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SAMPLE PAPER TEST 01 (2020-21)
(SAMPLE ANSWERS)

SUBJECT: PHYSICS **MAX. MARKS : 70**
CLASS : XII **DURATION : 3 HRS**

General Instruction:

*(i) All questions are compulsory. There are **33** questions in all.*
(ii) This question paper has five sections: Section A, Section B, Section C, Section D and Section E.
*(iii) **Section A** contains ten very short answer questions and four assertion reasoning MCQs of 1 mark each, **Section B** has two case based questions of 4 marks each, **Section C** contains nine short answer questions of 2 marks each, **Section D** contains five short answer questions of 3 marks each and **Section E** contains three long answer questions of 5 marks each.*
(iv) There is no overall choice. However internal choice is provided. You have to attempt only one of the choices in such questions.
(v) You may use the following values of physical constants wherever necessary :

$c = 3\times10^{8} m/s,\quad h = 6.63\times10^{-34} Js,\quad e = 1.6\times10^{-19} C,\quad \mu_0 = 4\pi\times10^{-7} TmA^{-1},$

$\varepsilon_0 = 8.854\times10^{-12} C^2N^{-1}m^{-2},\quad m_e = 9.1\times10^{-31} kg,\quad \frac{1}{4\pi\varepsilon_0} = 9\times10^{9} Nm^2C^{-2},$

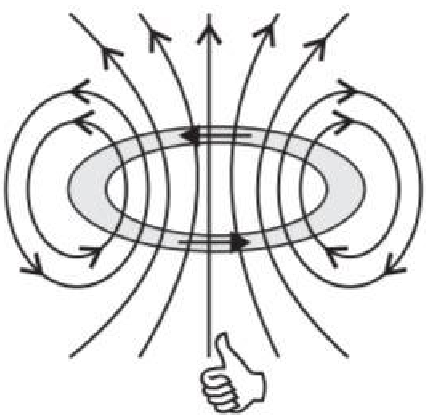
Mass of neutron $= 1.675\times10^{-27} kg$, Mass of proton $= 1.673\times10^{-27} kg$,

Avogadro's number $= 6.023\times10^{23}$ per gram mole, Boltzmann constant $= 1.38\times10^{-23} JK^{-1}$

SECTION – A

Questions 1 to 14 carry 1 mark each.

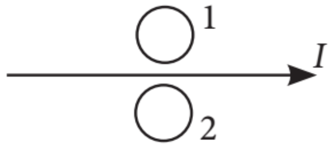
1. Depict the direction of the magnetic field lines due to a circular current carrying loop.
Ans: Magnetic field lines due to a circular wire carrying current I :



2. From the information of energy bandgaps of diodes, how do you decide which can be light emitting diode?
Ans: Diodes with bandgap energy in the visible spectrum range can function as LED.

3. The total energy of an electron in the first excited state of the hydrogen atom is about –3.4 eV.
(i) What is the kinetic energy of electron in this state?
(ii) What is the potential energy of electron in this state?
Ans: (i) E_K= - E = - (-3.4) = + 3.4 eV (ii) E_p = 2E = 2 x (-3.4) = - 6.8 eV

4. What is the direction of induced currents in metal rings 1 and 2 when current I in the wire is increasing steadily?



Ans: The direction of induced current in metal ring 1 is clockwise. In metal ring 2 is anticlockwise when current I in the wire is increasing steadily.

OR

A long straight current carrying wire passes normally through the centre of circular loop. If the current through the wire increases, will there be an induced emf in the loop? Justify.

Ans: The magnetic lines of force due to current are parallel to the plane of the loop. So angle between magnetic field and area vector is 90°. Hence, the flux linked with the loop is zero. Hence, there will be no induced emf in the loop.

5. An electron is moving along +ve x – axis in the presence of uniform magnetic field along +ve y – axis. What is the direction of the force acting on it?

Ans: Using Fleming's right hand rule, the direction of force will be along -ve z-axis.

6. Long distance radio broadcasts use short-wave bands. Why?

Ans: Electromagnetic waves in frequency range of short-wave band reflect from ionosphere where lower frequency radio waves i.e., medium waves are absorbed. So, short-waves are suitable for long distance radio broadcast.

OR

Optical and radio telescopes are built on the ground but X-ray astronomy is possible only from satellites orbiting the earth. Why?

Ans: Atmosphere absorb X-rays, while visible and radiowaves can penetrate through it. Hence optical telescope can work on ground but X-ray astronomical telescopes only work above atmosphere, hence installed on the satellite orbiting around earth.

7. What is the effect on the velocity of the emitted photoelectrons if the wavelength of the incident light is decreased?

Ans:

$$\frac{1}{2}mv^2 = h\upsilon - W_0 = \frac{hc}{\lambda} - W_0$$

So, if λ of incident light is decreased, energy hυ of photon increases and hence K.E. and velocity of emitted photoelectron also increases.

8. In a half wave rectifier circuit operating from 50 Hz mains frequency, what would be the fundamental frequency in the ripple?

Ans: As the output voltage obtained in a half wave rectifier circuit has a single variation in one cycle of ac voltage, hence the fundamental frequency in the ripple of output voltage would be = 50 Hz.

9. Which physical quantity in a nuclear reaction is considered equivalent to the Q-value of the reaction?

Ans: Q-value is the difference in initial mass energy and energy associated with mass of products or total kinetic energy in the process.

OR

Give the relation between radius of a nucleus and mass number A?

Ans: The volume of the nucleus is directly proportional to the number of nucleons (mass number) constituting the nucleus.

$\frac{4}{3}\pi R^3 \propto A$ Where $R \rightarrow$ radius

$R \propto A^{1/3}$ $A \rightarrow$ Mass number

$R = R_0 A^{1/3}$

10. A potential barrier of 0.3 V exists across a p-n junction. If the depletion region is 1 mm wide, what is the intensity of electric field in this region?

Ans:

$$\text{Electric field } E = \frac{V}{d} = \frac{0.3}{1 \times 10^{-6}} = 3 \times 10^5 \text{ V m}^{-1}$$

OR

When the voltage drop across a p-n junction diode is increased from 0.65 V to 0.70 V, the change in the diode current is 5 mA. Find the value of the dynamic resistance of the diode.

Ans:

$$\text{Dynamic resistance, } r_d = \frac{\Delta V}{\Delta I}$$

$$r_d = \frac{0.70 \text{ V} - 0.65 \text{ V}}{5 \times 10^{-3} \text{ A}} = \frac{0.05 \times 1000}{5} \Omega = 10\,\Omega$$

For question numbers 11, 12, 13 and 14, 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

11. Assertion (A): A single lens produces a coloured image of an object illuminated by white light.

Reason (R): The refractive index of the material of lens is different for different wavelengths of light.

Ans: (a): Due to the variation of the refractive index of the material of the lens, the focal length also varies accordingly. Now as white light is composed of different colours of light, each colour will produce its own image based on the focal length for that colour. This particular phenomenon for a single lens is known as chromatic aberration.

12. Assertion (A): If a dielectric is placed in external field then field inside dielectric will be less than applied field.

Reason (R): Electric field will induce dipole moment opposite to field direction.

Ans: (c): Dipole moment will be in the same direction as the external field. The collective effect of dipole moments produces a field that opposes the external field and hence, the net electric field inside the dielectric is less than the external electric field.

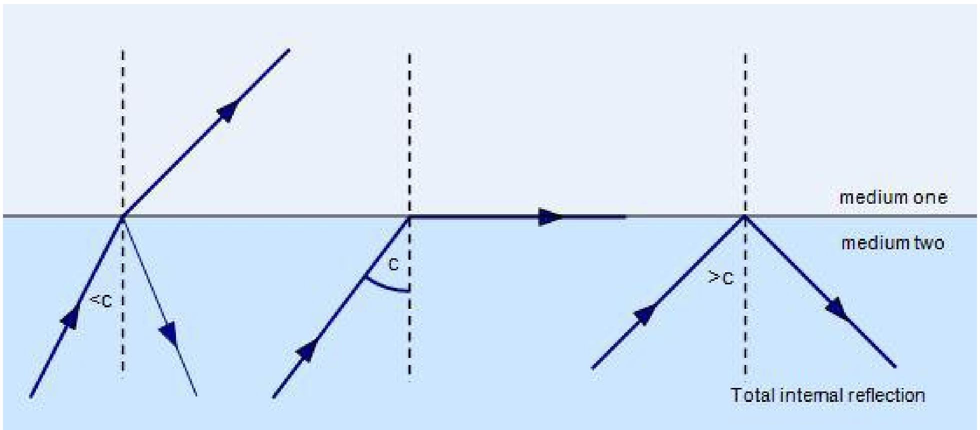
13. **Assertion (A):** When a charged particle moves in a circular path. It produces electromagnetic wave.
Reason (R): Charged particle has acceleration.
Ans: (a): Accelerated charges radiate electromagnetic waves.

14. **Assertion (A):** Net electric field insider a conductor is zero.
Reason (R): Total positive charge equals to total negative charge in a charged conductor.
Ans: (c)

SECTION - B

Questions 15 and 16 are Case Study based questions and are compulsory. Attempt any 4 sub parts from each question. Each question carries 1 mark.

15. Total internal reflection is the phenomenon that involves the reflection of all the incident light off the boundary. Light must travel from denser to rarer medium and angle of incidence in denser medium must be greater than critical angle (C) for the pair of media in contact. For internal reflection we can show that μ = 1/sinC.



(i) Critical angle for glass air interface where μ of glass is 3/2 is
(a) 41.8° (b) 60° (c) 30° (d) 44.3°
Ans:

(a) : $\sin C = \frac{1}{\mu} = \frac{1}{3/2} = \frac{2}{3} = 0.6667$

$C = \sin^{-1}(0.6667) = 41.8°$

(ii) Critical angle for water air interface is 48.6°. What is the refractive index of water?
(a) 1 (b) 3/2 (c) 4/3 (d) 3/4
Ans:

(c) : $\mu = \frac{1}{\sin C} = \frac{1}{\sin 48\cdot 6} = \frac{1}{0\cdot 75} = \frac{4}{3}$

(iii) Critical angle for air water interface for violet colour is 49°. Its value for red colour would be
(a) 49° (b) 50° (c) 48° (d) 52°
Ans:

(c): From $\mu = \frac{1}{\sin C}$, $\sin C = \frac{1}{\mu}$

As $\mu_v < \mu_r \therefore C_v > C_r$

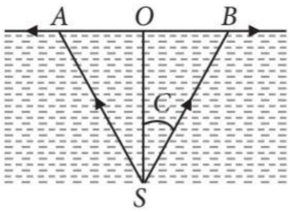
(iv) A point source of light is held at a depth h below the surface of water. If C is critical angle of air-water interface, the diameter of circle of light coming from water surface would be

(a) 2 h tanC (b) h tanC (c) h sinC (d) h/sinC

Ans:

(a) : $SO = h$

When angle of incidence is slightly greater than C, light undergoes total internal reflection.



$\therefore$ Diameter of circle of light coming from water surface

$= 2r = 2\,(OB) = 2\,OS \tan C = 2\,h \tan C$

(v) If the critical angle for total internal reflection from a medium to vaccum is 30°, then the velocity of light in the medium is,

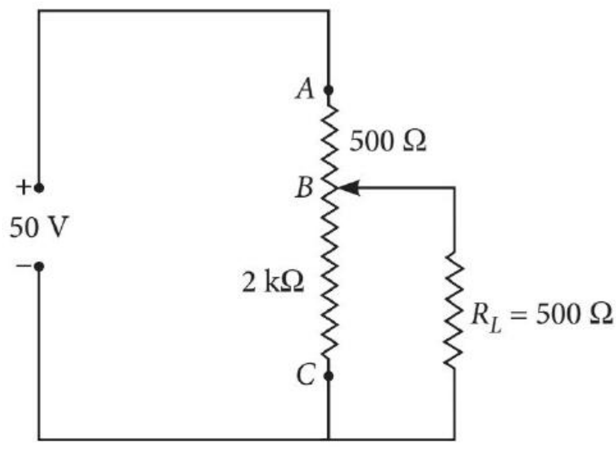
(a) 3×10^8 m/s (b) 1.5×10^8 m/s (c) 6×10^8 m/s (d) 3×10^8 m/s

Ans:

(b) : $\mu = \frac{1}{\sin C} = \frac{1}{\sin 30^\circ} = 2$

$\therefore \quad v = \frac{3\times10^8}{2} = 1{\cdot}5\times10^8\,\text{m/s}$

16. A rheostat is a variable resistor which is used to control the current flowing in a circuit. They are able to vary the resistance in a circuit without interruption. The construction is very similar to the construction of a potentiometers. It uses only two connections, even when 3 terminals (as in a potentiometer) are present. The first connection is made to one end of the resistive element and the other connection to the wiper (sliding contact). In contrast to potentiometers, rheostats have to carry a significant current. Therefore, they are mostly constructed as wire wound resistors. Resistive wire is wound around an insulating ceramic core and the wiper slides over the windings. Rheostats were often used as power control devices, for example to control light intensity (dimmer), speed of motors, heaters and ovens. As shown in figure, a variable rheostat of 2 kW is used to control the potential difference across a 500 Ω load. Here, the source emf is 50 V and resistance AB is 500 Ω.



(i) The total resistance of the circuit is

(a) 500 Ω (b) 375 Ω (c) 875 Ω (d) 1500 Ω

Ans: (b): Here, load resistance, RL = 500 Q ; and e.m.f. of the source, E = 50 V

Total resistance of the rheostat between points A and C, R_{AC} = 2kΩ = 2000Ω

The resistance of the rheostat between points A and B, R_{AB}= 500Ω

Therefore, resistance between points B and C, $R_{BC} = R_{AC} – R_{AB}$= 2000Ω – 500Ω = 1500Ω

Now, R_{BC} and R_L are connected in parallel. If R' is resistance of their combination, then

$$\frac{1}{R'} = \frac{1}{R_{BC}} + \frac{1}{R_L} = \frac{1}{1500} + \frac{1}{500} = \frac{4}{1500}$$

or $R' = 375\ \Omega$

(ii) The value of total current flowing through the circuit is

(a) 2.87 A (b) 0.057 A (c) 0.87 A (d) 0.677 A

Ans: (b): Further, R_{AB} and R are in series. If I is the current in the circuit, then

$$I = \frac{E}{R_{AB} + R'} = \frac{50}{500+375} = \frac{2}{35}\text{ A} = 0.057\text{ A}$$

(iii) The potential difference across the load is

(a) 21.43 V (b) 32.45 V (c) 17.62 V (d) 19.83 V

Ans: (a): Potential drop across R_L is same as the potential drop across the parallel combination of R_{BC} and R_L.

$$\therefore \quad V_L = \frac{50 \times 375}{500+375} = 21.43\text{ V}$$

(iv) If the load is removed, the current across the rheostat is,

(a) 1/4 A (b) 1/20 A (c) 1/40 A (d) 40 A

Ans: (c): When the load is removed, the source of e.m.f. will send current through the rheostat wire AB having a total resistance of 2000 Q. Therefore, current through the rheostat,

$$I' = \frac{50}{2,000} = \frac{1}{40}\text{A}$$

(v) If the load is removed, what should be the resistance at BC to get 40 V between B and C?

(a) 500 Ω (b) 375 Ω (c) 1600 Ω (d) 1500 Ω

Ans: (c): If R'_{BC} is the value of the resistance of the rheostat between points B and C, which will give a potential difference of 40 V across these two points, then

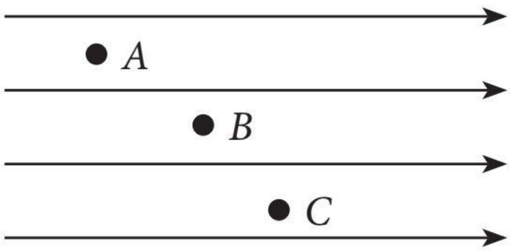
$$I'R'_{BC} = 40$$

$$\text{or} \quad R'_{BC} = \frac{40}{I'} = \frac{40}{1/40} = 1600\Omega$$

SECTION – C

Questions 17 to 25 carry 2 marks each.

17. Figure shows three points A, B and C in an uniform electric field. At which of the points the electric potential is maximum?



Ans: $V_A > V_B > V_C$, direction of electric field is from higher to lower potential

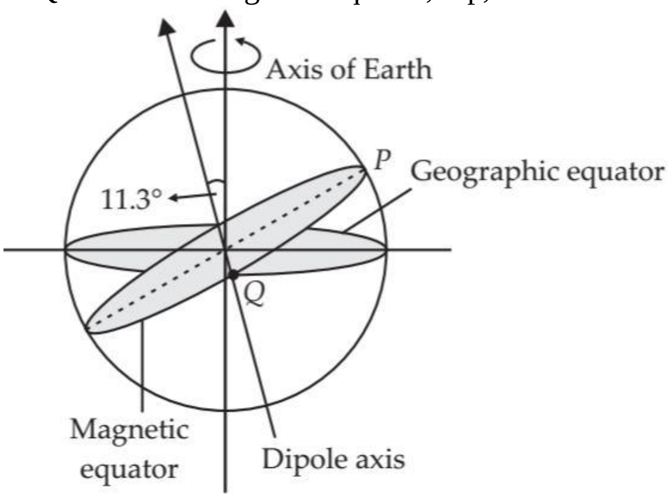
OR

Is it possible to transfer all the charge from a conductor to another insulated conductor?
Ans: 'Yes'. By enclosing uncharged conductor inside charged conductor and then by connecting them with wire.

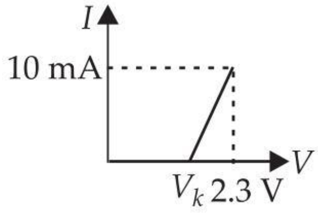
18. Interstellar space has an extremely weak magnetic field of the order of 10^{-12} T. Can such a weak field be of any significant consequence? Explain.
Ans: A weak field of the order of 10^{-12} T can cause the charged particles to move along circular paths of very large radii. Over a small distance, we may not be able to notice the deflection in the path of the charged particles but over large interstellar distance the distance is quite noticeable.

OR

Consider the plane S formed by the dipole axis and the axis of earth. Let P be point on the magnetic equator and in S. Let Q be the point of intersection of the geographical and magnetic equators. Obtain the declination and dip angles at P and Q.
Ans: From figure,
For point P: Since point P lies in plane S formed by the dipole axis and the axis of the Earth, declination, D = 0°.
For point Q: Since point Q lies on the magnetic equator, dip, $\delta = 0°$ Declination, D = 11.3°



19. Find the resistance of a germanium junction diode whose V – I is shown in figure. (V_k = 0.3 V)

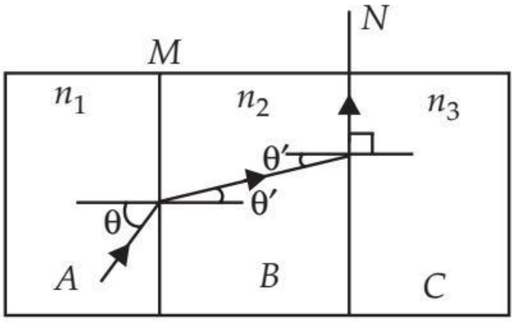


Ans:

From graph,
Resistance of the germanium junction diode,

$$R = \frac{\Delta V}{\Delta I} = \frac{2.3\text{ V} - 0.3\text{ V}}{10\text{ mA} - 0} = \frac{2\text{ V}}{10 \times 10^{-3}\text{ A}} = 0.2\text{ k}\Omega$$

20. A, B and C are the parallel sided transparent media of refractive index n_1, n_2 and n_3 respectively. They are arranged as shown in the figure. A ray is incident at an angle q on the surface of separation of A and B is as shown in the figure. After the refraction into the medium B, the ray grazes the surface of separation of the media B and C. Find the value of sinθ.

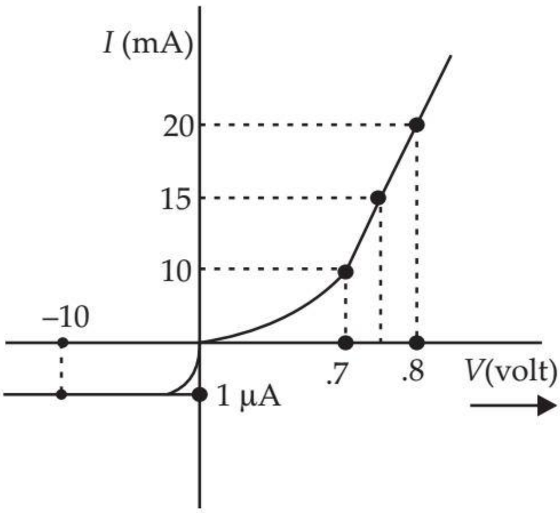


Ans:
Applying Snell's law

$$n_1 \sin\theta = n_2 \sin\theta' = n_3 \sin 90° = n_3$$

$$\therefore \quad \sin\theta = \frac{n_3}{n_1}$$

21. The V-I characteristic of a diode is shown in the figure. Find the ratio of forward to reverse bias resistance.



Ans:

Forward bias resistance, $R_1 = \frac{\Delta V}{\Delta I_{\text{for}}} = \frac{0.8 - 0.7}{(20-10)\times 10^{-3}} = \frac{0.1}{10 \times 10^{-3}} = 10$

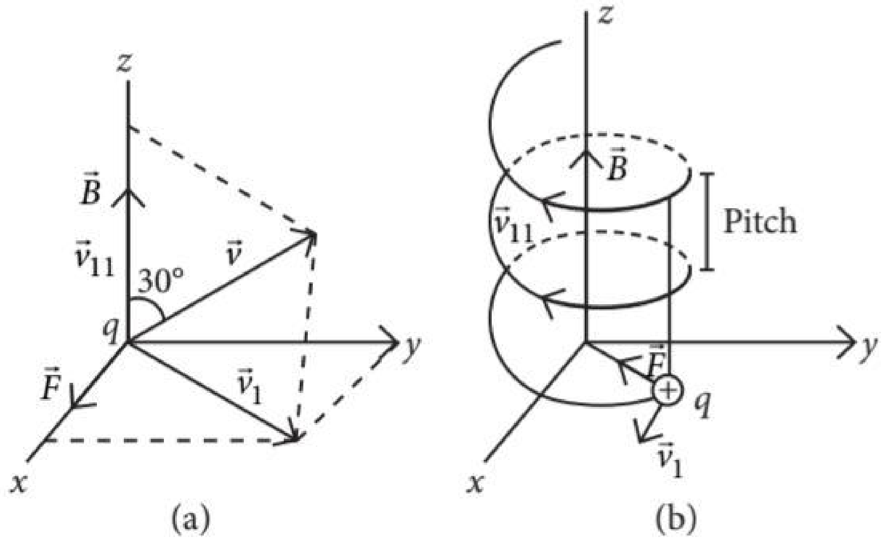
Reverse bias resistance, $R_2 = \frac{10}{1 \times 10^{-6}} = 10^7$

then, the ratio of forward to reverse bias resistance,

$$\frac{R_1}{R_2} = \frac{10}{10^7} = 10^{-6}$$

22. A charged particle q is moving in the presence of a magnetic field B which is inclined to an angle 30° with the direction of the motion of the particle. Draw the trajectory followed by the particle in the presence of the field and explain how the particle describes this path.

Ans: When a charged particle moving in a uniform magnetic field has two concurrent motions. A linear motion in the direction of $\vec{B}$. (along z-axis) as shown in figure (a) and a circular motion in a plane perpendicular to $\vec{B}$. (in xy-plane). Hence the resultant path of the charged particle will be a helix, with its axis along the direction of $\vec{B}$. as shown in figure (b).



23. Starting from the expression for the energy W = ½ LI², stored in a solenoid of self-inductance L to build up the current I, obtain the expression for the magnetic energy in terms of the magnetic field B, area A and length *l* of the solenoid having n number of turns per unit length. Hence, show that the energy density is given by $B^2/2\mu_0$.

Ans:

The magnetic energy is, $U_B = \frac{1}{2}LI^2 = \frac{1}{2}L\left(\frac{B}{\mu_0 n}\right)^2$ $(\because\ B = \mu_0 nI$, for a solenoid)

$$= \frac{1}{2}(\mu_0 n^2 Al)\left(\frac{B}{\mu_0 n}\right)^2 = \frac{1}{2\mu_0}B^2 Al$$

The magnetic energy per unit volume is, $u_B = \frac{U_B}{V}$ (where V is volume that contains flux)

$$= \frac{U_B}{Al} = \frac{B^2}{2\mu_0}$$

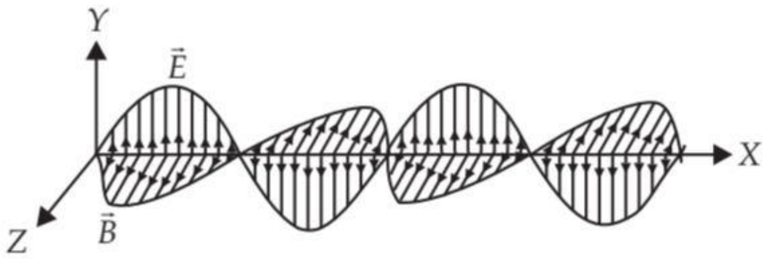
24. Show, by giving a simple example, how e.m. waves carry energy and momentum.

Ans: Consider a plane perpendicular to the direction of propagation of the wave. An electric charge, on the plane will be set in motion by the electric and magnetic fields of e.m. wave, incident on this plane. This illustrates that e.m. waves carry energy and momentum.

OR

An e.m. wave is travelling in a medium with a velocity $\vec{v} = v\hat{i}$. Draw a sketch showing the propagation of the e.m. wave, indicating the direction of the oscillating electric and magnetic fields.

Ans: In figure, the velocity of propagation of e.m. wave is along X-axis $\vec{v} = v\hat{i}$ and electric field $\vec{E}$ along Y-axis and magnetic field $\vec{B}$ along Z-axis.



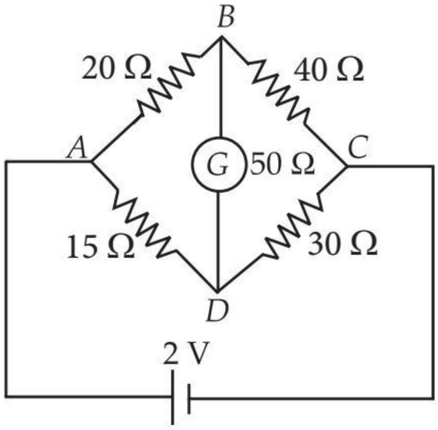
25. For a single slit of width ‘a’, the first minimum of the interference pattern of a monochromatic light of wavelength *l* occurs at an angle of λ/a. At the same angle of λ/a, we get a maximum for two narrow slits separated by a distance ‘a’. Explain.

Ans: For a single slit of width "a" the first minima of the interference pattern of a monochromatic light of wavelength X occurs at an angle of (λ/a) because the light from centre of the slit differs by a half of a wavelength. Whereas a double slit experiment at the same angle of (A/a) and slits separation "a" produces maxima because one wavelength difference in path length from these two slits is produced.

SECTION – D

Questions 26 to 30 carry 3 marks each.

26. The given figure shows a network of resistances. Name the circuit so formed. What is the current flowing in the arm BD of this circuit? State the two laws used to find the current in different branches of this circuit.



Ans:

This circuit is called Wheatstone bridge. Wheatstone bridge is balanced when

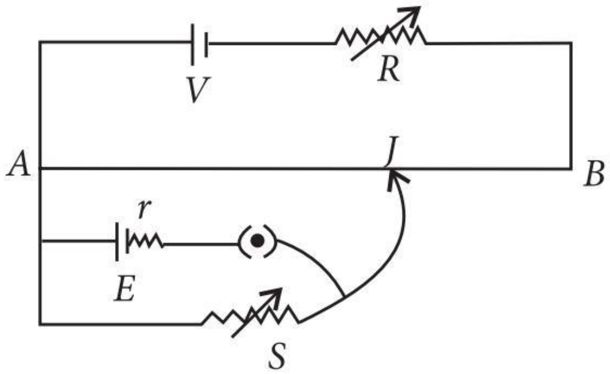
$$\frac{\text{Resistance in branch } AB}{\text{Resistance in branch } BC} = \frac{\text{Resistance branch } AD}{\text{Resistance in branch } CD}$$

$$\text{or} \quad \frac{20}{40} = \frac{15}{30} \quad \text{or} \quad \frac{1}{2} = \frac{1}{2}$$

No current flows through the arm BD containing galvanometer, as B and D are at same potential.
Two laws used to find the current in different branches of this circuit are:
(i) Kirchhoff's junction rule : It states that at any junction in an electrical circuit, sum of incoming currents is equal to sum of outgoing currents.
(ii) Kirchhoff's loop rule : It states that in any closed loop in a circuit, algebraic sum of applied emf's and potential drops across the resistors is equal to zero.

OR

State working principle of potentiometer. Explain how the balance point shifts when value of resistor R increases in the circuit of potentiometer, given below.



Ans: Principle of potentiometer: When a constant current flows through a wire of uniform area of cross-section, the potential drop across any length of the wire is directly proportional to the length. Let resistance of wire AB be R_1 and its length be *l* then current drawn from driving cell

$$l = \frac{V}{R+R_1}$$

and hence potential drop across the wire *AB* will be,

$$V_{AB} = IR_1 = \frac{V}{R+R_1} \times \frac{\rho l}{a}$$

where *a* is the area of cross-section of the wire *AB*.

$$\therefore \quad \frac{V_{AB}}{l} = \frac{V\rho}{(R+R_1)a} = \text{constant} = k$$

Where R increases, current and potential difference across wire AB will be decreased and hence potential gradient k will also be decreased. Thus the null point or balance point will shift to right (towards, B) side.

27. $_{86}Rn^{222}$ is converted into $_{84}Po^{218}$ and $_{93}Np^{239}$ is converted into $_{94}Pu^{239}$. Name the particles emitted in each case and write down the corresponding equations.

Ans:

Let the particle emitted in each case be represented as $_ZX_A$. Therefore,

(i) $_{86}Rn^{222} \rightarrow {_{84}Po^{218}} + {_ZX_A}$

Using the law of conservation of mass number and charge number, we get

$222 = 218 + A$

$\therefore \quad A = 222 - 218 = 4$

$86 = 84 + Z$

$\therefore \quad Z = 86 - 84 = 2$

Now, $A = 4$ and $Z = 2$ correspond to an alpha particle $_2He^4$. Therefore, emitted particle is an alpha particle, and the equation is

$$_{86}Rn^{222} \rightarrow {_{84}Po^{218}} + {_2He^4}$$

(ii) $_{93}Np^{239} \rightarrow {_{94}Pu^{239}} + {_ZX_A}$

Using the law of conservation of mass number and charge number, we get

$239 = 239 + A, \quad \therefore \quad A = 239 - 239 = 0$

$93 = 94 + Z, \quad \therefore \quad Z = 93 - 94 = -1.$

Now, $A = 0$ and $Z = -1$ correspond to electron ($_{-1}e^0$).

Therefore, emitted particle is a beta particle, and the equation is

$$_{93}Np^{239} \rightarrow {_{94}Pu^{239}} + {_{-1}e^0} + \bar{\nu}$$

28. The work function for the following metals is given:
Na: 2.75 eV; K: 2.30 eV; Mo: 4.17 eV; Ni: 5.15 eV.
Which of these metals will not give photoelectric emission for a radiation of wavelength 3300 Å from a He-Cd laser placed 1 m away from the photocell? What happens if the laser is brought nearer and placed 50 cm away?

Ans: The distance between laser source and receiver does not affect the energy of each photon incident, hence does not affect the energy of emitted photoelectrons. But the reduction in distance will increase the intensity of incident light and hence number of photons. This will increase the photoelectric current.

Given that, wavelength of incident radiation is

$$\lambda = 3300 \text{ Å}$$

So, energy of incident radiation is

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{3300 \times 10^{-10} \times 1.6 \times 10^{-19}} = 3.75 \text{ eV}$$

Now, work function of Mo : 4.17 eV, Ni : 5.15 eV is more than energy of incident photon, hence these two metals will not give photoelectric emission.

OR

Why should gases be insulators at ordinary pressures and start conducting at very low pressure?

Ans: At ordinary pressures a few positive ions and electrons produced by the ionisation of the gas molecules by energetic rays (like X-rays, y-rays, cosmic rays etc., coming from outer space and entering the earth's atmosphere) are not able to reach their respective electrodes, even at high voltages, due to their frequent collisions with gas molecules and recombinations. That is why the gases at ordinary pressures are insulators. At low pressures, the density of the gas decreases, the mean free path of the gas molecules become large. Now under the effect of external high voltage, the ions acquire sufficient energy before they collide with molecules causing further ionisation. Due to it, the number of ions in the gas increases and it becomes a conductor.

29. Derive an expression for the total energy of the electron in hydrogen atom, using Rutherford's model of the atom. Also, explain the significance of total negative energy possessed by the electron?

Energy of electron in n^{th} orbit hydrogen atom

An electron revolving in an orbit of H-atom, has both kinetic energy and electrostatic potential energy.

Kinetic energy of the electron revolving in a circular orbit of radius r is $E_K = \frac{1}{2}mv^2$

Since, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$

$\therefore \quad E_K = \frac{1}{2} \times \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$ or $E_K = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r}$

Electrostatic potential energy of electron of charge $-e$ revolving around the nucleus of charge $+e$ in an orbit of radius r is

$E_P = \frac{1}{4\pi\varepsilon_0}\frac{+e \times -e}{r}$ or $E_P = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{r}$

So, total energy of electron in orbit of radius r is

$E = E_K + E_P$ or $E = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r} - \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$

or $E = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{2r}$

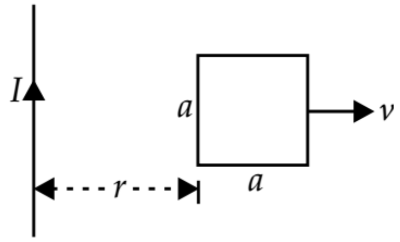
Putting $r = \frac{n^2h^2\varepsilon_0}{\pi me^2}$, we get

$$E = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{2\left(\frac{n^2h^2\varepsilon_0}{\pi me^2}\right)} \quad \text{or} \quad E = -\frac{me^4}{8\varepsilon_0^2 n^2 h^2}$$

or $E_n = -\frac{13.6}{n^2}$ eV

The –ve sign of the energy of electron indicates that the electron and nucleus together form a bound system, *i.e.*, electron is bound to the nucleus.

30. Obtain an expression for the mutual inductance between a long straight wire and a square loop of side a as shown in figure.

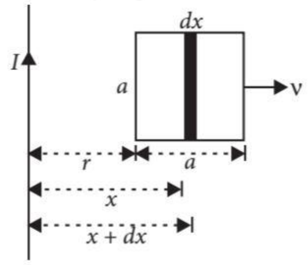


Ans:

Consider a rectangular strip of small width dx of the square loop at a distance x from the wire as shown in figure.

Magnetic field due to current carrying wire at a distance x from the wire is

$$B = \frac{\mu_0 I}{2\pi x}$$



Area of the strip, $dA = adx$

$\therefore$ Magnetic flux linked with the strip is

$$d\phi = BdA = \frac{\mu_0 I}{2\pi x}(adx)$$

Total magnetic flux linked with the square loop is

$$\phi = \int_{x=r}^{x=r+a} d\phi = \int_{x=r}^{x=r+a} \frac{\mu_0 I}{2\pi x}(adx) = \frac{\mu_0 Ia}{2\pi}\int_{x=r}^{x=r+a}\frac{dx}{x}$$

$$= \frac{\mu_0 Ia}{2\pi}|\ln x|_{x=r}^{x=r+a} = \frac{\mu_0 Ia}{2\pi}\ln\left(\frac{r+a}{r}\right)$$

$$\phi = \frac{\mu_0 Ia}{2\pi}\ln\left(\frac{a}{r}+1\right)$$

If M is the mutual inductance between the straight wire and the square loop, then, $MI = \phi$

or $MI = \frac{\mu_0 Ia}{2\pi}\ln\left(\frac{a}{r}+1\right)$ $\therefore$ $M = \frac{\mu_0 a}{2\pi}\ln\left(\frac{a}{r}+1\right)$

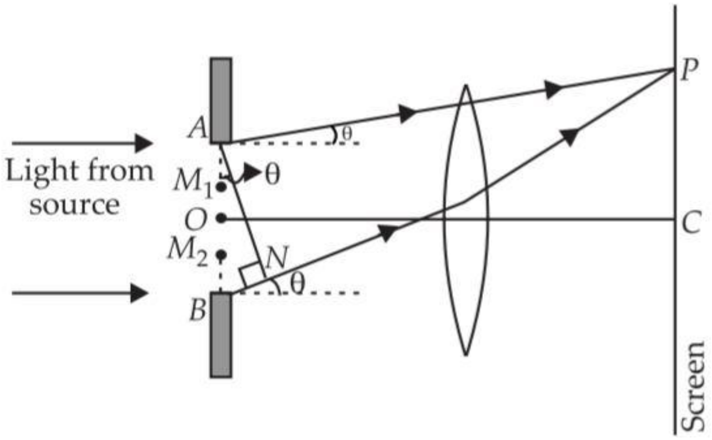
SECTION – E

Questions 31 to 33 carry 5 marks each.

31. Use Huygen's principle to explain the formation of diffraction pattern due to a single slit illuminated by a monochromatic source of light.

Ans: When the width of the slit is made double the original width, how would this affect the size and intensity of the central diffraction band?

Consider a parallel beam of monochromatic light is incident normally on a single slit AB of width a as shown in the figure. According to Huygens principle every point of slit acts as a source of secondary wavelets spreading in all directions. The mid point of the slit is O. A straight line through 0 perpendicular to the slit plane meets the screen at C. At the central point C on the screen, the angle 0 is zero. All path differences are zero and hence all the parts of the slit contribute in phase. This gives maximum intensity at C.



Consider a point P on the screen. The observation point is now taken at P. Secondary minima : Now we divide the slit into two equal halves AO and OB, each of width a/2. For every point, M_1 in AO, there is a corresponding point M_2 in OB, such that M_1M_2 = a/2. The path difference between waves arriving at P and starting from M_1 and M_2, will be (a/2)sin = λ/2 .

$$\therefore a\sin\theta = \lambda$$

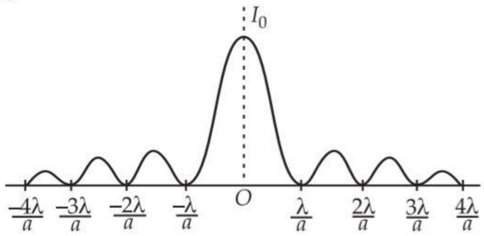
In general, for secondary minima

$a\sin\theta = n\lambda$ where $n = \pm1, \pm2, \pm3......$

Secondary maxima : Similarly it can be shown that for secondary maxima

$a\sin\theta = (2n+1)\frac{\lambda}{2}$ where $n = \pm1, \pm2........$

The intensity pattern on the screen is shown in the given figure.



Width of central maximum $= \frac{2D\lambda}{a}$

When width of slit (a) is doubled, central maximum width is halved. Its area becomes (1/4)th. Hence intensity of central diffraction band becomes 4 times.

OR

Using Huygens' principle, draw a diagram to show propagation of a wavefront originating from a monochromatic point source.

Ans: Propagation of wavefront from a point source : Huygen's principle is useful for determining the position of a given wavefront at any time in future if we know its present position. The principle may be stated in three parts as follows :

(i) Every point on a given wavefront may be regarded as a source of new disturbance.

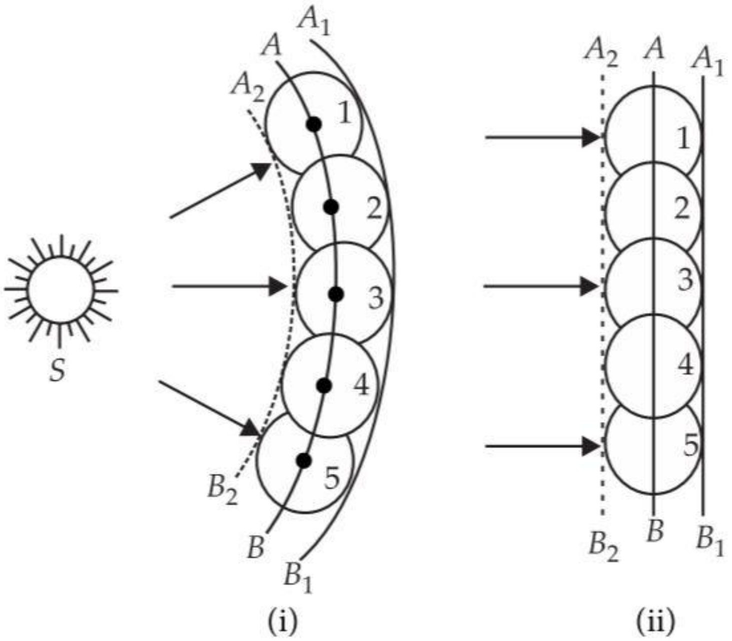
(ii) The new disturbances from each point spread out in all directions with the velocity of light and are called the secondary wavelets.

(iii)The surface of tangency to the secondary wavelets in forward direction at any instant gives the new position of the wavefront at that time.

Let us illustrate this principle by the following example : Let AB shown in figure (i) be the section of a wavefront in a homogeneous isotropic medium at t = 0. We have to find the position of the wavefront at time t using Huygens principle. Let v be the velocity of light in the given medium.

(a) Take the number of points, 1, 2, 3,... on the wavefront AB. These points are the sources of secondary wavelets.

(b) At time t the radius of these secondary wavelets is vt. Taking each point as centre, draw circles of radius vt.
(c) Draw a tangent A_1B_1 common to all these circles in the forward direction.
This gives the position of new wavefront at the required time t.
The Huygens' construction gives a backward wavefront also shown by dotted line A_2B_2 which is contrary to observation. The difficulty is removed by assuming that the intensity of the spherical wavelets is not uniform in all directions; but varies continuously from a maximum in the forward direction to a minimum of zero in the backward direction.
The directions which are normal to the wavefront are called rays, i.e., a ray is the direction in which the disturbance is propagated.



32. (a) An alternating voltage $V = V_m \sin \omega t$ applied to a series LCR circuit drives a current given by $i = i_m \sin(\omega t + \phi)$. Deduce an expression for the average power dissipated over a cycle.
(b) Determine the current and quality factor at resonance for a series LCR circuit with L = 1.00 mH, C = 1.00 nF and R =100 Ω connected to an ac source having peak voltage of 100 V.

Ans:

(a) $V = V_m \sin \omega t,\ i = i_m \sin(\omega t + \phi)$

and instantaneous power, $P = Vi$

$= V_m \sin \omega t \,.\, i_0 \sin(\omega t + \phi) = V_m\, i_m \sin \omega t \sin(\omega t + \phi) = \frac{1}{2} V_m i_m\, 2 \sin \omega t \,.\, \sin(\omega t + \phi)$

From trignometric formula, $2 \sin A \sin B = \cos(A - B) - \cos(A + B)$

$\therefore$ Instantaneous power, $P = \frac{1}{2} V_m i_m [\cos(\omega t + \phi - \omega t) - \cos(\omega t + \phi + \omega t)]$

$P = \frac{1}{2} V_m\, i_m [\cos\phi - \cos(2\omega t + \phi)]$ ...(i)

Average power for complete cycle

$\overline{P} = \frac{1}{2} V_m\, i_m [\cos\phi - \overline{\cos(2\omega t + \phi)}]$

For a complete cycle, $\overline{\cos(2\omega t + \phi)} = 0$

$\therefore$ Average power,

$$\bar{P} = \frac{1}{2}V_m i_m \cos\phi = \frac{V_0}{\sqrt{2}}\frac{i_0}{\sqrt{2}}\cos\phi = V_{rms} i_{rms} \cos\phi$$

(b) Given, $L = 1.00$ mH $= 1\times10^{-3}$ H,

$C = 1.00$ nF $= 1 \times 10^{-9}$ F

$R = 100\ \Omega$, $E_0 = 100$ V

$$I_0 = \frac{E_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} = \frac{E_0}{Z} \quad \left\{\begin{array}{l}\text{At resonance } \omega L = \frac{1}{\omega C} \\ \text{Hence } Z = R\end{array}\right\}$$

$$\therefore\ I_0 = \frac{V}{R} = \frac{100}{100}, I_0 = 1\text{ A}$$

$$I_v = \frac{I_0}{\sqrt{2}} = \frac{1}{\sqrt{2}} = \frac{\sqrt{2}}{2} = \frac{1.414}{2} = 0.707\text{ A}$$

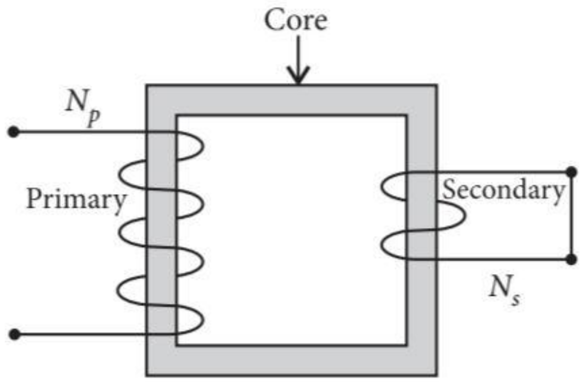
$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{1}{100}\sqrt{\frac{1.0\times10^{-3}}{1.0\times10^{-9}}} = \frac{1}{100}\times10^3 = 10$$

OR

(a) Draw the diagram of a device which is used to decrease high ac voltage into a low ac voltage and state its working principle. Write four sources of energy loss in this device.

(b) A small town with a demand of 1200 kW of electric power at 220 V is situated 20 km away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 Ω per km. The town gets the power from the line through a 4000-220 V step-down transformer at a substation in the town. Estimate the line power loss in the form of heat.

Ans: (a) Step down transformer (or transformer):



Principle: When the current flowing through the primary coil changes, an emf is induced in the secondary coil due to the change in magnetic flux linked with it i.e., it works on the principle of mutual induction. There are number of energy losses in a transformer.

(i) Copper losses due to Joule's heating produced across the resistances of primary and secondary coils. It can be reduced by using copper wires.

(ii) Hysteresis losses due to repeated magnetization and demagnetization of the core of transformer. It is minimized by using soft iron core, as area of hysteresis loop for soft iron is small and hence energy loss also becomes small.

(iii)Iron losses due to eddy currents produced in soft iron core. It is minimized by using laminated iron core.

(iv) Flux losses due to flux leakage or incomplete flux linkage and can be minimised by proper coupling of primary and secondary coils.

(b) Power required, $P = 1200 \text{ kW} = 1200 \times 10^3 \text{ W}$

Total resistance of two wire lines, $R = 2 \times 20 \times 0.5 = 20\,\Omega$

$E_v = 4000$ volt

As, $P = E_v I_v \;\therefore\; 1200 \times 10^3 = 4000 \times I_v$

$$\Rightarrow \quad I_v = \frac{1200 \times 10^3}{4000} = 300 \text{ A}$$

where I_v is the rms value of current.

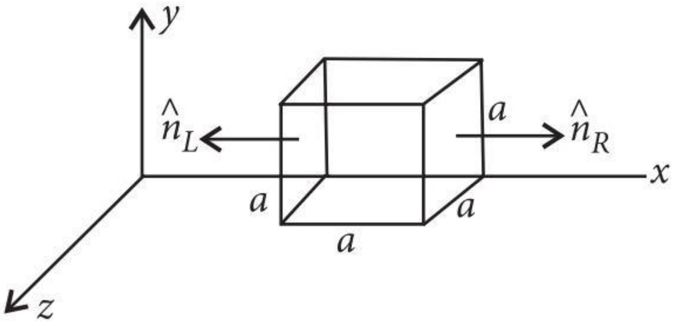
Line power loss in the form of heat is,

$= (I_p)^2 \times$ Resistance of line wire

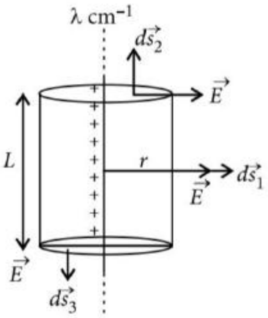
$= (300)^2 \times 20 = 1800$ kW

33. (a) Using Gauss's law, derive expression for intensity of electric field at any point near the infinitely long straight uniformly charged wire.

(b) The electric field components in the following figure are $E_x = \alpha x$, $E_y = 0$, $E_z = 0$; in which $\alpha = 400$ N/C m. Calculate (i) the electric flux through the cube, and (ii) the charge within the cube, assume that a = 0.1m.



(a)



Net charge $= q = \lambda L$

where, λ = line charge density.

According to Gauss's law, $\oint \vec{E} \cdot d\vec{s} = \frac{1}{\varepsilon_0}(q)$

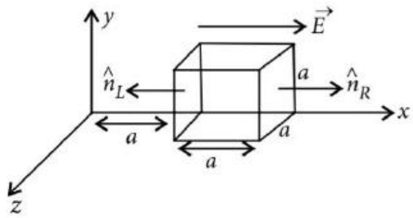
$$\int \vec{E} \cdot d\vec{s}_1 + \int \vec{E} \cdot d\vec{s}_2 + \int \vec{E} \cdot d\vec{s}_3 = \frac{1}{\varepsilon_0}(\lambda L)$$

$$\int E ds_1 \cos 0° + \int E ds_2 \cos 90° + \int E ds_3 \cos 90° = \frac{\lambda L}{\mu_0}$$

$$E \int ds_1 = \frac{\lambda L}{\varepsilon_0} \quad \text{or} \quad E \times 2\pi r L = \frac{\lambda L}{\varepsilon_0}$$

$$\Rightarrow \quad E = \frac{\lambda}{2\pi\varepsilon_0 r}. \text{ In vector form, } \vec{E} = \frac{\lambda}{2\pi\varepsilon_0}\hat{r}$$

(b)



$\because \quad E_x = \alpha x = 400x$

$\quad E_y = E_z = 0$

Hence flux will exist only on left and right faces of cube as $E_x \neq 0$.

$$\therefore \quad \vec{E}_L \cdot a^2(\hat{n}_L) + \vec{E}_R \cdot a^2 \hat{n}_R = \frac{1}{\varepsilon_0}(q_{in}) = \phi$$

$$-E_L \cdot a^2 + a^2 E_R = \phi_{\text{Net}}$$

$\phi_{Net} = -(400a)a^2 + a^2(400 \times 2a)$

$\quad = -400a^3 + 800a^3 = 400a^3 = 400 \times (0.1)^3$

$\phi_{\text{Net}} = 0.4 \text{ N m}^2 \text{ C}^{-1}$

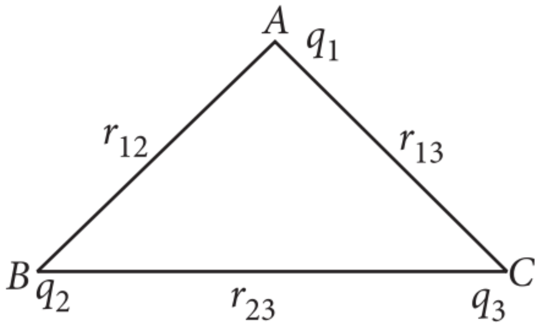
$$\because \; \phi_{\text{Net}} = \frac{1}{\varepsilon_0}\{q_{in}\}$$

$\therefore \quad q_{in} = \varepsilon_0 \phi_{\text{Net}} = 8.85 \times 10^{-12} \times 0.4 = 3.540 \times 10^{-12}$ C

OR

(a) Define electrostatic potential at a point. Write its SI unit. Three charges q_1, q_2 and q_3 are kept respectively at points A, B and C as shown in figure. Write the expression for electrostatic potential energy of the system.

(b) Depict the equipotential surfaces due to (i) an electric dipole (ii) two identical negative charges separated by a small distance.



(a) Electrostatic potential : Work done by an external force in bringing a unit positive charge from infinity to a point in the region of another charge particle is equal to the electrostatic potential at that point.

SI unit : J/C or volt.

Let no source charge be present in the system initially and hence no potential at any point.

Now the charge q, is brought at point A from infinite

Work done to bring charge q_1 at A

$W_1 = q_1 V_A$

or $W_1 = 0$ ...(i) $[\because V_A = 0]$

Due to presence of q_1 a potential develops at point B

i.e., $V_B = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_{12}}$

Work required to bring a charge q_2 from ∞ to B

$W_2 = q_2 V_B$; $W_2 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$ ...(ii)

Total work done to form the system of two point charges or the potential energy of the system of charges is then given by

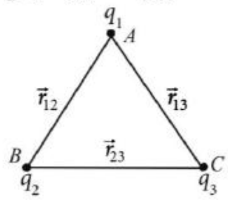
$U = W_1 + W_2 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$

Work done in bringing the charge q_3 from ∞ to point C is

$W_3 = q_3 [V_C - V_\infty] = q_3 [V_C - 0] = q_3 [V_{CA} - V_{CB}]$

$= q_3 \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_{13}} + \frac{q_2}{r_{23}}\right]$

or $W_3 = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right]$



So work done to form system of three point charges or the potential energy of system of three point charges is $U = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_1 q_3}{r_{13}}\right]$

Here it is important to note that potential energy is not localised but it is distributed all over the field.

(b)