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# Physics

Sample Question Paper 2024



# Sample Paper

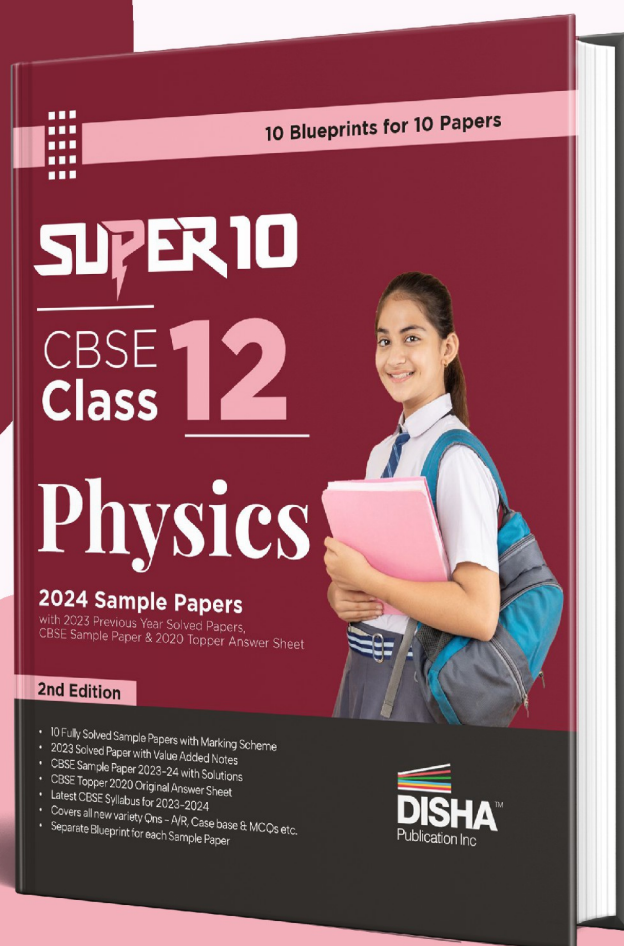
**LATEST PATTERN**

Ch. No.	Chapter Name	Per Unit Marks	Section-A MCQs 1 Mark	Section-B SA 2 Marks	Section-C LA-I 3 Marks	Section-D Case Study 4 Marks	Section-E LA-II 5 Marks	Total Marks
1	Electric Charges and Fields	16	1 (Q. 14)			1 (Q. 29)	1 (Q. 31)	10
2	Electrostatic Potential and Capacitance		2 (Q. 1, 15)					2
3	Current Electricity		1 (Q. 2)		1 (Q. 24)			4
4	Moving Charges and Magnetism	17			1 (Q. 27)			3
5	Magnetism and Matter				1 (Q. 22)			3
6	Electromagnetic Induction			1 (Q. 19)	1 (Q. 23)			5
7	Alternating Current		1 (Q. 3)				1 (Q. 32)	6
8	Electromagnetic Waves	18	2 (Q. 4, 12)					2
9	Ray optics and Optical Instruments		2 (Q. 11, 16)	1 (Q. 21)		1 (Q. 30)		8
10	Wave Optics		1 (Q. 5)	1 (Q. 17)			1 (Q. 33)	8
11	Dual Nature of Radiation and Matter	12	1 (Q. 8)		1 (Q. 25)			4
12	Atoms		1 (Q. 7)		1 (Q. 26)			4
13	Nuclei		1 (Q. 6)		1 (Q. 28)			4
14	Semiconductor Electronics: Materials, Devices and Simple Circuits	7	3 (Q. 9, 10, 13)	2 (Q. 18, 20)				7
	<b>Total Marks (Total Questions)</b>		<b>16 (16)</b>	<b>10 (5)</b>	<b>21 (7)</b>	<b>8 (2)</b>	<b>15 (3)</b>	<b>70 (33)</b>

**NOTE :** The number given inside the bracket denotes question number, ask in the sample paper, while the number given outside the bracket are the number of questions from that particular chapter.

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**Time Allowed : 3 Hours**

**Max. Marks : 70**

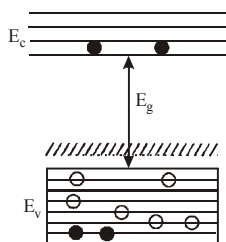
### General Instructions

1. There are 33 questions in all. All questions are compulsory.
2. This question paper has five sections: Section A, Section B, Section C, Section D and Section E. All the sections are compulsory.
3. **Section A** contains sixteen questions, twelve MCQ and four Assertion Reasoning based of 1 mark each, **Section B** contains five questions of two marks each, **Section C** contains seven questions of three marks each, **Section D** contains two case study based questions of four marks each and **Section E** contains three long answer questions of five marks each.
4. There is not overall choice. However, an internal choice has been provided in one question in Section B, one question in Section C, one question in each CBQ in Section D and all three questions in Section E. You have to attempt only one of the choices in such questions.
5. Use of calculators is not allowed.

### SECTION-A

1. The capacitors of capacity  $C_1$  and  $C_2$  are connected in parallel, then the equivalent capacitance is  
 (a)  $C_1 + C_2$                       (b)  $\frac{C_1 C_2}{C_1 + C_2}$                       (c)  $\frac{C_1}{C_2}$                       (d)  $\frac{C_2}{C_1}$
2. The powers of two electric bulbs are 100 watt and 200 watt. Both of them are joined with 220 volt. The ratio of resistance of their filament will be  
 (a) 4 : 1                      (b) 1 : 4                      (c) 1 : 2                      (d) 2 : 1
3. The transformer voltage induced in the secondary coil of a transformer is mainly due to  
 (a) a varying electric field                      (b) a varying magnetic field  
 (c) the vibrations of the primary coil                      (d) the iron core of the transformer
4. The magnetic field in a travelling electromagnetic wave has a peak value of 20 nT. The peak value of electric field strength is  
 (a) 3 V/m                      (b) 6 V/m                      (c) 9 V/m                      (d) 12 V/m
5. If the width of the slit in single slit diffraction experiment is doubled, then the central maximum of diffraction pattern becomes  
 (a) broader and brighter                      (b) sharper and brighter  
 (c) sharper and fainter                      (d) broader and fainter.
6. If the total binding energies of  ${}^2_1\text{H}$ ,  ${}^4_2\text{He}$ ,  ${}^{56}_{26}\text{Fe}$  &  ${}^{235}_{92}\text{U}$  nuclei are 2.22, 28.3, 492 and 1786 MeV respectively, identify the most stable nucleus of the following.  
 (a)  ${}^{56}_{26}\text{Fe}$                       (b)  ${}^2_1\text{H}$                       (c)  ${}^{235}_{92}\text{U}$                       (d)  ${}^4_2\text{He}$
7. The significant result deduced from the Rutherford's scattering experiment is that  
 (a) whole of the positive charge is concentrated at the centre of atom  
 (b) there are neutrons inside the nucleus  
 (c)  $\alpha$ -particles are helium nuclei  
 (d) electrons are embedded in the atom
8. With reference to the observations in photo-electric effect, identify the correct statements from below:  
 A. The square of maximum velocity of photoelectrons varies linearly with frequency of incident light.  
 B. The value of saturation current increases on moving the source of light away from the metal surface.  
 C. The maximum kinetic energy of photo-electrons decreases on decreasing the power of LED (light emitting diode) source of light.  
 D. The immediate emission of photo-electrons out of metal surface can not be explained by particle nature of light/ electromagnetic waves.  
 E. Existence of threshold wavelength can not be explained by wave nature of light/electromagnetic waves.  
 Choose the correct answer from the options given below:  
 (a) A and B only                      (b) A and E only                      (c) C and E only                      (d) D and E only
9. In the energy band diagram of a material shown below, the open circles and filled circles denote holes and electrons respectively. The material is





- (a) an insulator                      (b) a metal                              (c) an n-type semiconductor      (d) a p-type semiconductor
10. In the half wave rectifier circuit operating from 50 Hz mains frequency, the fundamental frequency in the ripple would be  
(a) 25 Hz                              (b) 50 Hz                              (c) 70.7 Hz                              (d) 100 Hz
11. The focal length of the objective of a telescope is 60 cm. To obtain a magnification of 20, the focal length of the eye piece should be  
(a) 2 cm                              (b) 3 cm                              (c) 4 cm                              (d) 5 cm
12. In electromagnetic spectrum, the frequencies  $\gamma$ -rays, X-rays and ultraviolet rays are denoted by  $n_1$ ,  $n_2$  and  $n_3$  respectively then  
(a)  $n_1 > n_2 > n_3$                       (b)  $n_1 < n_2 < n_3$                       (c)  $n_1 > n_2 < n_3$                       (d)  $n_1 < n_2 > n_3$

**For question numbers 13 to 16, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.**

- (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 and R is also false

13. **Assertion (A) :** In insulators, the forbidden gap is very large.

**Reason (R) :** The valence electrons in an atom of an insulator are very tightly bound to the nucleus.

14. **Assertion (A) :** On going away from a point charge or a small electric dipole, electric field decreases at the same rate in both the cases.

**Reason (R) :** Electric field is inversely proportional to square of distance from the charge or an electric dipole.

15. **Assertion (A) :** When a dielectric slab is gradually inserted between the plates of an isolated parallel-plate capacitor, the energy of the system decreases.

**Reason (R) :** The force between the plates decreases.

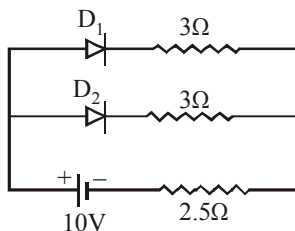
16. **Assertion (A) :** The objective of telescope has small focal length.

**Reason (R) :** If objective and eye lenses of a microscope are interchanged then it can work as telescope.

### SECTION-B

17. A plane wavefront is incident on  
(i) a prism                              (ii) a convex lens.  
Draw the emergent wavefront in each case.

18. Assuming that the two diodes  $D_1$  and  $D_2$  used in the electric circuit shown in the figure are ideal, find out the value of the current flowing through  $2.5\Omega$  resistor.

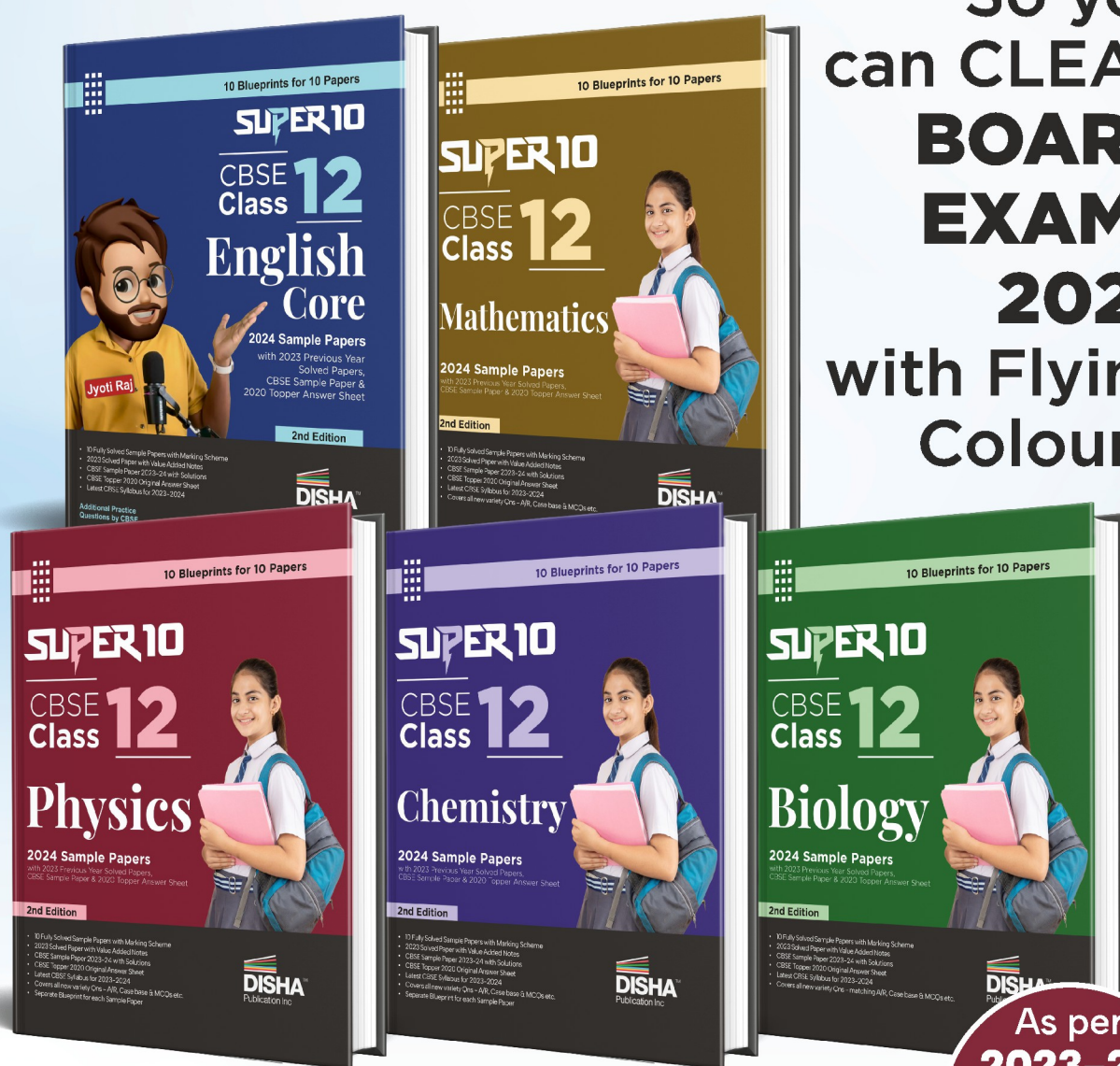


# FINAL HOUR

## PREP MATERIAL

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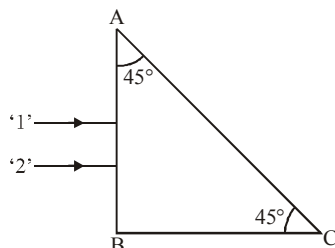
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19. If the rate of change of current is 2 A/s and induces an e.m.f. of 40 mV in the solenoid, what is the self-inductance of the solenoid?
20. What are the requirements for an element to be a good dopant?
21. Two monochromatic rays of light are incident normally on the face AB of an isosceles right-angled prism ABC. The refractive indices of the glass prism for the two rays '1' and '2' are respectively 1.35 and 1.45. Trace the path of these rays after entering the prism.



**OR**

A ray of light passes through an equilateral prism in such a manner that the angle of incidence is equal to angle of emergence and each of these angle is equal to  $\frac{3}{4}$  of angle of prism. Find angle of deviation.

### SECTION-C

22. Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each.
23. Define the term mutual inductance. Write its S.I. unit. Give two factors on which the coefficient of mutual inductance between a pair of coil depends.
24. Define the term resistivity of a conductor. Give its S.I. unit. Show that the resistivity of a conductor is given by  $\frac{m}{ne^2\tau}$  where symbols have their usual meanings.
25. Write Einstein's photoelectric equation. Mention the underlying properties of photons on the basis of which this equation is obtained.  
Write two important observations of photoelectric effect which can be explained by Einstein's equation.
26. 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?
27. Using Biot-Savart's law, derive the expression for the magnetic field in the vector form at a point on the axis of a circular current loop.
28. How the size of a nucleus is experimentally determined? Write the relation between the radius and mass number of the nucleus. Show that the density of nucleus is independent of its mass number.

**OR**

- (a) In a nuclear reaction :  

$${}^3_2\text{He} + {}^3_2\text{He} \longrightarrow {}^4_2\text{He} + {}^1_1\text{H} + {}^1_1\text{H} + 12.86 \text{ MeV},$$
 though the number of nucleons is conserved on both sides of the reaction, yet the energy is released. How? Explain.
- (b) Draw a plot of potential energy between a pair of nucleons as a function of their separation. Mark the regions where potential energy is (i) positive and (ii) negative.

### SECTION-D

#### 29. Case Study: Electric Flux & Gauss's Law

**Read the following paragraph and answer the questions.**

Electric flux over an area in an electric field is the total number of electric lines of force crossing this area.

It is measured by the product of surface area and the corresponding component of electric field normal to the area.

$$\phi = \oint \vec{E} \cdot d\vec{s}$$

It is a scalar quantity. Its SI unit is volt metre (Vm) or  $\text{Nm}^2/\text{C}$ .

From the Gauss's law, electric flux through a closed surface S.

$$\phi = \frac{q}{\epsilon_0}$$

Here,  $q$  = total charge enclosed by S.

- (i) A charge  $Q$  is enclosed by a Gaussian spherical surface of radius  $R$ . If the radius is doubled, then the outward electric flux will
  - (a) increase four times
  - (b) be reduced to half
  - (c) remain the same
  - (d) be doubled
- (ii) At the centre of a cubical box +  $Q$  charge is placed. The value of total flux that is coming out a wall is
  - (a)  $Q/\epsilon_0$
  - (b)  $Q/3\epsilon_0$
  - (c)  $Q/4\epsilon_0$
  - (d)  $Q/6\epsilon_0$
- (iii) The Gaussian surface
  - (a) can pass through a continuous charge distribution.
  - (b) cannot pass through a continuous charge distribution.
  - (c) can pass through any system of discrete charges.
  - (d) can pass through a continuous charge distribution as well as any system of discrete charges.

**OR**

For a given surface the Gauss's law is stated as  $\oint \vec{E} \cdot d\vec{A} = 0$ . From this we can conclude that

- (a)  $E$  is necessarily zero on the surface
  - (b)  $E$  is perpendicular to the surface at every point
  - (c) the total flux through the surface is zero
  - (d) the flux is only going out of the surface
- (iv) The electric field in a region of space is given by,  $\vec{E} = E_0 \hat{i} + 2E_0 \hat{j}$  where  $E_0 = 100 \text{ N/C}$ . The flux of the field through a circular surface of radius  $0.02 \text{ m}$  parallel to the  $Y$ - $Z$  plane is nearly:
- (a)  $0.125 \text{ Nm}^2/\text{C}$
  - (b)  $0.02 \text{ Nm}^2/\text{C}$
  - (c)  $0.005 \text{ Nm}^2/\text{C}$
  - (d)  $3.14 \text{ Nm}^2/\text{C}$

### 30. Case Study: Total internal Reflection

**Read the following paragraph and answer the questions.**

When light travels from an optically denser medium to a rarer medium at the interface, it is partly reflected back into the same medium and partly refracted to the second medium. This reflection is called the internal reflection.

If the angle of incidence is increased still further, refraction is not possible, and the incident ray is totally reflected. This is called total internal reflection.

The angle of incidence in denser medium to which angle of refraction is  $90^\circ$  in rarer medium is called critical angle.

Also, Refractive index =  $\frac{1}{\sin C}$ . Here,  $C$  = critical angle.

- (i) When the angle of incidence of a light ray is greater than the critical angle it gets
  - (a) critically refracted
  - (b) totally reflected
  - (c) total internally reflected
  - (d) totally refracted
- (ii) Critical angle of light passing from glass to water is minimum for
  - (a) red colour
  - (b) green colour
  - (c) yellow colour
  - (d) violet colour
- (iii) The speed of light in media ' $A$ ' and ' $B$ ' are  $2.0 \times 10^{10} \text{ cm/s}$  and  $1.5 \times 10^{10} \text{ cm/s}$  respectively. A ray of light enters from the medium  $B$  to  $A$  at an incident angle ' $\theta$ '. If the ray suffers total internal reflection, then

$$(a) \theta = \sin^{-1}\left(\frac{3}{4}\right) \quad (b) \theta > \sin^{-1}\left(\frac{2}{3}\right) \quad (c) \theta < \sin^{-1}\left(\frac{3}{4}\right) \quad (d) \theta > \sin^{-1}\left(\frac{3}{4}\right)$$

- (iv) Light travels in two media  $A$  and  $B$  with speeds  $1.8 \times 10^8 \text{ ms}^{-1}$  and  $2.4 \times 10^8 \text{ ms}^{-1}$  respectively. Then the critical angle between them is

$$(a) \sin^{-1}\left(\frac{2}{3}\right) \quad (b) \tan^{-1}\left(\frac{3}{4}\right) \quad (c) \tan^{-1}\left(\frac{2}{3}\right) \quad (d) \sin^{-1}\left(\frac{3}{4}\right)$$

**OR**

A ray of light travelling in a transparent medium of refractive index  $\mu$ , falls on a surface separating the medium from air at an angle of incidence of  $45^\circ$ . For which of the following value of  $\mu$  the ray can undergo total internal reflection?

- (a)  $\mu = 1.33$
- (b)  $\mu = 1.40$
- (c)  $\mu = 1.50$
- (d)  $\mu = 1.25$

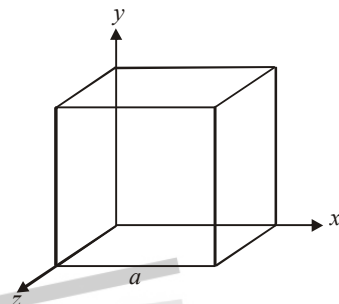


**SECTION-E**

31. State Gauss theorem in electrostatics and write its mathematical form. Using it, derive an expression for electric field at a point near a thin infinite plane sheet of electric charge. How does this electric field change with a uniformly thick sheet of charge?

**OR**

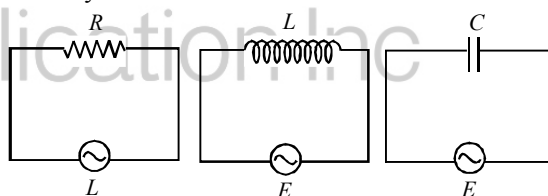
- (a) An electric dipole of dipole moment  $\vec{P}$  consists of point charges  $+q$  and  $-q$  separated by a distance  $2a$  apart. Deduce the expression for the electric field  $\vec{E}$  due to the dipole at a distance  $x$  from the centre of the dipole on its axial line in terms of the dipole moment  $\vec{P}$ . Hence show that in the limit  $x \gg a$ ,  $\vec{E} \longrightarrow 2\vec{P} / (4\pi\epsilon_0 x^3)$ .
- (b) Given the electric field in the region  $\vec{E} = 2x\hat{i}$ , find the net electric flux through the cube and the charge enclosed by it



32. A series L-C-R circuit is connected to an AC source having voltage  $V = V_m \sin \omega t$ . Derive the expression for the instantaneous current  $I$  and its phase relationship to the applied voltage. Obtain the condition for resonance to occur.

**OR**

- (a) A voltage  $V = V_0 \sin \omega t$  is applied to a series LCR circuit. Derive the expression for the average power dissipated over a cycle. Under what condition (i) no power is dissipated even though the current flows through the circuit, (ii) maximum power is dissipated in the circuit?
- (b) Three electrical circuits having AC sources of variable frequency are shown in the figures. Initially, the current flowing in each of these is same. If the frequency of the applied AC source is increased, how will the current flowing in these circuits be affected? Give the reason for your answer.



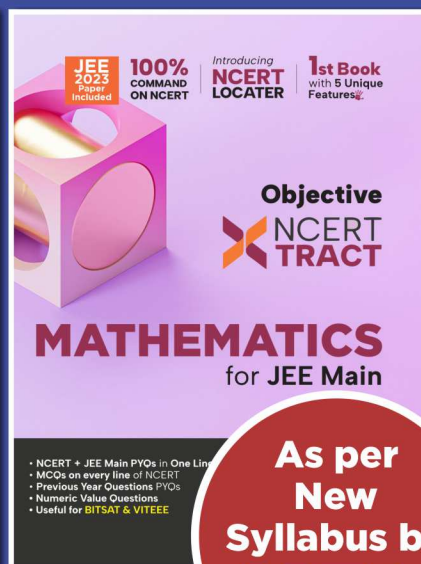
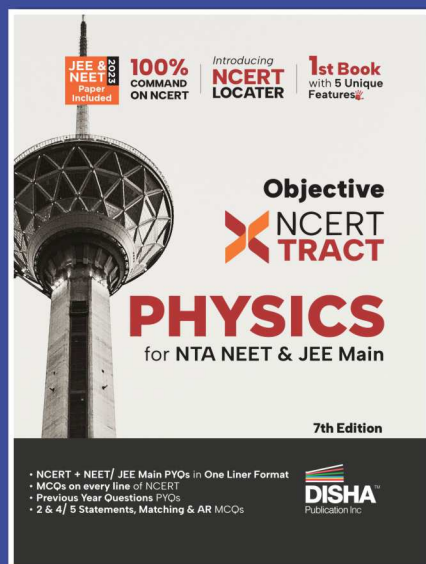
33. (a) Define a wavefront. Using Huygens' principle, verify the laws of reflection at a plane surface.
- (b) In a single slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band? Explain.
- (c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the obstacle. Explain why?

**OR**

- (i) What is the effect on the interference fringes to the Young's double slit experiment when
- (a) the separation between the two slits is decreased?
- (b) the width of the source-slit is increased?
- (ii) The intensity at the central maxima in Young's double slit experimental setup is  $I_0$ . Show that the intensity at a point where the path difference is  $\lambda/3$ , is  $I_0/4$ .

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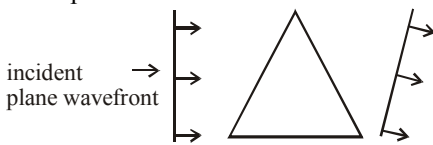
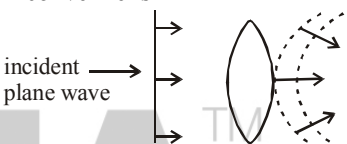
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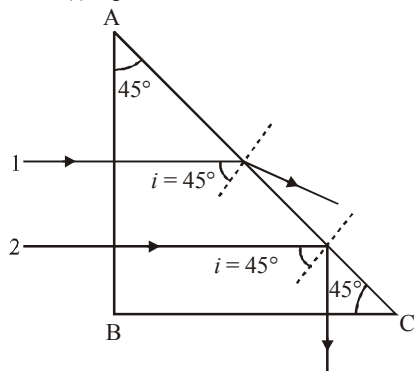
Matching, Statement  
& A-R Type MCQs

# SOLUTIONS

## SAMPLE PAPER-1

1. (a) In parallel grouping of capacitors  
 $C_{eq} = C_1 + C_2 + \dots + C_n$  (1 mark)
2. (d) As  $R = \frac{1}{\text{Power}}$   $\therefore R_1 : R_2 = 2 : 1$  (1 mark)
3. (b) Voltage induced in the secondary coil of a transformer is mainly due to a varying magnetic field. (1 mark)
4. (b) From question,  
 $B_0 = 20 \text{ nT} = 20 \times 10^{-9} \text{ T}$   
 $\vec{E}_0 = \vec{B}_0 \times \vec{C}$   
 $|\vec{E}_0| = |\vec{B}_0| \cdot |\vec{C}| = 20 \times 10^{-9} \times 3 \times 10^8 = 6 \text{ V/m.}$  (1 mark)  
 $(\because \text{velocity of light in vacuum } C = 3 \times 10^8 \text{ ms}^{-1})$
5. (b) Width of central maximum in diffraction pattern due to single slit =  $\frac{2\lambda D}{d}$  where  $\lambda$  is the wavelength,  $D$  is the distance between screen and slit and  $a$  is the slit width. As the slit width  $a$  increases, width of central maximum becomes sharper or narrower. As same energy is distributed over a smaller area. Therefore central maximum becomes brighter. (1 mark)
6. (a)  $B.E_H = \frac{2.22}{2} = 1.11$   
 $B.E_{He} = \frac{28.3}{4} = 7.08$   
 $B.E_{Fe} = \frac{492}{56} = 8.78 = \text{maximum}$   
 $B.E_U = \frac{1786}{235} = 7.6$   
 ${}^{56}_{26}\text{Fe}$  is most stable as it has maximum binding energy per nucleon. (1 mark)
7. (a) The significant result deduced from the Rutherford's scattering is that whole of the positive charge is concentrated at the centre of atom i.e. nucleus. (1 mark)
8. (d) Intensity  $\propto 1 / (\text{distance})^2$ ; No. of photoelectrons emitted is proportional to intensity of incident light. (1 mark)
9. (d) For a p-type semiconductor, the acceptor energy level, as shown in the diagram, is slightly above the top  $E_v$  of the valence band. With very small supply of energy an electron from the valence band can jump to the level  $E_A$  and ionise acceptor negatively. (1 mark)
10. (b) In half wave rectifier, we get the output only in one half cycle of input a.c. therefore, the frequency of the ripple of the output is same as that of input a.c. i.e., 50 Hz. (1 mark)
11. (b) In normal adjustment,  
 $M = \frac{f_0}{f_e} = 20, f_e = \frac{f_0}{20} = \frac{60}{20} = 3 \text{ cm}$  (1 mark)
12. (a) From electromagnetic spectrum, frequencies of  $\gamma$ -rays is greater than frequency of X-rays. Frequency of X-rays is greater than frequency of ultraviolet rays. (1 mark)
13. (a) In insulators, the valence electrons in an atom are very tightly bound to the nucleus. So insulators forbidden gap is very large. (1 mark)
14. (d) A is false but R is also false (1 mark)
15. (c) A is true but R is false (1 mark)
16. (d) A is false but R is also false (1 mark)
17. Refraction of a plane wave form by  
 (i) A thin prism.  

- (ii) A convex lens  

 (1 + 1 = 2 marks)
18. Diodes  $D_1$  and  $D_2$  are ideal, therefore, they do not offer any resistance. Hence the two 3 ohm resistors are in parallel, hence,  
 $R_p = 3 \times 3 / 3 + 3 = 9/6 = 1.5 \Omega$   
 Now,  $R_p$  and 2.5 ohm resistors are in series, hence, net resistance  
 $R = R_p + 2.5 = 1.5 + 2.5 = 4.0 \Omega$   
 Hence, current through the circuit and through 2.5  $\Omega$  resistors  
 $I = V/R = 10/4 = 2.5 \text{ A}$  (2 marks)
19. Induced e.m.f. =  $e = -L \frac{di}{dt}$   
 $\therefore L = \left| \frac{e}{di/dt} \right| = \frac{40 \times 10^{-3}}{2}$   
 $= 20 \times 10^{-3} \text{ H} = 20 \text{ mH.}$  (2 marks)
20. The impurity atoms should be such that (i) it doesn't distort the original pure semiconductor lattice, (ii) it occupies only a few of the original semiconductor atom sites in the crystal and (iii) size of the dopant and semiconductor atom should be same. (2 marks)
21. Critical angle of ray 1:  
 $\sin(c_1) = 1/\mu_1 = 1/1.35 \Rightarrow c_1 = \sin^{-1}(1/1.35) = 47.73^\circ$   
 Similarly, critical angle of ray 2:  
 $\sin(c_2) = 1/\mu_2 = 1/1.45 \Rightarrow c_2 = \sin^{-1}(1/1.45) = 43.6^\circ$

Both the rays will fall on the side AC with angle of incidence ( $i$ ) equal to  $45^\circ$ .



(2 marks)

Critical angle of ray 1 is greater than that of  $i$ . Hence, it will emerge from the prism, as shown in the figure. Critical angle of ray 2 is less than that of  $i$ . Hence, it will be internally reflected.

OR

$$\begin{aligned} \text{Here, } i &= e = \frac{3}{4}A, A = 60^\circ; \delta = i + e - A \\ &= 2 \times \frac{3}{4}A - A = \frac{2A}{4} = \frac{1}{2} \times 60^\circ = 30^\circ \end{aligned} \quad (2 \text{ marks})$$

22.

Property	Diamagnetic	Paramagnetic	Ferromagnetic
Effect of magnets	They are feebly repelled by magnets	They are feebly attracted by magnets	They are strongly attracted by magnets
Susceptibility $\chi_m$	Susceptibility is small and negative $-1 \leq \chi_m < 0$	Susceptibility is small and positive.	Susceptibility is very large and positive.
Relative permeability value ( $\mu_r$ )	Slightly less than $1.0 \mu_r < 1$	Slightly greater than $1.0 \mu_r > 1$	Of the orders of thousands. $\mu_r > 1000$ .
Examples	Bi, Cu, Pb, H <sub>2</sub> O	Al, Na, Ca	Fe, Ni, Co

(3 marks)

23. Coefficient of mutual inductance between a pair of coils is numerically equal to the amount of magnetic flux linked with one coil when unit current flows through the other coil. Its S.I. unit is Henry.

It depends on size, shape, number of turns and nature of material of two coils. It also depends on the relative placement of the two coils. (1 + 1 + 1 = 3 marks)

24. Specific resistance of a material is defined as the resistance of unit length and unit cross-sectional area of the conductor. S.I. unit is ohm - m.

$$R = \frac{m\ell}{ne^2 A \tau} = \left( \frac{m}{ne^2 \tau} \right) \frac{\ell}{A} \quad (1 + \frac{1}{2} \text{ marks})$$

$$\text{Also } R = \frac{\rho \ell}{A} \quad (1 + \frac{1}{2} \text{ marks})$$

25. Einstein's photoelectric equation

$$h\nu = h\nu_0 + \frac{1}{2}mv^2 \quad h\nu = h\nu_0 + eV_s,$$

where  $v$  is the velocity of the ejected electrons and  $V_s$  is the stopping potential.

This equation is based on the following properties of photons:

(i) A photon is a packet of energy. Its frequency and  $h$  plank's constant.

(ii) When a photon is incident on a photoelectric material, it is completely absorbed by the electron. The energy of the photon is used in ejecting electron and the balance if any is used up in imparting kinetic energy to the electron. Two important observation which can be explained by the equation :

(i) The photoelectric emission takes place only if the incident light has a frequency greater than the threshold

frequency  $\nu_0$ . If  $\nu < \nu_0$ , then  $\frac{1}{2}mv^2$  will be -ve, which is not possible. Hence, electron will not be emitted.

(1 + 1 + 1 = 3 marks)

(ii) When the frequency of the incident light increases,

then  $\frac{1}{2}mv^2$  i.e., kinetic energy of electron increases because work function  $= h\nu_0$  is fixed. With increase in frequency more and more energy is available to the electron ejected and hence stopping potential also increases.

26. If,  $F_c$  - centripetal force required to keep a revolving electron in orbit

$F_e$  - electrostatic force of attraction between the revolving electron and the nucleus then, for a dynamically stable orbit in a hydrogen atom, where  $Z = 1$ ,

$$F_c = F_e$$

$$\frac{mv^2}{r} = \frac{(e)(e)}{4\pi\epsilon_0 r^2} \quad \dots(i)$$

$$r = \frac{e^2}{4\pi\epsilon_0 mv^2} \quad \dots(ii)$$

K.E. of electron in the orbit,

$$K = \frac{1}{2}mv^2$$

From equation (i),

$$K = \frac{e^2}{8\pi\epsilon_0 r}$$

Potential energy of electron in orbit,

$$U = \frac{(e)(-e)}{4\pi\epsilon_0 r} = \frac{-e^2}{4\pi\epsilon_0 r}$$

Negative sign indicates that revolving electron is bound to the positive nucleus.

$\therefore$  Total energy of electron in hydrogen atom

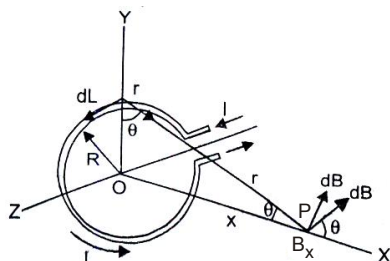
$$E = K + U = \frac{e^2}{8\pi\epsilon_0 r} - \frac{e^2}{4\pi\epsilon_0 r}$$

$$E = -\frac{e^2}{8\pi\epsilon_0 r} \quad (1 \frac{1}{2} \text{ marks})$$

Therefore, total energy of electrons in orbit of hydrogen atom is negative. Hence, the electron bound to the nucleus i.e., the electron is not free to leave the orbit around the nucleus. (1/2 marks)



27. Let there be a circular loop of wire of radius  $R$  and having  $N$ -turns located in the  $YZ$  plane and carrying a steady current  $I$  as shown in figure. (2 marks)



Let us calculate the magnetic field at an axial point  $P$  at a distance  $x$  from the centre of the loop.

From the figure, it is clear that any element  $dL$  is perpendicular to  $\hat{r}$ , furthermore all the elements around the loop are at the same distance  $r$  from  $P$ , where  $r^2 = x^2 + R^2$ .

By Biot-Savart's law, the magnetic field at point  $P$  due to the current element  $dL$  is given by

$$dB = \frac{\mu_0}{4\pi} \frac{I |d\vec{L} \times \hat{r}|}{r^2} = \frac{\mu_0}{4\pi} \frac{I dL}{(x^2 + R^2)} \quad \dots(i) \quad (1 \text{ mark})$$

The direction of the magnetic field  $dB$  due to the element  $dL$  is perpendicular to the plane formed by  $\hat{r}$  and  $dL$ . The vector  $dB$  can be resolved into components  $dB_x$  along the  $X$ -axis and  $dB_y$  perpendicular to the  $X$ -axis. When the components perpendicular to the  $X$ -axis are added over the whole loop, the resultant is zero.

By integrating the components

$$dB_x = dB \cos \theta$$

$$\text{We have } B = \oint dB \cos \theta = \frac{\mu_0 I}{4\pi} \oint \frac{dL \cos \theta}{x^2 + R^2} \quad \dots(ii) \quad (1 \text{ mark})$$

The integral is to be taken over the entire loop since  $\theta$ ,  $x$  and  $R$  are constant for all elements of the loop and

$$\cos \theta = \frac{R}{\sqrt{x^2 + R^2}}$$

$$\therefore B = \frac{\mu_0 I R}{4\pi (x^2 + R^2)^{3/2}} \oint dL = \frac{\mu_0 I R^2}{2 (x^2 + R^2)^{3/2}} \quad [\because \oint dL = 2\pi R]$$

If there are  $N$  number of turns, then

$$\vec{B} = \frac{\mu_0 N I R^2}{2 (x^2 + R^2)^{3/2}} \cdot \hat{i}$$

where  $\hat{i}$  is unit vector in the direction of the  $x$ -axis

(1 mark)

28. The size of the nucleus is experimentally determined using Rutherford's  $\alpha$ -scattering experiment and the distance of closed approach and impact parameter. The relation between radius and mass number of nucleus is,

$$R = R_0 A^{1/3}, \text{ where } R_0 = 1.2 \text{ fm}$$

Nuclear density,

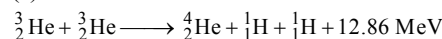
$$\rho = \frac{\text{Mass of nucleus}}{\text{Volume of nucleus}} = \frac{mA}{\frac{4}{3}\pi(R_0 A^{1/3})^3}$$

$$\rho = \frac{mA}{\frac{4}{3}\pi R_0^3 A} \quad \text{or} \quad \rho = \frac{m}{\frac{4}{3}\pi R_0^3} \quad (1 + 1 + 1 = 3 \text{ marks})$$

It is clear that  $\rho$  does not depend on mass number.

**OR**

(a) In the nuclear reaction



Number of nucleons on left side

= number of nucleons on right side

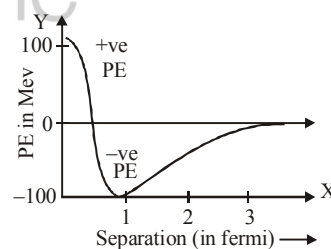
$3 + 3 = 4 + 1 + 1 = 6$ . Thus, total number of nucleons is conserved. The energy is being released because sum of the masses of  ${}^3_2\text{He}$  and  ${}^3_2\text{He}$  is more than the sum of the masses of  ${}^4_2\text{He}$ ,  ${}^1_1\text{H}$  and  ${}^1_1\text{H}$  i.e., products. Thus there is some mass defect  $\Delta m$ . (1½ marks)

According to Einstein's mass energy relation

$$\Delta E = \Delta mc^2$$

Hence in nuclear reaction though the number of nucleons is conserved, the energy is released.

(b) Plot of potential energy between a pair of nucleons as a function of their separation :



(1½ marks)

29. (i) (c) By Gauss's theorem,  $\phi = \frac{Q_{in}}{\epsilon_0}$

Thus, the net flux depends only on the charge enclosed by the surface. Hence, there will be no effect on the net flux if the radius of the surface is doubled. (1 mark)

(ii) (d) According to Gauss' Law

$$\oint \vec{E} \cdot d\vec{s} = \frac{Q_{\text{enclosed by closed surface}}}{\epsilon_0} = \text{flux}$$

so total flux =  $Q/\epsilon_0$

Since cube has six face, so flux coming out through one wall or one face is  $Q/6\epsilon_0$ . (1 mark)

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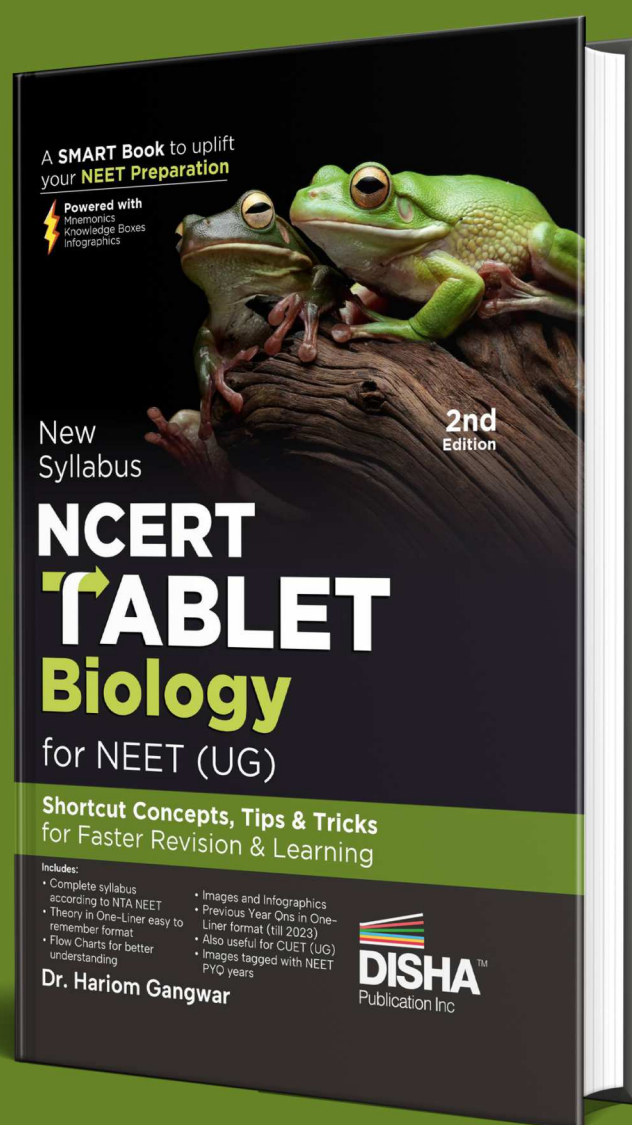
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- (iii) (a) Gaussian surface cannot pass through any discrete charge because electric field due to a system of discrete charges is not well defined at the location of the charges. But the Gaussian surface can pass through a continuous charge distribution. (1 mark)

**OR**

(c)  $\oint \vec{E} \cdot d\vec{A} = 0$ , represents charge inside close surface is zero. Electric field at any point on the surface may be zero. (1 mark)

- (iv) (a)  $\vec{E} = E_0 \hat{i} + 2E_0 \hat{j}$

**Given,**  $E_0 = 100 \text{ N/C}$  So,  $\vec{E} = 100\hat{i} + 200\hat{j}$

Radius of circular surface = 0.02 m

$$\text{Area} = \pi r^2 = \frac{22}{7} \times 0.02 \times 0.02$$

$$= 1.25 \times 10^{-3} \hat{i} \text{ m}^2 \quad [\text{Loop is parallel to Y-Z plane}]$$

Now, flux ( $\phi$ ) =  $EA \cos \theta$

$$= (100\hat{i} + 200\hat{j}) \cdot 1.25 \times 10^{-3} \hat{i} \cos \theta^\circ \quad [\theta = 0^\circ]$$

$$= 125 \times 10^{-3} \text{ Nm}^2/\text{C} = 0.125 \text{ Nm}^2/\text{C} \quad (1 \text{ mark})$$

30. (i) (c)

As  $i > i_c$

At  $i = i_c$  angle of refraction  $r' = 90^\circ$

$$\therefore \frac{\sin i_c}{\sin 90^\circ} = \mu = 1 \quad (1 \text{ mark})$$

- (ii) (d)

(1 mark)

- (iii) (d) We know that critical angle is given by

$$\sin C = \frac{\mu_r}{\mu_d} \text{ and } \mu \propto \frac{1}{V} \Rightarrow \frac{\mu_r}{\mu_d}$$

$$= \frac{v_d}{v_r} = \frac{1.5 \times 10^{10}}{2 \times 10^{10}} = \frac{3}{4}$$

$$\text{So, } \sin C = \frac{3}{4} \Rightarrow C = \sin^{-1} \left( \frac{3}{4} \right)$$

Therefore, for TIR

$$\theta > C \Rightarrow \theta > \sin^{-1} \left( \frac{3}{4} \right) \quad (1 \text{ mark})$$

- (iv) (d)

(1 mark)

**OR**

(c) For total internal reflection

$\sin i > \sin C$

where,

$i$  = angle of incidence,  $C$  = critical angle

$$\text{But, } \sin C = \frac{1}{\mu}$$

$$\therefore \sin i > \frac{1}{\mu} \text{ or } \mu > \frac{1}{\sin i}$$

$$\mu > \frac{1}{\sin 45^\circ} \quad (i = 45^\circ \text{ (Given)})$$

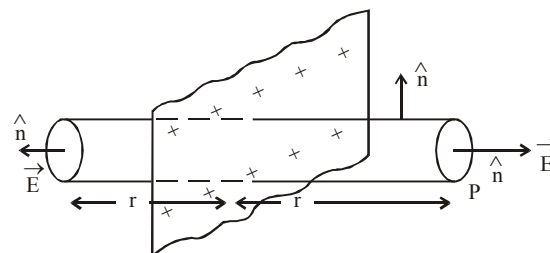
$$\mu > \sqrt{2} \quad (1 \text{ mark})$$

31. **Gauss's theorem:**— The surface integral of electrostatic field ( $\vec{E}$ ) produced by any source over any closed surface  $S$  in vacuum, or the total electric flux over the closed surface in vacuum is  $\frac{1}{\epsilon_0}$  times the total charge ( $Q$ ) contained inside  $S$ .

$$\phi_E = \oint \vec{E} \cdot d\vec{S} = \frac{Q}{\epsilon_0} \quad (1 \text{ mark})$$

**Electric field intensity due to a thin infinite sheet of charge:**

Let  $\sigma$  be the surface density of charge and  $P$  be a point at a distance  $r$  from the sheet where  $\vec{E}$  has to be calculated.  $\vec{E}$  on either side is perpendicular to the sheet.



Imagine a cylinder of cross-sectional area  $dS$  around  $P$  and length  $2r$ , piercing through the sheet. At the two edges,  $\vec{E} \parallel \hat{n}$  (or  $d\vec{S}$ ). At the curved surfaces  $\vec{E} \perp \hat{n}$  (or  $d\vec{S}$ ). So, there is no contribution to electric flux from the curved surfaces of the cylinder.

Electric flux over the edges =  $2\vec{E} \cdot d\vec{S} = 2EdS$

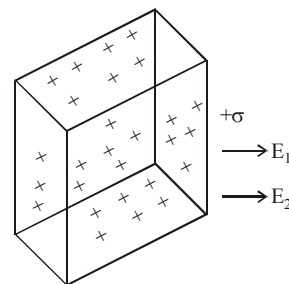
Total charge enclosed by the cylinder =  $\sigma dS$

$$\text{By Gauss's theorem, } 2EdS = \frac{q}{\epsilon_0} = \frac{\sigma dS}{\epsilon_0}$$

$$\therefore E = \frac{\sigma}{2\epsilon_0}$$

If the infinite plane sheet has uniform thickness, the surface density of charge is same on both the surfaces of the sheet.

Electric field intensity at any point  $P$  due to each surface =  $E_1 = E_2 = \sigma / 2\epsilon_0$

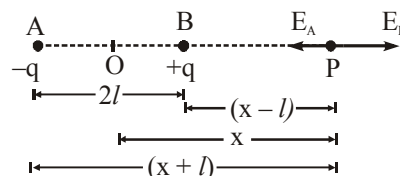


$\therefore$  By superposition principle, total electric field intensity

$$= E = E_1 + E_2 = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0} \quad (2 \text{ marks})$$

**OR**

- (a) We have to calculate the field intensity ( $E$ ) at a point  $P$  on the axial line of the dipole and at a distance  $OP = x$  from the centre  $O$  of the dipole.



Electric field on axial line of an electric dipole

Resultant electric field intensity at the point P is

$$E_p = E_A + E_B$$

The vectors  $E_A$  and  $E_B$  are collinear and opposite.

$$\therefore E_p = E_B - E_A$$

$$\text{Here, } E_A = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{(x+l)^2} \Rightarrow E_B = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{(x-l)^2}$$

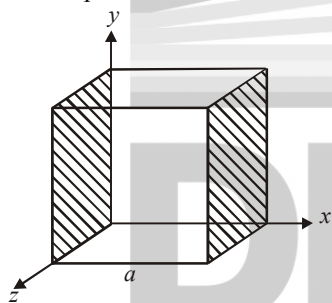
$$\therefore E_p = \frac{1}{4\pi\epsilon_0} \left[ \frac{q}{(x-l)^2} - \frac{q}{(x+l)^2} \right] = \frac{1}{4\pi\epsilon_0} \frac{4qlx}{(x^2 - l^2)^2}$$

$$\text{Hence, } E_p = \frac{1}{4\pi\epsilon_0} \frac{4px}{(x^2 - l^2)^2} \quad (2\frac{1}{2} \text{ marks})$$

$$\text{If dipole is short, } 2l \ll x, \text{ then } E_p = \frac{2px}{4\pi\epsilon_0 x^3}$$

(b) The electric field has only x component, for faces normal to x direction, the angle between  $E$  and  $\Delta s$  is

$\pm \frac{\pi}{2}$ . Therefore, the flux is separately zero for each face of the cube except the two shaded ones.



The magnitude of the electric field at the left face is  $E_L = 0$  (As  $x = 0$  at the left face)

The magnitude of the electric field at the right face is  $E_R = 2a$  (As  $x = a$  at the right face)

Their corresponding fluxes are

$$\phi_L = \vec{E}_L \cdot \Delta \vec{S} = 0$$

$$\phi_R = \vec{E}_R \cdot \Delta \vec{S} = E_R \Delta S \cos \theta = E_R \Delta S \quad (\because \theta = 0^\circ)$$

$$\Rightarrow \phi_R = E_R a^2$$

$$\text{Net flux } (\phi) \text{ through the cube} = \phi_L + \phi_R = 0 + E_R a^2 = E_R a^2$$

$$\phi = 2a(a^2) = 2a^3$$

From, Gauss's law

$$\phi = \frac{q}{\epsilon_0} \Rightarrow q = \phi \epsilon_0 \quad (2\frac{1}{2} \text{ marks})$$

$$\therefore q = 2a^3 \epsilon_0$$

32. Phase difference between voltage and current,

$$\tan \phi = \frac{X_L - X_C}{R} \quad \dots (i)$$

$$\text{and, } I_0 = \frac{V_0}{2} = \frac{V_0}{\sqrt{(X_L - X_C)^2 + R^2}}$$

$$\therefore \text{Expression of AC, } I = I_0 \sin(\omega t + \phi) \quad (2 \text{ marks})$$

**Condition for resonance**

Inductive reactance must be equal to capacitive reactance

$$\text{i.e., } X_L = X_C$$

$$\text{As, } X_L = X_C$$

(1 mark)

$$\Rightarrow \omega_0 L = \frac{1}{\omega_0 C} \Rightarrow \omega_0^2 = \frac{1}{LC}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

where,  $\omega_0$  = resonant angular frequency.

Impedance becomes minimum and equal to ohmic resistance

$$\text{i.e., } Z = Z_{\text{minimum}} = R$$

AC becomes maximum,

$$\therefore I_{\text{max}} = \frac{V_{\text{max}}}{Z_{\text{min}}} = \frac{V_{\text{max}}}{R}$$

(2 marks)

Voltage and current arrives in same phase.

**OR**

(a) The power is defined as the rate of at which work is being done in the circuit.

When  $V = V_0 \sin \omega t$  is applied to a series LCR circuit.

$$\text{Current is } I = I_0 \sin(\omega t + \phi)$$

$$I_0 = \frac{V_0}{Z} \text{ and } \phi = \tan^{-1} \left( \frac{X_C - X_L}{R} \right)$$

Instantaneous power supplied by the source is

$$P = VI = (V_0 \sin \omega t) \times (I_0 \sin(\omega t + \phi))$$

$$P = V_0 I_0 \sin \omega t \sin(\omega t + \phi)$$

$$P = \frac{V_0 I_0}{2} [\cos \phi - \cos(2\omega t + \phi)]$$

$$P_{av} = \frac{V_0 I_0}{2} [\cos \phi - 0] \quad \{ \because \cos(2\omega t) = 0 \}$$

The average power  $P_{av} = V_{\text{rms}} I_{\text{rms}} \cos \phi$

$$= \frac{V_0}{\sqrt{2}} \cdot \frac{I_0}{\sqrt{2}} \cdot \cos \phi \quad (1 \text{ mark})$$

In this expression  $\cos \phi$  is known as the power factor.

**Case I :** For pure inductive circuit or pure capacitive circuit,

the phase difference between current and voltage is  $\frac{\pi}{2}$ .

$$\therefore \phi = \frac{\pi}{2}, \cos \phi = 0$$

Therefore,  $P_{av} = 0$ . Thus no power is dissipated in the circuit. This current is sometimes referred to as wattless current and such a circuit is called wattless circuit.

(1 mark)

**Case II :** For power dissipated at resonance in an LCR circuit,

$$X_C - X_L = 0, \phi = 0$$

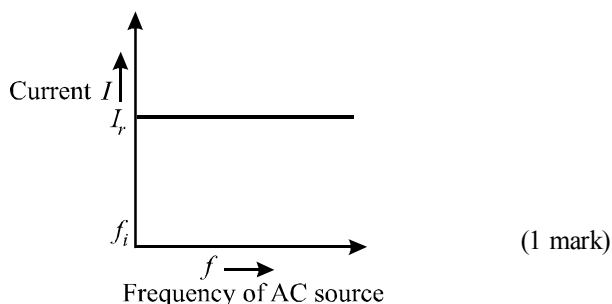


$$\therefore \cos \phi = 1$$

So, maximum power is dissipated in the circuit. (1 mark)

(b) Let initially  $I_r$  current is flowing in all the three circuits. If frequency of applied AC source is increased then, the change in current will occur in following manner:

**Circuit containing resistance R only** There will not be any effect in the current, on changing the frequency of AC source.



where,  $f_i$  = initial frequency of AC source.

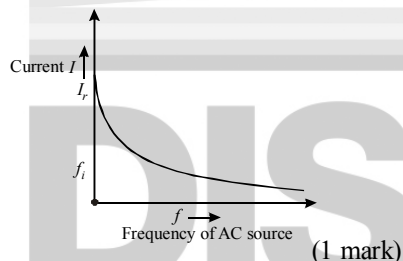
There is no effect on current with the increase in frequency.

**AC circuit containing inductance only** With the increase of frequency of AC source, inductive reactance increase as

$$I = \frac{V_{\text{rms}}}{X_L} = \frac{V_{\text{rms}}}{2\pi fL}$$

For given circuit,

$$I \propto \frac{1}{f}$$

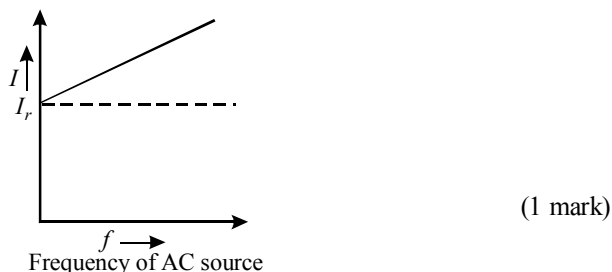


Current decreases with the increase of frequency.

**AC circuits containing capacitor only**

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$$

$$\text{Current, } I = \frac{V_{\text{rms}}}{X_C} = \left( \frac{V_{\text{rms}}}{\frac{1}{2\pi fC}} \right)$$



$$I = 2\pi fCV_{\text{rms}}$$

For given circuit,  $I \propto f$

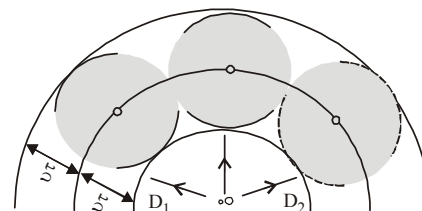
Current increases with the increase of frequency.

33. (a) A **wavefront** is defined as the continuous locus of all the particles of a medium, which are vibrating in the same phase or it is a surface of constant phase. ( $\frac{1}{2}$  mark)

### Huygens' principle:

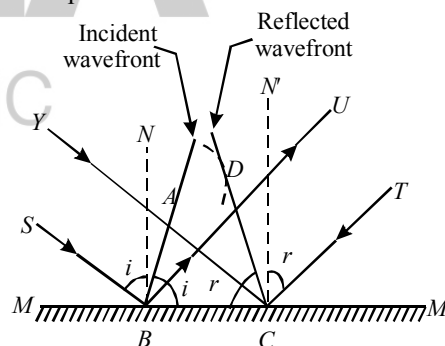
(1) Every points on the given wavefront (called primary wavefront) acts as a fresh source of new disturbance (secondary wavelets), which travel in all directions with the velocity of light in the medium.

(2) A surface touching these secondary wavelets, tangentially in the forward direction at any instant gives the new wavefront at that instant. This is called secondary wavefront. (1 mark)



The above model has one shortcoming: we also have a backwave which is shown as  $D_1D_2$  in figure. Huygens argued that the amplitude of the secondary wavelets is maximum in the forward direction and zero in the backward direction, by making this assumption, Huygens could explain the absence of the backwave.

Let a plane wavefront  $AB$  is incident on the plane mirror  $MM'$ . As per Huygen's wave theory, every point on wavefront again behaves like a light source and emits secondary wavelets. In the time taken by the wave to reach from  $A$  to  $C$ , the secondary wavelets from  $B$  gets spread over a hemisphere of radius.



where,  $c$  is velocity of light and  $t$  is the time taken by wave in going from  $A$  to  $C$ . The tangent plane  $CD$  drawn from the point  $C$  over this hemisphere of radius  $ct$  gives new reflected wavefront  $CD$  corresponding to incident wavefront  $AB$ .

Let  $i$  and  $r$  be angles of incidence and reflection respectively.

Now, in  $\triangle ABC$  and  $\triangle DCB$

$$\angle BAC = \angle CDB$$

[each  $90^\circ$ , ray  $\perp$  wavefront]  
(common)

$$BC = BC$$

$$AC = DB$$

[From Eq. (i)]

$$\Rightarrow \triangle ABC \cong \triangle DCB$$

(RHS congruence)

$$\Rightarrow \angle ABC = \angle DCB$$

or  $i = r$

$$\left[ \because SB \perp AB \Rightarrow \angle NBA = 90^\circ - i \text{ and } BN \perp BC \right] \\ \Rightarrow \angle ABC = i$$

Similarly,  $\angle N'CT = \angle DCB = r$

$\Rightarrow$  Angle of incidence = Angle of reflection

Also, incident ray, reflected ray and normal meet at one point on a plane.

Thus, laws of reflection are verified using Huygen's principle. (2 marks)

**(b)** As the number of point sources increases, their contribution towards intensity also increases. Intensity varies as square of the slit width. Thus, when the width of the slit is made double the original width, intensity will get four times of its original value.

Width of central maximum is given by,  $\beta = \frac{2D\lambda}{b}$

So, with the increase in size of slit, the width of central maxima decreases. Hence, double the size of the slit would results as half the width of the central maxima. (1 mark)

**(c)** The waves diffracted from the edge of the circular obstacle interfere constructively at the centre of the shadow producing a bright spot. (½ mark)

**OR**

**(i) (a)** From the fringe width expression,

$$\beta = \frac{\lambda D}{d}$$

With the decrease in separation between two slits, the fringe-width  $d$  increases. (1 mark)

**(b)** For interference fringes to be seen,

$$\frac{s}{S} < \frac{\lambda}{d}$$

Condition should be satisfied

where,  $s$  = size of the source,

$S$  = distance of the source from the plane of two slits.

As the source-slit-width increase, fringe pattern gets less and less sharp.

When the source-slit is so wide, the above condition does not satisfied and the interference pattern disappears. (1 mark)

**(ii)** Intensity at a point is given by,

$$I = 4I' \cos^2 \phi/2 \quad (1 \text{ mark})$$

where,  $\phi$  = phase difference,

$I'$  = intensity produced by each one of the individual sources.

At central maxima,  $\phi = 0$ , the intensity at the central maxima,  $I = I_0 = 4I'$

$$\text{or } I' = \frac{I_0}{4} \quad \dots (i)$$

$$\text{As, path difference} = \frac{\lambda}{3},$$

Phase difference,

$$\phi' = \frac{2\pi}{\lambda} \times \text{path difference} = \frac{2\pi}{\lambda} \times \frac{\lambda}{3} = \frac{2\pi}{3} \quad (1 \text{ mark})$$

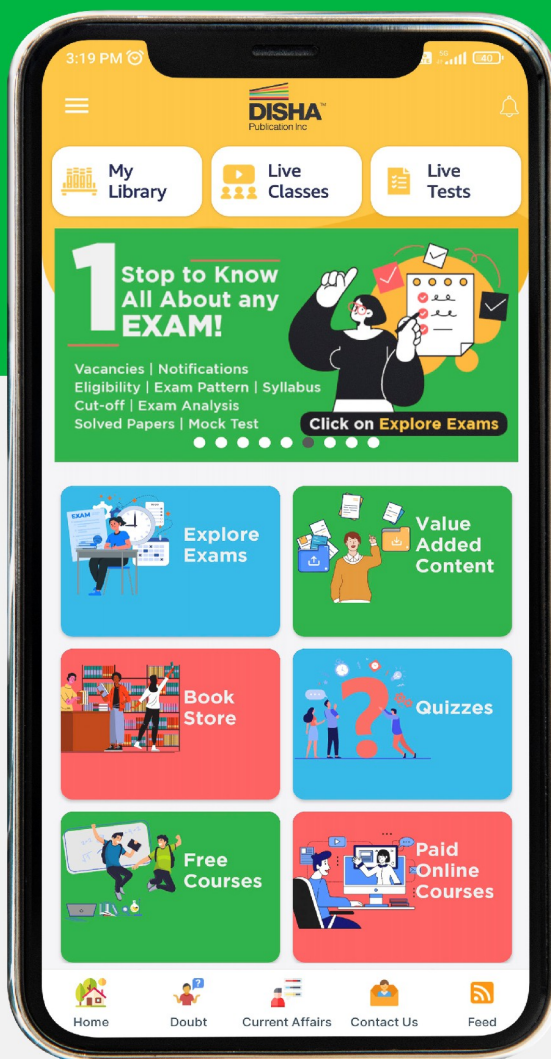
Now, intensity at the point,

$$I'' = 4I' \cos^2 \frac{1}{2} \left( \frac{2\pi}{3} \right) = 4I' \cos^2 \frac{\pi}{3} = 4I' \times \frac{1}{4} = I' \quad (1 \text{ mark})$$

$$\text{or } I'' = \frac{I_0}{4}$$

[From eq. (i)]

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