523 \times 10^6\, m^{-1}$ => $\lambda = 6.56 \times 10^{-7} m$ => $\boxed{\lambda = 656\, nm}$

1(b) Radius of nth Orbit: According to Bohr model:

Step 1: Electrostatic Force = Centripetal Force $\frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$

Step 2: Bohr Quantisation Condition $mvr = \frac{nh}{2\pi}$ => $v = \frac{nh}{2\pi mr}$

Step 3: Substitute Value of v $\frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} = \frac{m}{r}\left(\frac{nh}{2\pi mr}\right)^2$ on Solving, $r_n = \frac{\epsilon_0 n^2 h^2}{\pi m e^2}$

For hydrogen atom: $r_n = n^2 a_0$, Where. $a_0 = 0.53$ Å. is called Bohr radius.

Answer - 2. Bohr's Postulates and Total Energy

Bohr's Postulates

1. Electrons revolve in certain stable circular orbits without radiating energy.
2. Only those orbits are allowed for which angular momentum is quantised: $mvr = \frac{nh}{2\pi}$
3. Radiation is emitted or absorbed when electron jumps from one stationary orbit to another. $h\nu = E_i - E_f$

Derivation of Total Energy

Total energy: $E = K + U$, Where K = Kinetic Energy, U = Potential Energy

Step 1: Kinetic Energy $\frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$ =>. $mv^2 = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r}$ => $K = \frac{1}{2}mv^2 = \frac{1}{8\pi\epsilon_0}\frac{e^2}{r}$

Step 2: Potential Energy. $U = -\frac{1}{4\pi\epsilon_0}\frac{e^2}{r}$

Step 3: Total Energy $E = K + U = \frac{1}{8\pi\epsilon_0}\frac{e^2}{r} - \frac{1}{4\pi\epsilon_0}\frac{e^2}{r}$ => $E = -\frac{1}{8\pi\epsilon_0}\frac{e^2}{r}$

Substituting value of radius, $E_n = -\frac{13.6}{n^2}\, eV$

Significance of Negative Energy

Negative sign indicates that electron is bound to the nucleus. Energy must be supplied to remove electron from atom to infinity.

Bohr Radius :- Radius of first orbit of hydrogen atom is called Bohr radius. $\boxed{a_0 = 0.53 \text{ Å}}$

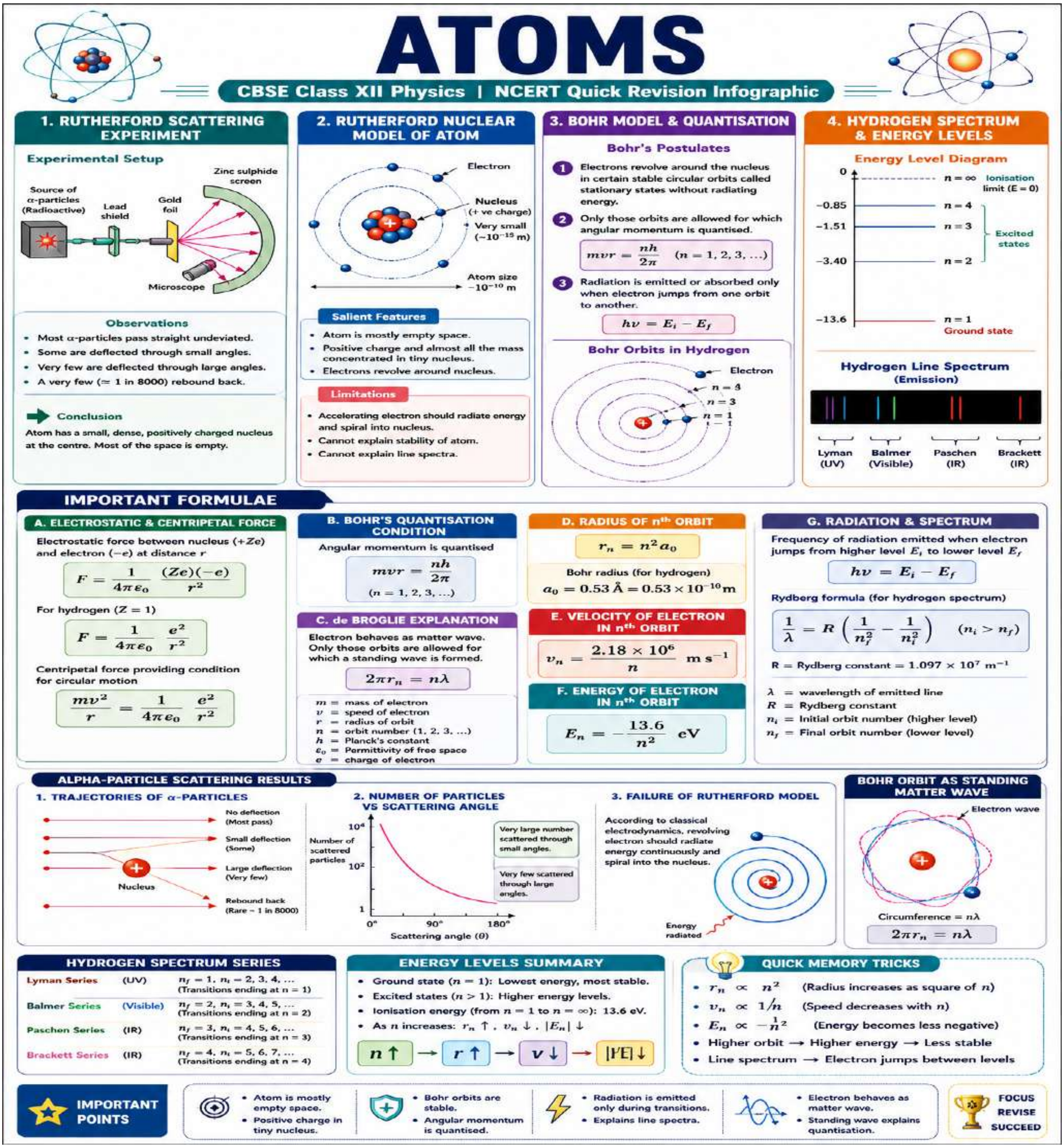
Answer : 3. Frequency of Radiation Emitted : When electron jumps from higher orbit (n_i) to lower orbit (n_f): $h\nu = E_i - E_f$

Energy of nth orbit: $E_n = -\frac{13.6}{n^2}\, eV$ =>. Therefore, $h\nu = 13.6\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) eV$

Hence, $\boxed{\nu = \frac{13.6}{h}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)}$

Identification of Spectral Series

1. Transition: 4 → 3 This belongs to: $\boxed{\text{Paschen Series}}$
2. Transition: 4 → 2, This belongs to: $\boxed{\text{Balmer Series}}$
3. Transition: 4 → 1 This belongs to: $\boxed{\text{Lyman Series}}$



CHAPTER 13

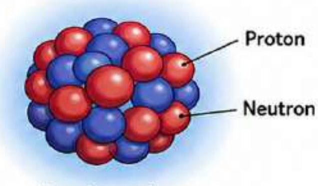
WARM-UP: THINK LIKE A SCIENTIST

CHAPTER
Nuclei
CLASS 12 PHYSICS

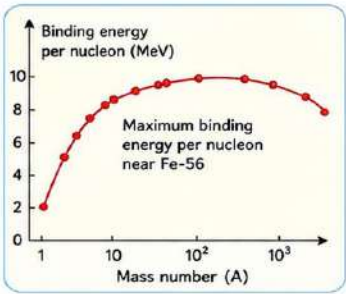
Before You Begin...

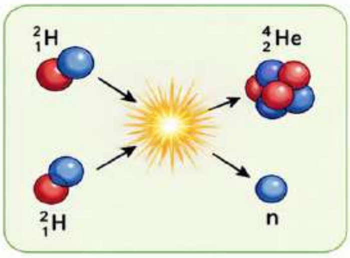
Observe & Predict

1. Why do nuclei remain stable despite the strong repulsion between protons?
2. What would happen if the strong nuclear force did not exist?
3. Why do lighter nuclei release more energy by fusion, while heavier nuclei release energy by fission?
4. Why are nuclear reactions used in power plants to produce electricity?
5. If radioactive decay did not exist, how would it affect the natural balance of elements on Earth?

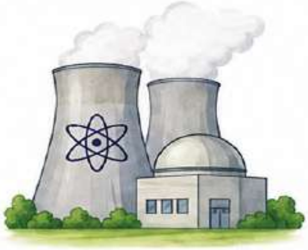


Atomic nucleus





Nuclear fusion


Nuclear power plant

Write your ideas before studying the chapter.

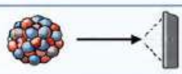
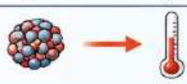
____

____

NUCLEI AROUND US

Real-Life Connections

CHAPTER 13
Nuclei
CLASS 12 PHYSICS

Application / Device		How Nuclear Science Is Used	
	**Nuclear Power Plant** (e.g., Tarapur, Kudankulam)		Fission of heavy nuclei like ^{235}U releases large energy used to generate electricity.
	**Medical Imaging (PET Scan)** (e.g., Cancer diagnosis)		Radioactive tracers (like ^{18}F) emit positrons which help in imaging internal organs.
	**Cancer Treatment (Radiotherapy)** (e.g., Cobalt-60 therapy)		Radioactive isotopes emit gamma rays which destroy cancer cells.
	**Smoke Detector** (e.g., ^{241}Am)		Alpha particles ionize air. Ionization current changes when smoke enters.
	**Thickness Gauge** (Industries)		Beta particles pass through materials. Their absorption measures thickness.
	**Radioisotope Thermoelectric Generator (RTG)** (e.g., in space missions)		Radioactive decay produces heat which is converted into electricity for spacecraft.

Did You Know? Nuclear science helps in producing energy, diagnosing diseases, treating cancer, exploring space and even keeping us safe!

Atoms may be tiny, but their impact is huge!

MULTIPLE CHOICE QUESTIONS

1 A nucleus splits into two nuclear parts having radii in the ratio 1:2. Their velocities are in the ratio
(a) 8:1 (b) 6:1 (c) 4:1 (d) 2:1

2 The radius of a spherical nucleus as measured by electron scattering is 3.6 fm. What is the mass number of the nucleus most likely to be? (Given R0 = 1.2 fm)
(a) 27 (b) 48 (c) 56 (d) 120

3. If the binding energy per nucleon of ^2H and ^4He nuclei are 1.1 MeV and 7.0 MeV respectively, then the energy released in the reaction $^2H + ^2H \rightarrow ^4He$ is:
(a) 23.6 MeV (b) 28.0 MeV (c) 5.9 MeV (d) 25.2 MeV

4 The radius of a nucleus of mass number A is proportional to:
(a) A **(b)** A^2 **(c)** $A^{(1/3)}$ **(d)** $A^{(1/2)}$

5. Which of the following particles has the smallest de Broglie wavelength, if all move with the same kinetic energy?
(a) Electron **(b)** Proton **(c)** Alpha particle **(d)** Neutron

6. If the nuclear radius of ^{27}Al is 3.6 Fermi, the approximate nuclear radius of ^{64}Cu (in Fermi) is:
(a) 2.4 **(b)** 4.8 **(c)** 3.6 **(d)** 5.2

7. The nuclear density of all nuclei is approximately the same because:
(a) All nuclei have the same mass **(b)** Nuclear radius ∝ A^(1/3) and mass ∝ A
(c) Nuclei are all spherical in shape **(d)** All nuclei have same number of protons

8. The mass number of an atom is 40 and its atomic number is 18. Which of the following is correct?
(a) 18 protons, 18 electrons, 18 neutrons **(b)** 18 protons, 18 electrons, 22 neutrons **(c)** 22 protons, 22 electrons, 18 neutrons **(d)** 40 protons, 40 electrons, 18 neutrons

9. The binding energy per nucleon is maximum for:
(a) ^2H **(b)** ^{56}Fe **(c)** ^{235}U **(d)** ^{208}Pb

10. The mass defect of a nucleus is Δm. The binding energy per nucleon (for mass number A) is:
(a) $\Delta m \cdot c^2/A$ **(b)** $\Delta m \cdot c^2$ **(c)** $A \cdot \Delta m \cdot c^2$ **(d)** $\Delta m/(A \cdot c^2)$

11. If the binding energy of deuteron is 2.23 MeV, the mass defect (in amu) of deuteron is approximately:
(a) 0.0024 u **(b)** 0.0024 kg **(c)** 0.024 u **(d)** 0.24 u

Observe and Think:

Why do you think nature prefers iron (^{56}Fe) to be the most stable nucleus? What advantages might this provide in stars and galaxies?

12. Which of the following is NOT a correct statement about binding energy per nucleon?
(a) It is maximum for Fe-56 **(b)** It is nearly 8 MeV for nuclei in the middle of the periodic table **(c)** It decreases with increasing mass number for very heavy nuclei
(d) It is always greater for heavier nuclei than lighter nuclei

13. In the graph of binding energy per nucleon versus mass number, two nuclei can release energy by:

(a) Fusion only (b) Fission only

(c) Either fission or fusion depending on their mass number

(d) Neither fission nor fusion

14. In a nuclear reactor, the function of the moderator is to:

(a) Absorb fast neutrons (b) Slow down fast neutrons to thermal energies

(c) Increase the energy of neutrons (d) Reflect neutrons back into the core

15. The energy released in nuclear fusion reactions is due to:

(a) Decrease in binding energy per nucleon

(b) Increase in binding energy per nucleon of the product over reactants

(c) Emission of gamma rays (d) Conversion of protons into neutrons

16. In the fission of ^{235}U by a slow neutron, one of the products is ^{140}Ba. What is the other heavy fragment?

(a) ^{93}Kr (b) ^{94}Kr (c) ^{92}Kr (d) ^{95}Kr

17. Given below are two statements:

Statement I: The number of protons in an atom equals its atomic number Z.

Statement II: Isotopes of an element have same mass number but different atomic numbers.

In the light of the above statements, choose the most appropriate answer:

(a) Both Statement I and Statement II are correct

(b) Both Statement I and Statement II are incorrect

(c) Statement I is correct but Statement II is incorrect

(d) Statement I is incorrect but Statement II is correct

18. Nucleus X^{235} splits into two nuclei having the mass numbers in the ratio 2:1. The ratio of the radii of those two nuclei is

(a) 2:1 (b) 1:2 (c) $2^{1/3}$:1 (d) 1:$2^{1/3}$

19. The energy equivalent of 1 amu (atomic mass unit) in MeV is:

(a) 931 MeV (b) 1.6 MeV (c) 931 eV (d) 9.31 MeV

Creative Scientific Thinking

Imagine a world where fusion reactors become common in every city. How would transportation, pollution, and electricity generation change?

20. In the nuclear reaction $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + n$, the energy released is (given: mass of $^{2}_{1}H$ = 2.01410 u; mass of $^{3}_{2}He$ = 3.01609 u; mass of n = 1.00867 u; 1 u = 931.5 MeV/c^2):

(a) 3.27 MeV (b) 4.03 MeV (c) 2.23 MeV (d) 17.6 MeV

ANSWERS

1,a, 2. a, 3. a, 4. c, 5. c, 6. b, 7. b, 8. b, 9. b, 10. a,

11. a, 12. d, 13. c, 14. b, 15. b, 16. a, 17. c, 18. c, 19. a, 20. a

ASSERTION- REASON BASED QUESTIONS

For these Questions two statements are given one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below

a. If both Assertion and Reason are true and Reason is correct explanation of Assertion.
b. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
c. If Assertion is true but Reason is false.
d. If both Assertion and Reason are false.

1. Assertion (A): The binding energy per nucleon in very heavy nuclei is less than that in medium-mass nuclei.

   Reason (R): Very heavy nuclei have a larger proportion of neutrons, which reduces nuclear stability.

2. Assertion (A): Nuclear forces are charge independent.

   Reason (R): The nuclear force between neutron-neutron, proton-proton, and proton-neutron pairs are approximately equal.

3. Assertion (A): Nuclear fusion cannot occur at room temperature.

   Reason (R): Nuclear fusion requires extremely high temperatures (of the order of 10^7 K) to overcome the Coulomb repulsion between nuclei.

4. Assertion (A): Isotopes of an element have similar chemical properties.

   Reason (R): Isotopes have the same number of electrons and hence the same electronic configuration.

5. Assertion (A): The nucleus of an atom has greater density than its outer electronic shells.

   Reason (R): Almost the entire mass of an atom is concentrated in its tiny nucleus, whereas electrons have negligible mass.

6. Assertion (A): The mass of a nucleus is less than the sum of the masses of its constituent protons and neutrons.

   Reason (R): The mass defect is converted into binding energy, which holds the nucleus together.

7. Assertion (A): The binding energy per nucleon is a measure of the unstability of a nucleus.

   Reason (R): A higher binding energy per nucleon means the nucleons are not tightly bound and the nucleus is more stable.

Physics in Real Life

How does nuclear energy help submarines remain underwater for long durations?

8. Assertion (A): Heavy nuclei tend to be unstable and undergo radioactive decay.

   Reason (R): In heavy nuclei, the repulsive electrostatic forces between protons are sufficiently balanced by the attractive nuclear forces

9 Assertion (A): Nuclear fission is accompanied by the release of a large amount of energy.

   Reason (R): The binding energy per nucleon of the fission fragments is greater than that of the original nucleus.

10 Assertion(A): Distance of closest approach of α-particle to the nucleus is always greater than the size of the nucleus.

   Reason(R): Strong nuclear repulsion does not allow α-particle to reach the surface of nucleus

ANSWERS

1. a, 2. a, 3. a, 4. a, 5. a, 6. a, 7. d, 8. c, 9. a, 10. a

SHORT ANSWER QUESTIONS (2 & 3 MARK)

1. Define atomic mass unit (amu). What is its value in kg and MeV?
2. What are isotopes and isobars? Give one example of each.
3. State two properties of nuclear forces that distinguish them from gravitational and electromagnetic forces.
4. Show that the density of nuclear matter is independent of mass number A. (Given: nuclear radius $R = R_0A^{(1/3)}$ where $R_0 = 1.2 \times 10^{-15}$ m)
5. Why do heavy nuclei have more neutrons than protons? Explain briefly.
6. Define binding energy of a nucleus. Write the expression for binding energy in terms of mass defect.
7. What is mass defect of a nucleus? How is it related to binding energy?
8. Draw a rough sketch of the graph showing the variation of binding energy per nucleon with mass number. Mark the position of ^{56}Fe on the graph.
9. Why is it not possible to use ^{238}U as a nuclear fuel for fission reactors (unlike ^{235}U)?
10. Find the binding energy of ^{4}He nucleus. Given: mass of ^{4}He = 4.002602 u, mass of proton = 1.007825 u, mass of neutron = 1.008665 u, 1 u = 931.5 MeV/c².
11. Calculate the energy released per fission of ^{235}U given that the average binding energy per nucleon of U-235 is 7.6 MeV and that of fission products is 8.5 MeV. Mass number of fission fragments ≈ 235.
12. Explain with the help of a suitable graph, how the binding energy per nucleon varies with mass number. Using this graph, explain the source of energy in nuclear fission and nuclear fusion.
13. Explain the working principle of a nuclear reactor. Name the main components and state the function of each.
14. What are nuclear forces? State four important properties of nuclear forces that distinguish them from other fundamental forces.
15. Calculate the binding energy of the nucleus of $^{56}_{26}$Fe. Comment on why iron has the most stable nucleus. (Given: M(^{56}Fe) = 55.9349 u; m_p = 1.00728 u; m_n = 1.00867 u; 1 u = 931.5 MeV)

Amazing Facts About Nuclei

One gram of nuclear fuel can produce energy equal to tons of coal.

16. In the nuclear reaction: $^{235}_{92}U + {}^1_0n \rightarrow {}^{139}_{56}Ba + {}^{94}_{36}Kr + x({}^1_0n)$, find x. Also calculate the energy released per fission, given: m(^{235}U) = 235.0439 u; m(^{139}Ba) = 138.9088 u; m(^{94}Kr) = 93.9341 u; m(n) = 1.00867 u; 1 u = 931.5 MeV.
17. (i) How is the size of a nucleus found experimentally? Write the relation between the radius and mass number of a nucleus.
(ii) Prove that the density of a nucleus independent of its mass number.
18. Draw the graph showing the variation of binding energy per nucleon with mass number. What inference you get from this graph. Also explain the importance of binding energy curve.
19. A nucleus with mass number, A = 240 and BE /A = 7. 6 MeV breaks into two fragments each of A = 120 with BE /A = 8. 5 MeV Calculate the released energy.

20. Draw a plot of potential energy of a pair of nucleons as a function of their separations. Mark the regions where the nuclear force is (i) attractive and (ii) repulsive. Write any two characteristic features of nuclear forces.

ANSWERS

1. Atomic mass unit (amu) is defined as 1/12th of the mass of a carbon-12 atom. 1 amu = 1.66×10^{-27} kg = 931.5 MeV/c^2.
2. Isotopes are atoms with same atomic number but different mass numbers (e.g., ^1H and ^2H). Isobars are atoms with same mass number but different atomic numbers (e.g., ^{14}C and ^{14}N).
3. Nuclear forces are very strong but short-ranged, and they are independent of electric charge.
4. Density ρ = Mass/Volume $\propto A/R^3$. Since $R = R_0A^{1/3}$, therefore $R^3 \propto A$. Hence ρ becomes independent of mass number A.
5. Heavy nuclei contain more neutrons to reduce electrostatic repulsion between protons and increase nuclear stability.
6. Binding energy is the energy required to separate a nucleus into its nucleons. BE = $(\Delta m)c^2$.
7. Mass defect is the difference between the sum of masses of nucleons and the actual nuclear mass. Binding energy is given by BE = $(\Delta m)c^2$.
8. Binding energy per nucleon increases rapidly, reaches maximum near ^{56}Fe, and then decreases slowly for heavier nuclei.
9. ^{238}U is not fissile with slow neutrons, whereas ^{235}U readily undergoes fission chain reaction.
10. Mass defect $\Delta m = [2(1.007825) + 2(1.008665) - 4.002602] = 0.030378$ u. Binding energy = $0.030378 \times 931.5 \approx 28.3$ MeV.
11. Energy released = $(8.5 - 7.6) \times 235 = 211.5$ MeV.
12. Binding energy per nucleon rises up to ^{56}Fe and then decreases slowly. Energy in fission and fusion is released because products have greater binding energy per nucleon.
13. A nuclear reactor works on controlled nuclear fission. Fuel produces fission, moderator slows neutrons, control rods control reaction, coolant removes heat, and shielding protects from radiation.
14. Nuclear forces act between nucleons. They are very strong, short-ranged, charge independent, and show saturation property.

Challenge Your Brain

Why do scientists continue researching fusion reactors despite the enormous technological difficulties?

15. Mass defect $\Delta m = [26(1.00728) + 30(1.00867) - 55.9349] = 0.52808$ u. Binding energy = $0.52808 \times 931.5 \approx 492$ MeV. Iron is most stable due to maximum binding energy per nucleon.
16. By conservation of mass number, x = 3. Mass defect $\Delta m = 0.18366$ u. Energy released = $0.18366 \times 931.5 \approx 171$ MeV.
17. (i) The size of a nucleus is determined experimentally by alpha-particle scattering experiments. The relation between nuclear radius and mass number is:
    $R = R_0A^{1/3}$ where $R_0 = 1.2 \times 10^{-15}$ m. (ii) Volume of nucleus:, $V = (4/3)\pi R^3$ Since, $R = R_0A^{1/3}$, Therefore, $V \propto A$ Mass of nucleus: $M \propto A$, Hence density, $\rho = M/V \propto A/A$ = constant, Thus nuclear density is independent of mass number.

18. The binding energy per nucleon rises rapidly for light nuclei, reaches maximum near ^{56}Fe, and then decreases slowly for heavy nuclei.
Inferences:• ^{56}Fe is the most stable nucleus. Light nuclei release energy by fusion.
• Heavy nuclei release energy by fission.
Importance:
• Explains nuclear stability. Explains energy production in stars. Explains nuclear fission and fusion.

19. Initial total binding energy: $BE_i = 240 \times 7.6 = 1824$ MeV
Final total binding energy: $BEf = 240 \times 8.5 = 2040$ MeV
Energy released: $E = BE_f - BE_i$, $E = 2040 - 1824$, $E = 216$ MeV

20. The potential energy curve shows:
• Attractive force at intermediate separations. • Repulsive force at very small separations.Regions:
• Attractive region: $0.8\text{ fm} < r < 2\text{ fm}$ • Repulsive region: $r < 0.8$ fm
Two characteristics of nuclear forces:
1. Nuclear forces are very strong but short-ranged.
2. Nuclear forces are charge independent.


Build Your Own Analogy

Research and prepare a short report on India’s major nuclear power plants.

LONG ANSWER QUESTIONS

1. (a) Explain mass defect and binding energy. Derive the relation: B.E. = $\Delta m \times c^2$. (b) Draw and explain the B.E. per nucleon vs mass number graph. Identify the peak. (c) Using this graph, explain how energy is released in (i) nuclear fission and (ii) nuclear fusion. (d) Calculate the mass defect of ^4He if its atomic mass is 4.002602 u.

2. (a) Explain nuclear fission. Write the reaction for fission of ^{235}U and calculate the energy released per fission. (b) Explain the working of a nuclear reactor with a labelled diagram. State the function of the moderator, control rods, coolant, and reflector. (c) Why is a chain reaction possible in ^{235}U but not in natural uranium (predominantly ^{238}U)?

3. (a) What is nuclear fusion? State the conditions necessary for fusion to occur. Write the fusion reaction occurring in the sun. (b) Calculate the energy released in the following fusion reaction: $^2_1H + ^3_1H \rightarrow ^4_2He + n$ ($m(^2H) = 2.01410$ u, $m(^3H) = 3.01604$ u, $m(^4He) = 4.00260$ u, $m(n) = 1.00867$ u) (c) Compare nuclear fission and fusion on the basis of: (i) fuel required (ii) energy released per nucleon (iii) radioactive waste.

4. (a) What are nuclear forces? List four of their important properties. (b) Show that the nuclear density is almost constant for all nuclei. (c) Why do lighter nuclei tend to undergo fusion while heavier nuclei tend to undergo fission? Explain using the B.E./nucleon curve. (d) The nuclear radii of ^1_1H and $^{208}_{82}Pb$ are R_1 and R_2 respectively. Calculate the ratio R_2/R_1. ($M_h = 1$, $M\_Pb = 208$)

5. (i) What characteristic property of nuclear force explains the constancy of binding energy per nucleon (BE/A) in the range of mass number ‘A’ lying $30 < A < 170$?
(ii) Show that the density of nucleus over a wide range of nuclei is constant- independent of mass number.

ANSWERS

1. (a)Mass defect (Δm) is the difference between the sum of masses of individual nucleons and the actual mass of the nucleus.
$\Delta m = [Zm_p + (A-Z)m_n] - M$
Binding energy (B.E.) is the energy required to separate a nucleus completely into its nucleons.
According to Einstein's mass-energy relation: $E = mc^2$
Therefore: B.E. = $\Delta m \times c^2$, (b) The binding energy per nucleon increases rapidly for light nuclei, reaches a maximum near iron (^{56}Fe), and then decreases slowly for heavy nuclei. The peak occurs near ^{56}Fe with maximum B.E./nucleon ≈ 8.8 MeV, indicating maximum nuclear stability.
(c) In nuclear fission, heavy nuclei split into medium-mass nuclei having higher binding energy per nucleon, releasing energy. In nuclear fusion, light nuclei combine to form heavier nuclei with greater binding energy per nucleon, releasing enormous energy. (d) $\Delta m = [2(1.007825) + 2(1.008665)] - 4.002602$
$\Delta m = 4.03298 - 4.002602 \quad \Delta m = 0.030378$ u
2. (a)Nuclear fission is the process in which a heavy nucleus splits into two lighter nuclei with release of energy and neutrons.
Reaction: $^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n$ + Energy
Average energy released per fission ≈ 200 MeV.
(b) A nuclear reactor works on controlled nuclear fission.
Components and functions:
• Fuel (^{235}U): Undergoes fission • Moderator: Slows down neutrons
• Control rods: Absorb excess neutrons • Coolant: Removes heat
• Reflector: Prevents neutron leakage • Shielding: Protects from radiation
Heat produced converts water into steam, which rotates turbines to generate electricity.
(c) ^{235}U is fissile and undergoes fission with slow neutrons, whereas ^{238}U does not undergo fission with slow neutrons. Hence sustained chain reaction is possible only in ^{235}U.
3. (a)Nuclear fusion is the process in which two light nuclei combine to form a heavier nucleus with release of energy.
Conditions required:
• Very high temperature (~10^7 K), High pressure, High density, Fusion reaction in the Sun: $4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He$ + Energy
(b) Reaction:
$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$
Initial mass = 2.01410 + 3.01604 = 5.03014 u
Final mass = 4.00260 + 1.00867 = 5.01127 u
$\Delta m = 5.03014 - 5.01127, \quad \Delta m = 0.01887$ u
Energy released: $E = 0.01887 \times 931.5, \quad E \approx 17.6$ MeV
(c) Fission:
• Fuel: Heavy nuclei • Energy per nucleon: Lower • Radioactive waste: More
Fusion:
• Fuel: Light nuclei • Energy per nucleon: Higher • Radioactive waste: Very less

4. (a) Nuclear forces are forces acting between nucleons inside the nucleus.
Properties:
1. Very strong 2. Short-ranged 3. Charge independent 4. Show saturation property
(b) Nuclear radius: $R = R_0A^{1/3}$
Volume: $V \propto R^3 \propto A$, Mass: $M \propto A$, Density: $\rho = M/V \propto A/A$
Therefore, nuclear density is almost constant for all nuclei.
(c) Light nuclei have lower binding energy per nucleon, so fusion increases stability and releases energy.
Heavy nuclei also have lower binding energy per nucleon compared to iron, so fission produces more stable nuclei and releases energy.
(d) Using: $R = R_0A^{1/3}$, $R_2/R_1 = (208/1)^{1/3}$, $R_2/R_1 \approx 5.94$, Therefore: $R_2/R_1 \approx 6$

5. (i)The saturation property of nuclear forces explains the constancy of binding energy per nucleon (BE/A) for $30 < A < 170$, because each nucleon interacts only with its nearest neighbours.
(ii) Nuclear radius $R = R_0A^{1/3}$. Hence volume $V \propto R^3 \propto A$, while nuclear mass $M \propto A$. Therefore, $\rho = M/V \propto A/A =$ constant, showing nuclear density is independent of mass number.

CASE STUDY-BASED QUESTIONS

1. **Binding Energy and Nuclear Stability**

The binding energy of a nucleus is the energy required to completely separate its nucleons. It equals $\Delta m \times c^2$, where Δm is the mass defect. The binding energy per nucleon (BEN) curve peaks near ^{56}Fe (~8.8 MeV/nucleon). For lighter nuclei ($A < 56$), the BEN increases — energy can be released by nuclear fusion. For heavier nuclei ($A > 56$), the BEN decreases — energy can be released by nuclear fission. This explains why both fusion (light nuclei) and fission (heavy nuclei) are exothermic reactions, forming products with greater BEN.

(i). The binding energy per nucleon is approximately 7.6 MeV for ^{235}U. If the average BEN of fission products is 8.5 MeV, the approximate energy released per fission event (for 235 nucleons) is:

(a) 20 MeV (b) 211.5 MeV (c) 100 MeV (d) 1 GeV

(ii). Which of the following nuclei has the highest binding energy per nucleon?

(a) $^{2}_{1}H$ (b) $^{4}_{2}He$ (c) $^{56}_{26}Fe$ (d) $^{235}_{92}U$

(iii). The mass defect of $^{4}_{2}He$ is 0.0304 u. Its binding energy is approximately:

(a) 28.3 MeV (b) 7.1 MeV (c) 56.5 MeV (d) 14.2 MeV

(iv). For which of the following processes is the binding energy per nucleon of the product greater than that of the reactants?

(a) Fission of ^{235}U only (b) Fusion of hydrogen nuclei only
(c) Both (a) and (b) (d) Neither (a) nor (b)

2. **Nuclear Fission and Chain Reaction**

When ^{235}U absorbs a slow (thermal) neutron, it splits into two medium-mass fragments along with 2–3 fast neutrons and energy (~200 MeV). These secondary neutrons can cause further fissions — a chain reaction. For a self-sustaining chain reaction, the multiplication factor k must equal 1 (critical state). In a nuclear reactor, control rods (e.g., cadmium) absorb excess neutrons to maintain $k = 1$.

A moderator (e.g., heavy water or graphite) slows fast neutrons to thermal energies, increasing the probability of fission. The coolant removes heat to generate steam for electricity.

(i). The minimum mass of fissile material required for a self-sustaining chain reaction is called:

(a) Critical temperature **(b)** Critical mass **(c)** Threshold mass **(d)** Activation mass

(ii). The material used in control rods of a nuclear reactor is:

(a) Uranium **(b)** Graphite **(c)** Heavy water **(d)** Cadmium

(iii). For a sub-critical nuclear reactor, the neutron multiplication factor k is:

(a) $k = 1$ **(b)** $k > 1$ **(c)** $k < 1$ **(d)** $k = 0$

(iv). The energy released per fission of ^{235}U (~200 MeV) is primarily in the form of:

(a) Kinetic energy of neutrons only **(b)** Gamma rays only

(c) Kinetic energy of fission fragments, neutrons, and gamma rays

(d) Heat energy of the moderator

ANSWERS

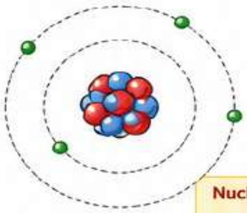
(i).b (ii). c (iii).a (iv). c

(i).b (ii). d (iii). c (iv). c

Nuclei

1 NUCLEUS & NUCLEONS

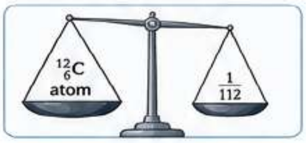
- The nucleus is the small, dense central region of an atom containing protons and neutrons.
- More than 99.9% mass of the atom is concentrated in the nucleus.



Nucleons: Protons and neutrons are collectively called nucleons.

2 ATOMIC MASS UNIT (amu)

The unit of mass used to express mass of an atom is called atomic mass unit. Atomic mass unit is defined as 1/12th of the mass of carbon ($^{12}_{6}C$) atom.



- 1 amu or 1 u = 1.660539×10^{-27} kg
- Mass of proton (m_p) = 1.00727 u
- Mass of neutron (m_n) = 1.00866 u
- Mass of electron (m_e) = 0.000549 u

Relation between amu and MeV

1 amu = 931 MeV

3 COMPOSITION OF NUCLEUS

Atomic Number (Z)

Number of protons present in the nucleus of an atom.

Z = Number of protons
= Number of electrons
(in a neutral atom)

Mass Number (A)

Total number of protons and neutrons in the nucleus.

A = Number of protons (Z)
+ Number of neutrons (N)
= Number of electrons
+ Number of neutrons

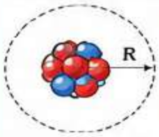
$$A = Z + N$$

4 SIZE & DENSITY OF NUCLEUS

Size of Nucleus

Nuclear sizes of different elements are assumed to be spherical.

Volume ∝ Mass number (A)



$R \propto A^{1/3}$

$R = R_0 A^{1/3}$

Where, $R_0 = 1.2 \times 10^{-15}$ m is the nuclear radius.

Nuclear Density

Density of nuclear matter,

$$\rho = \frac{m}{\frac{4}{3}\pi R_o^3}$$

$\Rightarrow \rho = 2.38 \times 10^{17}$ kg/m^3

Where, m = average mass of one nucleon and R_o = 1.2 fm = 1.2×10^{-15} m

⇒ Nuclear density (ρ) does not depend on A (mass number).

5 MASS DEFECT

The sum of the masses of neutrons and protons forming a nucleus is more than the actual mass of the nucleus. This difference of masses is known as mass defect.

$$\Delta m = Zm_p + (A - Z)m_n - M$$

Where,
Z = atomic number
A = mass number
m_p = mass of one proton
m_n = mass of one neutron
M = mass of nucleus

6 MASS–ENERGY RELATION

Einstein's mass–energy equivalence equation is given by

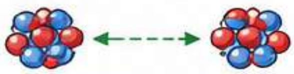
$$E = mc^2$$

Where,
E = energy
m = mass of nucleus
c = speed of light = 3×10^8 m/s

Mass can be converted into energy and energy into mass.

7 NUCLEAR FORCES

- Short ranged (2–3 fm) strong attractive forces which hold protons and neutrons together in against of Columbian repulsive forces between positively charged particles.
- The nuclear force between neutron–neutron, proton–neutron and proton–proton is approximately the same.
- The nuclear force does not depend on the electric charge.



Range ≈ 2 – 3 fm

8 NUCLEAR ENERGY

When nucleons form a nucleus, the mass of nucleus is slightly less than the sum of individual masses of nucleons. This mass is stored as nuclear energy in the form of mass defect.

Also, transmutation of less stable nuclei into more tightly bound nuclei provides an excellent possibility of releasing nuclear energy.

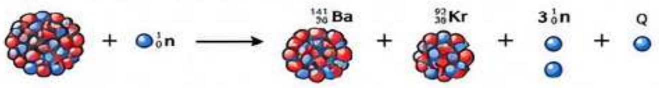
Two distinct ways of obtaining energy from nucleus are:

1. Nuclear Fission
2. Nuclear Fusion

9 NUCLEAR FISSION AND NUCLEAR FUSION

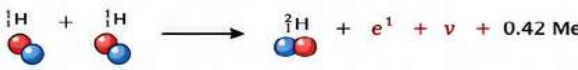
Nuclear Fission

The phenomenon of splitting of heavy nuclei (usually A > 230) into lighter nuclei of nearly equal masses is known as nuclear fission.



Nuclear Fusion

The phenomenon of fusing or combining of two lighter nuclei into a single heavy nucleus is called nuclear fusion.



[The energy released during nuclear fusion is known as thermonuclear energy.]

10 BINDING ENERGY

Binding energy of a nucleus is the minimum energy required to separate its nucleons and place them at rest at infinite distance apart.

Using Einstein's mass–energy relation,

$$\Delta E = (\Delta mc^2)$$

Hence, binding energy of the nucleus is

$$\Delta E = [Zm_p + (A - Z)m_n - M]\,c^2$$

11 AVERAGE BINDING ENERGY PER NUCLEON

It is the average energy required to extract a nucleon from the nucleus to infinite distance.

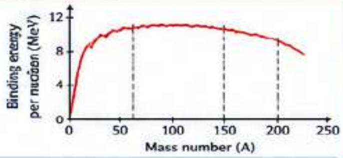
Average binding energy per nucleon

$$= \frac{\text{Total binding energy}}{\text{Mass number (A)}}$$

12 BINDING ENERGY CURVE AND NUCLEAR STABILITY

Binding Energy Curve

Plot of the binding energy per nucleon versus the mass number A for a large number of nuclei.



Nuclear Stability

The stability of a nucleus is determined by the value of its binding energy per nucleon. The constancy of the binding energy in the range 30 < A < 170 is a consequence of the fact that the nuclear force is short-ranged.

KEY CONSTANTS

Nuclear radius constant : $R_0 = 1.2 \times 10^{-15}$ m (1.2 fm) | Speed of light : $c = 3 \times 10^8$ m/s | 1 amu = 931 MeV

WARM-UP: THINK LIKE A SCIENTIST

Before You Begin...

Observe & Predict

1. Why are metals not used to make computer chips?
2. Why does silicon dominate the electronics world?
3. What would happen if semiconductors conducted electricity like copper?
4. Why are mobile phones becoming smaller every year?
5. If semiconductors did not exist, which modern technologies would disappear first?

✍ Write your ideas before studying the chapter.

____

____

SEMICONDUCTORS AROUND US

Real-Life Connections

Device	Semiconductor Use
Smartphone	Processor chips
Solar Panel	Converts sunlight to electricity
LED Bulb	Efficient light emission
Computer	Microprocessor & memory
Car Sensors	Smart automation

Semiconductor Electronics: Materials, Devices and Simple Circuits

1 ENERGY BANDS

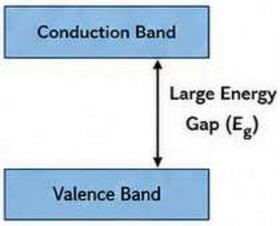
Insulators, conductors and semiconductors are differentiated based on their energy bands.

a) Metals (Conductors)

Valence band and conduction band lie very close to each other or overlap.

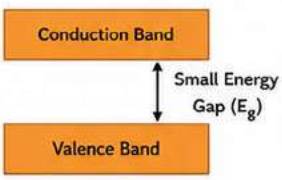
b) Insulators

Conduction band and valence band are separated by a large gap.



c) Semiconductors

Energy band gap is smaller in semiconductors which encourages some electrons to enter the conduction band.



E_g (Si) = 1.1 eV

E_g (Ge) = 0.74 eV

2 TYPES OF SEMICONDUCTORS

Semiconductors are classified into two types based on the number of electrons and holes.

- **Intrinsic (Pure)**
- **Extrinsic (Impure)**

A. Intrinsic (Pure) Semiconductor

- Free from impurities. Examples: Germanium (Ge) and Silicon (Si)
- For pure Si (Z=14) and pure Ge (Z=32). Both have 4 valence electrons.
- All 4 valence electrons are involved in covalent bond formation in Si or Ge crystal.
- It has an equal number of holes and free electrons.

Thus, $n_e = n_h = n_i$

Where, n_i = intrinsic carrier concentration

n_e = number of electrons

n_h = number of holes

B. Extrinsic (Impure) Semiconductor

- The electrical conductivity of intrinsic semiconductor is very poor at room temperature.
- Addition of certain impurities (very small amount–in ppm) increases conductivity.
- The process of addition of impurity is called doping and the impurity atoms are called dopants.
- The impure semiconductor thus formed is called a "doped" semiconductor or Extrinsic Semiconductor.

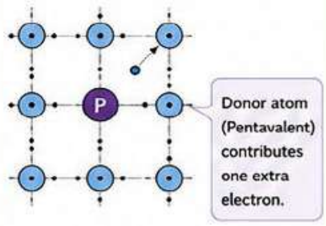
3 EXTRINSIC SEMICONDUCTORS

An extrinsic semiconductor can be of two types based on the type of doping.

(i) n-type Semiconductor

Doped with Pentavalent impurity atoms.

Examples: Phosphorus (P), Arsenic (As), Antimony (Sb)



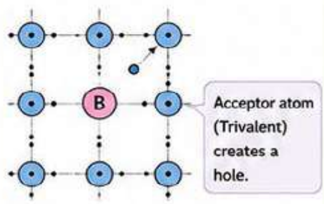
Here, $n_e >> n_h$

(Number of electrons greater than number of holes)

(ii) p-type Semiconductor

Doped with Trivalent impurity atoms.

Examples: Boron (B), Aluminium (Al), Indium (In)



Here, $n_h >> n_e$

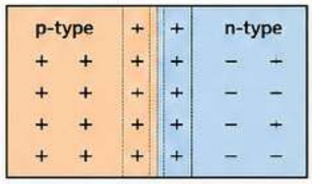
(Number of holes greater than number of electrons)

In thermal equilibrium:

$$n_e \cdot n_h = n_i^2$$

4 P–N JUNCTION

A p–n junction is formed by joining p-type and n-type semiconductor in a single crystal.



Formation: Two Important Processes

1. Diffusion

- Majority carriers diffuse from higher concentration to lower concentration across the junction.
- Electrons diffuse from n-side to p-side and holes from p-side to n-side and recombine.

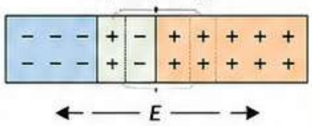
2. Drift

- Due to diffusion, fixed ions are left near the junction creating a space-charge (depletion) region.
- This sets up an electric field that opposes further diffusion.
- Minority carriers drift under the influence of this electric field.

At Equilibrium

Diffusion current equals drift current. A depletion region and a potential barrier are established across the junction which prevents further majority carrier flow.

Depletion Region

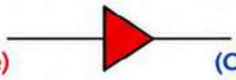


Built-in Potential (V_b)

5 SEMICONDUCTOR DIODE (p–n Junction Diode)

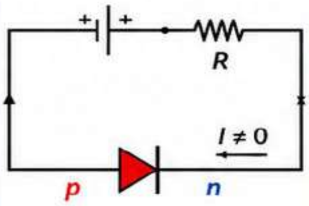
- A semiconductor diode is basically a p–n junction with metallic contacts provided at the ends for the application of an external voltage.
- It is a two-terminal device.

Symbol:



Forward Bias

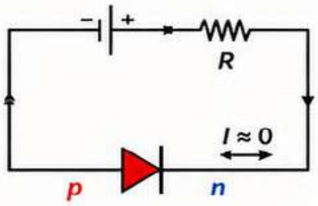
p-side connected to +ve terminal and n-side to −ve terminal.



- Barrier potential decreases.
- Offers very low resistance.
- Large current flows.

Reverse Bias

n-side connected to +ve terminal and p-side to −ve terminal.

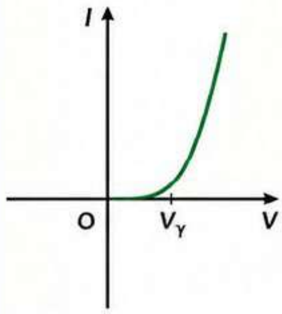


- Barrier potential increases.
- Offers very high resistance.
- Only a small leakage current flows.

The ratio of forward biased to reverse biased resistance for p–n junction diode is $10^{-4} : 1$

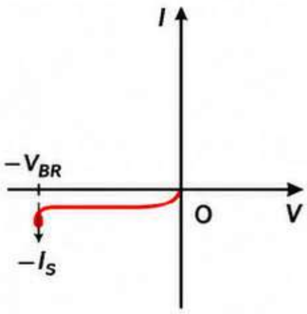
6 V–I CHARACTERISTICS OF DIODE

Forward Bias (Quadrant I)



- Current is almost zero until cut-in voltage (V_γ).
- After V_γ, current rises rapidly.
- $V_\gamma = 0.7$ V (Si)
  $V_\gamma = 0.3$ V (Ge)

Reverse Bias (Quadrant III)



- Small reverse saturation current ($-I_S$) flows.
- At breakdown voltage (V_{BR}), current increases sharply in reverse direction.

Information obtained from V–I characteristics

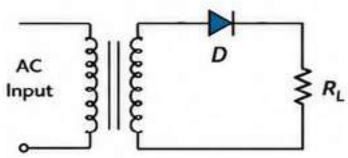
- Cut-in (knee) voltage (V_γ)
- Reverse saturation current (I_S) and breakdown voltage (V_{BR})

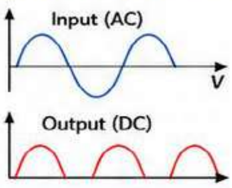
7 APPLICATION: DIODE AS RECTIFIER

A rectifier converts alternating current (AC) into direct current (DC) using diodes.

1. Half-Wave Rectifier

- One diode allows only one-half cycle of AC.
- Output is pulsating DC.

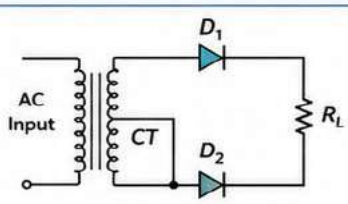


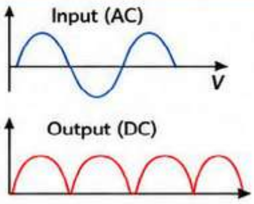


Average value of output direct current: $I_{DC} = \frac{I_0}{\pi}$

2. Full-Wave Rectifier

- Two diodes conduct in alternate half cycles.
- Output is full pulsating DC.
- Use of capacitor or inductor can filter pulsating DC into almost constant DC.





Average value of output direct current: $I_{DC} = \frac{2I_0}{\pi}$

Applications of Rectifiers

Powering DC motors

LED lighting systems

DC power supplies

Battery chargers

Radio and communication devices

Key Takeaways

- ✓ Semiconductors have a small energy band gap (Si: 1.1 eV, Ge: 0.74 eV).
- ✓ Doping creates n-type (extra electrons) and p-type (extra holes) materials.
- ✓ A p–n junction forms a depletion region and built-in potential.
- ✓ Diodes conduct in forward bias and block in reverse bias.
- ✓ Diodes are widely used as rectifiers to convert AC to DC.

MULTIPLE CHOICE QUESTIONS

1 Carbon, silicon and Germanium have four valence electrons each. At room temperature which one of the following statements is most appropriate ?

(a) The number of free electrons for conduction is significant only in Si and Ge but small in C.
(b) The number of free conduction electrons is significant in C but small in Si and Ge.
(c) The number of free conduction electrons is negligibly small in all the three.
(d) The number of free electrons for conduction is significant in all the three.

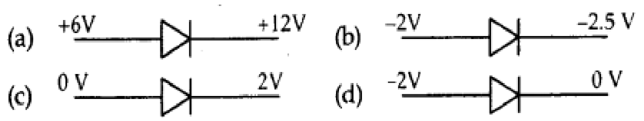
2 In the energy band diagram of a semiconductor, if more charge carriers are seen near valence band. It would be

(a) an intrinsic semiconductor (b) a metal may be n-type or p-type semiconductor
(c) an n-type semiconductor (d) a p-type semiconductor

3 The peak voltage in the output of a half wave diode rectifier fed with a sinusoidal signal without filter is 10 V. The d.c. component of the output voltage is

(a) $10/\sqrt{2}$ V (b) $10/\pi$ V (c) 10 V (d) $20/\pi$ V

4 In which case is the junction diode forward biased.



5 Assuming that the junction diode is ideal, and resistor has resistance of 200 Ω. The current in the arrangement shown here will be:

(a) 2 mA (b) 30 mA (c) 20 mA (d) 10 mA

6 Which of following statements is not true?

(a) Resistance of an intrinsic semiconductor decreases with increase in temperature.
(b) Doping pure Si with trivalent impurities gives p-type semiconductor.
(c) The majority carriers in n-type semiconductor are holes.
(d) A p-n junction can act as semiconductor diode.

7 A student wants to identify diode from a mixed collection of diodes, resistors, inductors, switch, thyristors, bulb etc using a multimeter. choose the correct statement out of the following about the diode :

(a) It is two terminal device which conducts current in both directions.
(b) It is two terminal device which conducts current in one direction only.
(c) It does not conduct current gives an initial deflection which decays to zero.
(d) It is three terminal device which conducts current in the direction only between central terminal and either of the remaining two terminals.

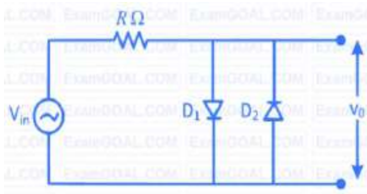
8 If the two ends of a p-n junction are joined by a wire

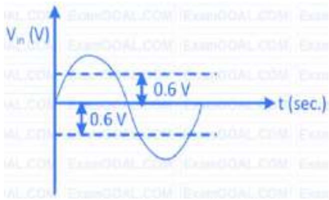
(a) there will not be a steady current in the circuit
(b) there will be a steady current from the n-side to the p side
(c) there will be a steady current from the p-side to the n side
(d) there may or may not be a current depending upon the resistance of the connecting wire

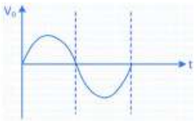
Suppose all holes disappeared from a p-type semiconductor.
Would current stop completely? Could the material still conduct? Discuss scientifically.

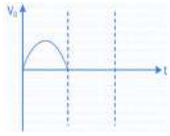
9 The diffusion current in a p-n junction is from the
(a) n-side to the p-side
(b) p-side to the n-side
(c) n-side to the p-side if the junction is forward-biased and in the opposite direction it is reverse-biased
(d) p-side to the n-side if the junction is forward-biased and in the opposite direction if it is reverse-biased

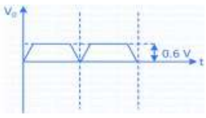
10 In the given circuit the input voltage V_{in} is shown in figure. The cut-in voltage of p-n junction diode (D_1 or D_2) is 0.6 V. Which of the following output voltage (V_0) waveform across the diode is correct?

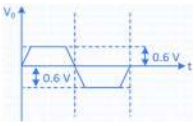




(a)


(b)


c)


(d)


ANSWERS

1.a, 2. d, 3. d, 4. b, 5. d, 6. c, 7. b, 8. a, 9. b, 10. d

ASSERTION- REASON BASED QUESTIONS

For these Questions two statements are given one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below

a. If both Assertion and Reason are true and Reason is correct explanation of Assertion.
b. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
c. If Assertion is true but Reason is false.
d. If both Assertion and Reason are false.

1 **Assertion (A):** As the temperature of a semiconductor increases, its resistance decreases.
Reason (R): The energy gap between conduction band and valence band is > 3eV in semiconductor.

2 **Assertion (A):** The resistivity of a semiconductor increases with temperature.
Reason (R): The atoms of a semiconductor vibrate with larger amplitude at higher temperature there by increasing it's resistivity.

3 **Assertion(A):** Semiconductors are used to build digital logic circuits.
Reason(R): They cannot easily switch between high and low voltage states.

THINK LIKE AN ENGINEER: Why are impurities added in quantities as small as: # "1 atom per million atoms"
Why not add more impurities?

4 **Assertion(A):** In digital electronics, we prefer Integrated circuits or diodes etc made up of Silicon over Germanium.
Reason(R): Silicon has better thermal stability.

5 **Assertion(A):** In an intrinsic semiconductor, the Fermi level lies midway between conduction and valence bands.
Reason(R): There are more electrons than holes in an intrinsic semiconductor.

6 **Assertion(A):** The band gap of Germanium is higher than that of silicon.
Reason(R): Germanium has higher resistivity than silicon.

7 **Assertion (A):** The reverse current in a p-n junction diode increases rapidly at high reverse voltages.
Reason (R): High reverse bias causes a reduction in the barrier potential and enhances carrier injection.

8 **Assertion (A)**: Ideal diode shows zero resistance in forward bias and infinite resistance in reverse bias.
Reason (R): Depletion region of a p-n junction diode extends in reverse bias and contracts in forward bias.

9 **Assertion (A):** A pure semiconductor has negative temperature coefficient of resistance.
Reason (R): In a semiconductor on raising the temperature, more charge carriers are released, conductance increases and resistance decreases.

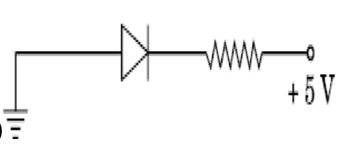
10 **Assertion (A):** When diode is used as a rectifier, applied voltage should not be exceeded beyond specified reverse breakdown voltage.
Reason (R): When p-n junction diode crosses the reverse break down voltage, it get destroyed.

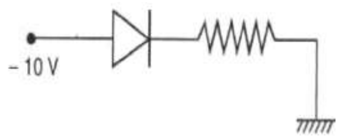
ANSWERS

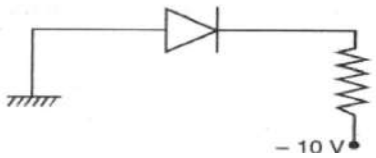
1. c, 2. d, 3. c, 4. a, 5. c, 6. d, 7. c, 8. a, 9. a, 10. a

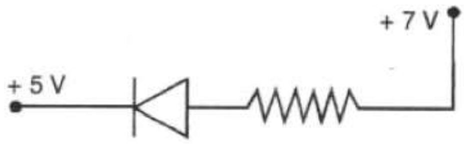
VERY-SHORT ANSWER QUESTIONS

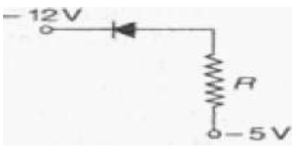
1. In the following circuit diagram, is the junction diode forward biased or reverse biased?

(i) 

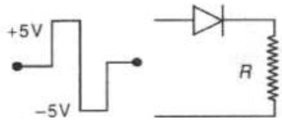
(ii) 

(iii) 

(iv) 

(v) 

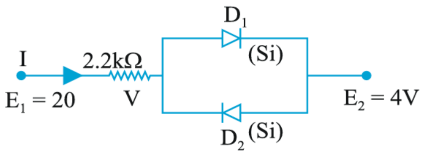
2. Draw and explain the output wave forms across the load resistor R, if the input waveform is as shown in the figure.



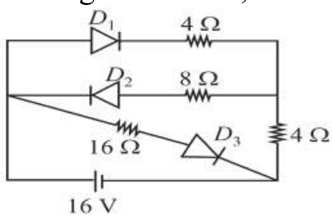
THINK LIKE A RESEARCHER : Suppose scientists create a diode with:

- zero cut-in voltage, zero power loss, no heating. How would technology change?

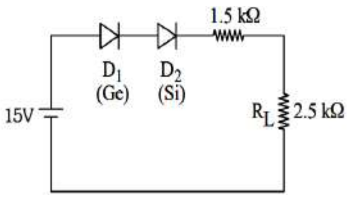
3. Determine the current for the network.(Barrier voltage for the Si diode is 0.7Volt)



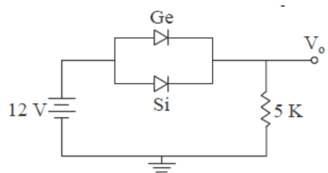
4. A p-n diode is fabricated with a semiconductor with a band-gap of 2.8 eV. Can it detect a wavelength of 6000 nm?
5. In the given circuit, Find the current through the battery**?**



6. In the given circuit, Find the voltage across load resistance (R_L)



7. How are charge carriers created in an intrinsic semiconductor ? Explain.
8. Write two points of difference between intrinsic and extrinsic semiconductors.
9. Differentiate between n-type and p-type semiconductors.
10. Ge and Si diodes start conducting at **0.3 V** and **0.7 V** respectively. In the following figure if Ge diode connection are reversed, the value of Vo changes by ?



SHORT-ANSWER QUESTIONS

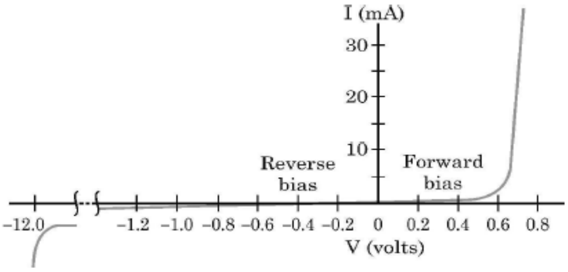
1. (a)Draw the energy – band diagrams for conductors, semiconductors and insulators at T = 0 K. How is an electron-hole pair formed in a semiconductor at room temperature?
(b)Carbon and silicon both, are members of IV group of periodic table and have the same lattice structure . Carbon is an insulator whereas silicon is a semiconductor. Explain.
2. Differentiate between half-wave and full-wave rectification. With the help of a circuit diagram, explain the working of a full-wave rectifier.
3. In an intrinsic semiconductor, carrier's concentration is 5 x 10^8 m^{-3}. On doping with impurity atoms, the hole concentration becomes 8 x 10^{12} m^{-3}.
   (a) Identify (i) the type of dopant and (ii) the extrinsic semiconductor so formed.
   (b) Calculate the electron concentration in the extrinsic semiconductor.

4. Draw energy band diagrams of n-type and p-type semiconductors at temperature T > 0 K. Show the donor/acceptor energy levels with the order of difference of their energies from the bands.

Imagine Earth suddenly loses all semiconductor technology for 24 hours.
Describe the impact? Would modern civilization survive normally? Explain scientifically.

5. A p-type Si semiconductor is made by doping an average of one dopant atom per 5×10^7 silicon atoms. If the number density of silicon atoms in the specimen is 5×10^{28} atoms m^{-3}, find the number of holes created per cubic centimetre in the specimen due to doping. Also give one of such dopants.
6. In an n-type semiconductor electron-hole combination is a continuous process at room temperature. Yet the electron concentration is always greater than the hole concentration in it. Explain.
7. .(a)Draw circuit arrangement for studying V-I characteristic of a p-n junction diode.
(b)Show the shape of the characteristics of a diode.
(c)Mention two information that you can get from these characteristics.
8. .(a)What are majority and minority charge carriers in an extrinsic semiconductor?
(b)A p-n junction is forward biased. Describe the movement of the charge carriers which produce current in it.
(c)The graph shows the variation of current with voltage for a p-n junction diode.
9. (a)What are majority and minority charge carriers of p-type and n-type semiconductors?
(b)Explain briefly the formation of diffusion current and drift current in a p-n junction diode.

Estimate the dynamic resistance of diode at V = -0.6 volt.

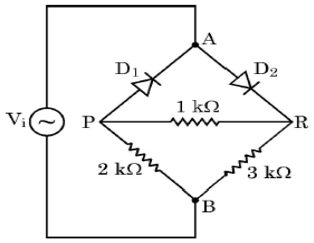


10. Explain the process of formation of 'depletion layer' and 'potential barrier' in a p-n junction region of a diode, with the help of a suitable diagram. Which feature of junction diode makes it suitable for its use as a rectifier ?
11. A semiconductor has equal electron and hole concentration of $3 \times 10^8\ m^{-3}$. On doping with a certain impurity, the hole concentration increases to $6 \times 10^{10}\ m^{-3}$.
(a) What type of semiconductor is obtained on doping ?
(b) Calculate the new electron concentration of the semiconductor.
(c) How does the energy gap of semiconductor change with doping ?
Draw the energy band diagram for it.
12. (a) Explain the working of a junction diode as a half-wave rectifier.
(b) The efficiency of a half-wave rectifier is 40%. What happens to the remaining 60% power ?
13. Suppose a pure Si crystal has 5×10^{28} atoms per m^3. It is doped with 5×10^{22} atoms per m^3 of Arsenic. Calculate the majority and minority carrier concentration in the doped silicon. (Given : $n_i = 1{\cdot}5 \times 10^{16}\ m^{-3}$)
14. Draw a circuit diagram of a full-wave rectifier using p-n junction diodes. Explain its working and show the input-output waveforms.

- Integrated Circuits (ICs) combine thousands to billions of semiconductor components on a tiny chip.

- Gallium Arsenide (GaAs) semiconductors are faster than silicon and are used in high-frequency applications.

15.



AN ac voltage Vi = 12 sin (100 πt)V is applied between points A and B in a network of two ideal diodes and three resistors as shown in figure. During the positive half cycle of the input voltage Vi supplied to the network.

(a) Identify which of the two diodes will conduct and why ?

(b) Redraw an equivalent circuit diagram to show the flow of current.

(c) Calculate the output voltage drops V0 across the three resistors when the input voltage attains its peak value.

16. Briefly explain the two important processes that occur during the formation of a p-n junction.
17. With the help of circuit diagrams, briefly explain the forward biasing and the reverse biasing of a p-n junction diode.
18. With the help of a circuit diagram, explain the working of a full wave rectifier. Depict the input and output waveforms.
19. The hole concentration in an intrinsic semiconductor is 5×10^8 m^{-3}. When it is doped with certain impurity, the electron concentration becomes 4×10^{12} m^{-3}. Find the new value of the hole concentration. Also identify the type of new semiconductor formed after doping.
20. A sample of Si doped with trivalent impurity and another Si sample which is doped with pentavalent impurity (each with impurity concentration 1 in million).

ANSWERS

1. **(a)** In conductors valence and conduction bands overlap; in semiconductors they are separated by a small gap; in insulators by a large gap. At room temperature, thermal energy breaks some covalent bonds producing electron-hole pairs.

   (b) Carbon has a larger band gap (~5.5 eV) so it behaves as an insulator, whereas silicon has a smaller band gap (~1.1 eV) and acts as a semiconductor.
2. Half-wave rectifier uses one half cycle of AC while full-wave rectifier uses both half cycles, giving higher efficiency. In a full-wave rectifier, two diodes conduct alternately during positive and negative half cycles to produce pulsating DC.
3. (a) (i) Dopant is trivalent impurity. (ii) Extrinsic semiconductor formed is p-type.

   (b) Electron concentration = 3.125×10^4 m^{-3}.
4. In n-type semiconductor, donor level lies just below the conduction band; in p-type semiconductor, acceptor level lies just above the valence band. The energy difference is very small (~0.01 eV).
5. Number of holes created = 10^{15} cm^{-3}. One suitable dopant is Boron (B).
6. In n-type semiconductor, pentavalent impurities provide a large number of free electrons. Though electron-hole recombination occurs continuously, electrons remain much more than holes because electrons are majority carriers.

Science Through Story® Pure silicon is like a quiet city. Doping adds “special citizens” that completely transform the city’s behaviour. Pentavalent atoms donate extra electrons. Trivalent atoms create electron vacancies called holes.This tiny modification powers the entire digital world.

7. **(a)** A battery, resistor, milli ammeter and p-n diode are connected in series with a voltmeter across the diode.
   (b) Forward bias gives exponential rise in current; reverse bias gives very small reverse saturation current.
   (c) Cut-in voltage and dynamic resistance can be obtained.
8. **(a)** Majority carriers are electrons in n-type and holes in p-type; minority carriers are holes in n-type and electrons in p-type.
   (b) In forward bias, electrons from n-side and holes from p-side cross the junction and constitute current flow.
   (c) Current increases rapidly after cut-in voltage in forward bias.
9. **a)** In p-type: holes are majority and electrons are minority carriers. In n-type: electrons are majority and holes are minority carriers.
   (b) Diffusion current is due to movement of majority carriers across the junction; drift current is due to movement of minority carriers under electric field.
   Dynamic resistance: rd = $\Delta V/\Delta I$.
10. Diffusion of electrons and holes across the junction leaves immobile ions near junction forming depletion layer. This creates an electric field called potential barrier. Unidirectional conductivity makes the diode useful as a rectifier.
11. (a) p-type semiconductor is formed.
    (b) Electron concentration = 1.5 × 10^6 m^-3.
    (c) Energy gap remains almost unchanged on doping. Acceptor level appears just above valence band.
12. **(a)** In half-wave rectifier, diode conducts during one half cycle and blocks the other, producing pulsating DC.
    (b) Remaining 60% power is lost as heat in the circuit components and unused AC output.
13. Majority carrier concentration = 5×10^{22} m^{-3}.
    Minority carrier concentration = 4.5×10^{9} m^{-3}.
14. A full-wave rectifier uses two diodes and a centre-tapped transformer. Each diode conducts during alternate half cycles, giving output current in the same direction for both halves.
15. **(a)** During positive half cycle, the forward biased diode conducts while reverse biased diode does not.
    (b) Equivalent circuit contains conducting diode as short circuit and non-conducting diode as open circuit.
    (c) At peak: Vi = 12 V; voltage drops are found using voltage division rule.
16. The two important processes are diffusion of majority carriers across junction and formation of depletion region with potential barrier due to uncovered ions.

17. In forward bias, p-side is connected to positive terminal and n-side to negative terminal reducing barrier potential and increasing current. In reverse bias, barrier potential increases and only small reverse current flows.
18. In a full-wave rectifier, alternate diodes conduct in alternate half cycles so current through load remains in same direction. Output waveform contains both half cycles as pulsating DC.
19. New hole concentration = 6.25 × 10^4 m^-3. Since electron concentration increases, semiconductor formed is n-type.
20. Si doped with trivalent impurity forms p-type semiconductor where holes are majority carriers. Si doped with pentavalent impurity forms n-type semiconductor where electrons are majority carriers.

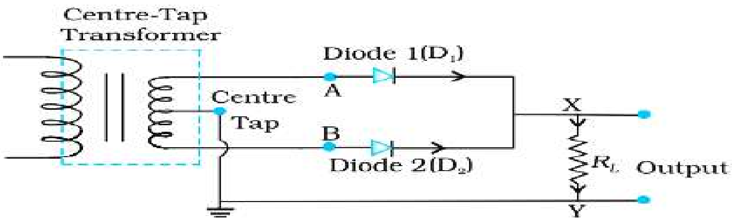

Build Your Own Analogy

Explain semiconductor behaviour using: traffic system, water flow, school corridors, shopping mall, airport security

LONG ANSWER QUESTIONS

1. **(a)** Explain the formation of depletion layer and potential barrier in a p–n junction.
   (b) In the figure given below the input waveform is converted into the output waveform by a device 'X'. Name the device and draw its circuit diagram.

2. **(a)** A student connects p-side of a **p-n junction** diode with positive terminal of battery and n-side is connected with negative terminal of battery. Another student connects the diode in opposite way with battery. Identify the biasing in both the cases. Draw the circuit diagram of these biasing of a p-n junction.



   (b) If the ratio of the concentration of electrons to that of holes in a semiconductor is 5/7 and the ratio of currents is 4/7. Find the ratio of their drift velocities.

ANSWERS

1. **(a)** When p-type and n-type semiconductors are joined, electrons and holes diffuse across the junction and recombine, leaving immobile ions near the junction. This region without free charge carriers is called the depletion layer, and the electric field developed across it forms the potential barrier.
   (b) The device 'X' is a rectifier diode (p–n junction diode) used as a rectifier. A diode connected in series with a load resistor across an AC source gives pulsating DC output.
2. **(a)** When p-side is connected to positive terminal and n-side to negative terminal, the diode is forward biased. When connections are reversed, the diode is reverse biased. In forward bias, current flows easily; in reverse bias, only a small leakage current flows.
   (b) Given n/p = 5/7 and In/Ip = 4/7. Using In/Ip = $(nv_n)/(pv_p)$, we get $v_n/v_p = 4/5$.
   Hence, the ratio of drift velocities is 4 : 5.

CASE STUDY-BASED QUESTIONS

1. Extrinsic semiconductors are made by doping pure or intrinsic semiconductors with suitable impurity.

There are two type of dopants used in doping, Si or Ge, and using them p-type and n-type semiconductors can be obtained. A p-n junction is the basic building block of many semiconductor devices. Two important processes occur during the formation of a p-n junction: diffusion and drift. When such a junction is formed, a depletion layer is created consisting of immobile ion-cores.

This is responsible for a junction potential barrier. The width of a depletion layer and the height of potential barrier changes when a junction is forward-biased or reverse biased. A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for application of an external voltage. Using diodes, alternating voltages can be rectified.

(i) Which of the following is a donor impurity atom for Ge ?

(a) Boron (b) Antimony (c) Aluminium (d) Indium

(ii) When a pentavalent atom occupies the position of an atom in the crystal lattice of Si, four of its electrons form covalent bonds with four silicon neighbours, while the fifth remains bound to the parent atom. The energy required to set this electron free is about :

(a) 0.5 eV (b) 0.1 eV (c) 0.05 eV (d) 0.01 eV

(iii) During formation of a p-n junction :

(a) a layer of negative charge on n-side and a layer of positive charge on p-side appear.
(b) a layer of positive charge on n-side and a layer of negative charge on p-side appear.
(c) the electrons on p-side of the junction move to n-side initially.
(d) initially diffusion current is small, and drift current is large.

(iv) (a) In reverse-biased p-n junction :

(a) the drift current is of the order of few mA.
(b) the applied voltage mostly drops across the depletion region.
(c) the depletion region width decreases.
(d) the current increases with increase in applied voltage.

OR

(v) The output frequency of a full-wave rectifier with 50 Hz as input frequency is :

(a) 25 Hz (b) 50 Hz (c) 100 Hz (d) 200 Hz

2. A p-n junction diode allows current to pass only when it is forward biased. So, if an alternating voltage is applied across a diode the current flows only in that part of the cycle when the diode is forward biased. This property is used to rectify alternating voltages and the circuit used for this purpose is called a rectifier.

If an alternating voltage is applied across a diode in series with a load, a pulsating voltage will appear across the load only during the half cycles of the ac input during which the diode is forward biased. Such rectifier circuit is called a half-wave rectifier.

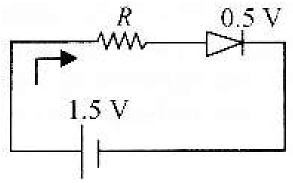
When two diodes are used to give output rectified voltage corresponding to both the positive as well as negative half of the ac cycle, it is known as *full-wave rectifier*.

The rectified voltage is in the form of pulses of the shape of half sinusoids. Though it is unidirectional it does not have a steady value. To get steady dc output from the pulsating voltage normally a capacitor is connected across the output terminals (parallel to the load R_L). One can also use an inductor in series with *RL* for the same purpose. Since these additional circuits appear to *filter* out the *ac ripple* and give a *pure dc* voltage, so they are called filters.

(i) In an unbiased p-n junction,

(a) high potential at n-side and low potential at p-side
(b) high potential at p-side and low potential at n-side
(c) p and n both are at same potential
(d) undetermined

(ii) The diode used in the circuit shown in the figure has a constant voltage drop at 0.5 V at all currents and a maximum power rating of 100 milliwatts. What should be the value of the resistor R, connected in series with diode for obtaining maximum current?



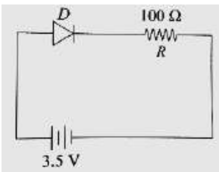
(a) 6.76 Ω (b) 20 Ω (c) 5 Ω (d) 5.6 Ω

(iii) The average value of full wave rectified voltage with a peak voltage of 66 V is
(a) 66 V (b) 32 V (c) 42 V (d) 88 V

(iv) The power delivered, and efficiency (for half wave rectifier and full wave rectifier) is
(a) low for half wave rectifier
(b) low for full wave rectifier
(c) same for both half wave rectifier and full wave rectifier
(d) can not say

OR

(v)In the given figure, a diode D is connected to an external resistance R = 100 Ω and an emf of 3.5 V. If the barrier potential developed across the diode is 0.5 V. the current in the circuit will be:



(a) 40 mA (c) 35 mA (b) 20 mA (d) 30 mA

ANSWERS

1.	i).b	(ii). c	(iii).b	(iv). b **OR**	(v). c
2.	(i). a	(ii). c	(iii).d	(iv). a OR	(v).d

DIGITAL RESOURCES

CBSE SQP 2026	**https://cbseacademic.nic.in/SQP_CLASSXII_2025-26.html**
CBSE QP 2026	**https://www.cbse.gov.in/cbsenew/question-paper.html**
CBSE MS 2026	**https://www.cbse.gov.in/cbsenew/marking-scheme.html**
CBSE QP 2025	**https://www.cbse.gov.in/cbsenew/marking-scheme.html**
CBSE MS 2025	**https://www.cbse.gov.in/cbsenew/marking-scheme.html**
CHAPTER WISE & PRACTICE QUESTION PAPER	Formula Sheet Infographics class XII Interactive worksheets class XII Practice QP Class XII
NCERT YOUTUBE CHANNEL	https://www.youtube.com/@NCERTOFFICIAL/search?query=physics%20class%20XII
PRACTICAL	https://www.youtube.com/@NCERTOFFICIAL/search?query=physics%20class%20XII%20PRACTICAL