Physics (Theory)

[*Time allowed: 3 hours*] [*Maximum marks:70*]

General Instructions:

(i) **All** questions are compulsory.

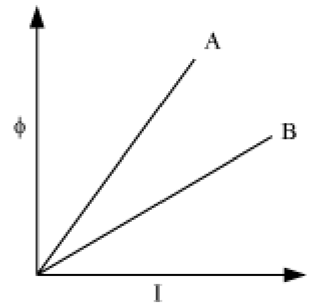
(ii) There are **30** questions in total.
Questions **1** to **8** carry **one** mark each.
Questions **9** to **18** carry **two** marks each.
Question **19** to **27** carry **three** marks each.
Question **28** to **30** carry **five** marks each.

(iii) There is no overall choice. However, an internal choice has been provided in **one** question of **two** marks; **one** question of **three** marks and all **three** questions of **five** marks each. You have to attempt only one of the choices in such questions.

(iv) Use of calculators is **not** permitted.

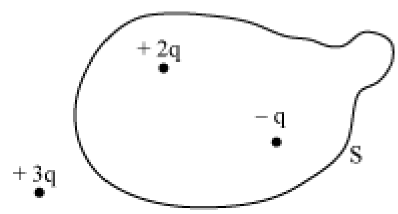
(v) You may use the following values of physical constants wherever necessary:
C = 3 × 108 ms^{-1}
H = 6.626 × 10^{-34} Js
e = 1.602 × 10^{-19} C
$\mu_0 = 4\pi \times 10^{-7}$ Tm A^{-1}
$$\frac{1}{4\pi\varepsilon_0} = 9\times10^9\,Nm^2C^{-2}$$
Mass of electron $m_e = 9.1 \times 10^{-31}$ kg
Mass of neutron $m_n \cong 1.675 \times 10^{-27}$ kg
Boltzmann's constant k = 1.381 × 10^{-23} JK^{-1}
Avogadro's number $N_A = 6.022 \times 10^{23}$ mol^{-1}
Radius of earth = 6400 km

1. A plot of magnetic flux (ϕ) versus current (I) is shown in the figure for two inductors A and B. Which of the two has larger value of self inductance? 1



Solution :
Inductor A has the larger value of self-inductance.

2. Figure shows three point charges +2q, –q and + 3q. Two charges + 2q and –q are enclosed within a surface 'S'. What is the electric flux due to this configuration through the surface 'S'? 1



Solution:

The net electric flux through the surface 'S' is $\frac{q}{\varepsilon_0}$, where ε_0 is the permittivity of free space.

3. In which orientation, a dipole placed in a uniform electric field is in (i) stable, (ii) unstable equilibrium? 1

Solution:
A dipole placed in a uniform electric filed is in
(i) Stable equilibrium when the electric field is directed along the direction of the dipole i.e., when $\vec{E}$ is parallel to $\vec{p}$.
(ii) Unstable equilibrium when the electric filed is directed at an angle of 180 degrees with the direction of the dipole, i.e., when $\vec{E}$ is anti-parallel to $\vec{p}$.

4. Which part of electromagnetic spectrum is used in radar systems? 1

Solution:
The microwave range of electromagnetic spectrum is used in radar systems.

5. Calculate the speed of light in a medium whose critical angle is 30°. 1

Solution:

$$\text{Speed of light in the medium} = \frac{\text{Speed of light in air}}{\text{Refractive index of the medium with respect to air}}$$

$$= \frac{3\times10^{8}\ \text{m/s}}{\left(\frac{1}{\sin 30^{\circ}}\right)}$$

$$= \frac{3\times10^{8}\ \text{m/s}}{2}$$

$$= 1.5\times10^{8}\ \text{m/s}$$

6. A glass lens of refractive index 1.45 disappears when immersed in a liquid. What is the value of refractive index of the liquid? 1

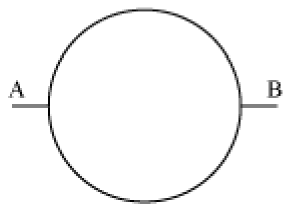
Solution:
The refractive index of the liquid is 1.45.

7. Write the expression for Bohr's radius in hydrogen atom. 1

Solution:

The expression for Bohr's radius in hydrogen atom is $a_0 = \frac{h^2\varepsilon_0}{\pi m e^2}$.

8. A wire of resistance 8R is bent in the form of a circle. What is the effective resistance between the ends of a diameter AB? 1



Solution:

The effective resistance between the ends of diameter AB is $\frac{1}{\frac{1}{4R}+\frac{1}{4R}} = \frac{1}{\frac{1}{2R}} = 2R$.

9. Explain the function of a repeater in a communication system. 2

Solution:
A repeater is used for extending the range of a communication system. It consists of a receiver and a transmitter. The receiver of a repeater collects the signal from the transmitter of another repeater and after amplifying, it retransmits the signal. Sometimes, it also changes the carrier frequency of the pick-up signal before transmitting it to the receiver.

10. (i) Write two characteristics of a material used for making permanent magnets.
(ii) Why is the core of an electromagnet made of ferromagnetic materials?

OR

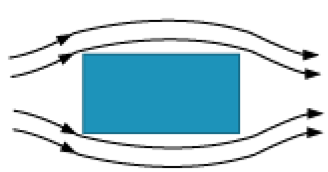
Draw magnetic field line when a (i) diamagnetic, (ii) paramagnetic substance is placed in an external magnetic field. Which magnetic property distinguishes this behaviour of the field line due to the substances? 2

Solution:
(i) The material used for making permanent magnets should have the following characteristics:
(a) High retentivity: It ensures that the magnet remains strong even after removal of the magnetising field.
(b) High coercivity: It ensures that the magnetism of the material does not get easily lost.
Apart from these two criteria, the material should have high permeability.

(ii) The core of an electromagnet should have high permeability and low retentivity. The high permeability of the core of an electromagnet ensures that the electromagnet is strong. On the other hand, low retentivity of the core ensures that the magnetism of the core material gets lost as soon as the current is switched off. Ferromagnetic materials have both high permeability and low retentivity. Hence, ferromagnetic materials are the most suitable for making the core of an electromagnet.

OR

(i) The magnetic field lines, when a diamagnetic material is placed in an external magnetic field, can be diagrammatically represented as



(ii) The magnetic field lines, when a paramagnetic material is placed in an external magnetic field, can be diagrammatically represented as

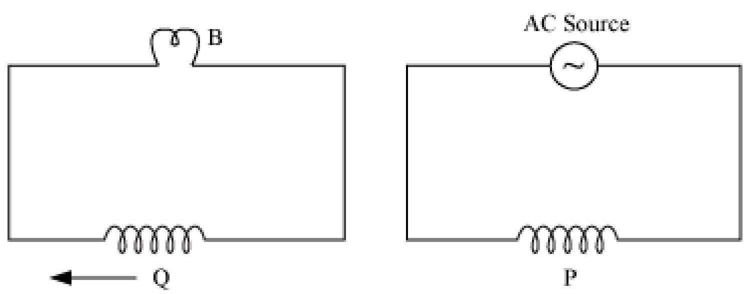
Diamagnetic and paramagnetic materials are distinguished by the magnetic property called magnetic susceptibility. For diamagnetic materials, magnetic susceptibility is negative, whereas for paramagnetic materials, magnetic susceptibility is slightly positive.

11. What is the range of frequencies used in satellite communication? What is common between these waves and light waves? 2

Solution:
The waves used for satellite communication lie in the following two frequency ranges.
(i) 3.7–4.2 GHz for downlink
(ii) 5.9–6.4 GHz for uplink

The waves used for satellite communication and light waves are both electromagnetic waves. Both of them travel in a straight line.

12. A coil Q is connected to low voltage bulb B and placed near another coil P as shown in the figure. Give reasons to explain the following observations: 2
(a) The bulb 'B' lights
(b) Bulb gets dimmer if the coil Q is moved towards left.



Solution:
(a) The A.C. source creates a varying magnetic field in coil P. This varying magnetic field of P is linked to coil Q. Hence, an induced current is produced in Q, which lights bulb B.

(b) As coil Q moves away from P, the rate of variation of magnetic flux changes. Therefore, the induced e.m.f. inside coil Q decreases and bulb B gets dimmer.

13. Find the radius of curvature of the convex surface of a plano-convex lens, whose focal length is 0.3 m and the refractive index of the material of the lens is 1.5. 2

Solution:

The focal length of a combined lens can be determined by the formula

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Here, $R_2 = \infty$ and $f = 0.3$ m

$$\frac{1}{0.3} = (\mu - 1) \times \frac{1}{R_1}$$

$$R_1 = 0.3(\mu - 1)$$
$$= 0.3(1.5 - 1)$$
$$= 0.3 \times 0.5$$
$$= 0.15 \text{ m}$$
$$= 15 \text{ cm}$$

14. An electron is accelerated through a potential difference of 64 volts. What is the de-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond? 2

Solution:

de-Broglie wavelength, $\lambda = \frac{h}{\sqrt{2meV}}$

Where,

$m \longrightarrow$ Mass of electron $= 9.1 \times 10^{-31}$ kg

$$\lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 64}}$$

$$\lambda = \frac{6.626 \times 10^{-34}}{\sqrt{1863.63. \times 10^{-50}}}$$

$$= \frac{6.626 \times 10^{-34}}{\sqrt{1063.86} \times 10^{-25}}$$

$$= \frac{6.626}{43.17} \times 10^{-9}$$

$$= 0.15 \times 10^{-9} \text{ m}$$

$$= 1.5 \times 10^{-10} \text{ m}$$

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

15. (i) Out of blue and red light which is deviated more by a prism? Give reason.

(ii) Give the formula that can be used to determine refractive index of materials of a prism in minimum deviation condition. 2

Solution:

(i) Between blue and red light, blue light is deviated more by a prism. This is because the wavelength of blue light is smaller than that of red light. Therefore, the speed of blue light is lower than that of red light in a medium.

(ii) The formula used for determining the refractive index of materials of a prism in minimum deviation condition,

$$n_{21} = \frac{\sin\ (A+D_m)/2}{\sin\left[\frac{A}{2}\right]}$$

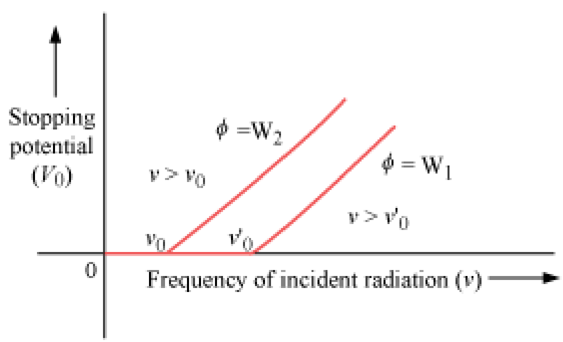
Where, $n_{21} \longrightarrow$ Refractive index of prism material with respect to the surrounding medium

A $\longrightarrow$ Angle of the prism

$D_m \longrightarrow$ Angle of minimum deviation

16. Plot a graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$). On what factors does the (i) slope and (ii) intercept of the lines depend? 2

Solution:



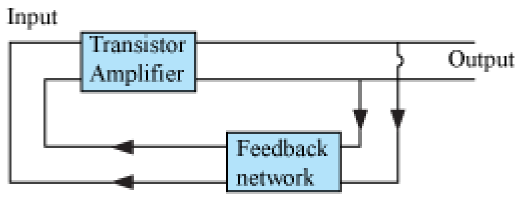
(i) The slope of the graph is content and equals to $\left(\frac{h}{e}\right)$. Therefore, the slope does not depend on any factor.

(ii) The intercept of the lines depends on the work function 'ϕ' of the metals.

17. Draw the circuit diagram of an illuminated photodiode in reverse bias. How is photodiode used to measure light intensity? 2

Solution:

The circuit diagram of an illuminated photodiode in reverse bias can be represented as



The greater the intensity of light, the greater is the number of photons falling per second per unit area. Thus, the greater the intensity of light, the greater is the number of electron–hole pairs produced at the junction. The photocurrent is, thus, directly proportional to the intensity of light. This can be used for measuring the intensity of incident light.

18. A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV is split into two fragments Y and Z of mass numbers 110 and 130. The binding energy of nucleons in Y and Z is 8.5 MeV per nucleon. Calculate the energy Q released per fission in MeV. 2

Solution:

Total energy of nucleus X = 240 × 7.6 = 1824 MeV

Total energy of nucleus Y = 110 × 8.5 = 935 MeV

Total energy of nucleus Z = 130 × 8.5 = 1105 MeV

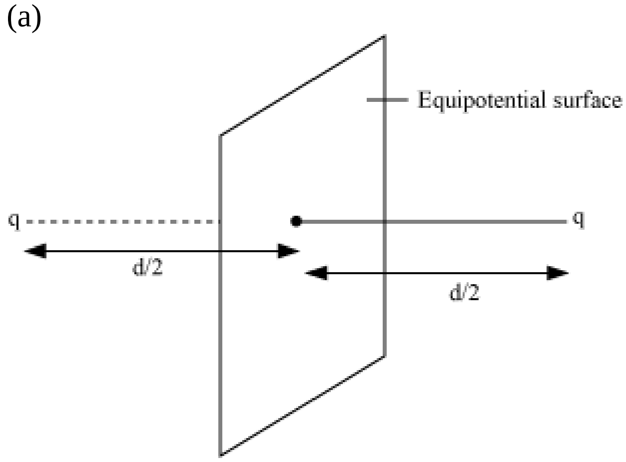
Therefore, energy released from fission, Q = 935 + 1105 – 1824 = 216 MeV

19. (a) Depict the equipotential surfaces for a system of two identical positive point charges placed a distance 'd' apart.

(b) Deduce the expression for the potential energy of a system of two point charges q_1 and q_2 brought from infinity to the points $\vec{r}_1$ and $\vec{r}_2$ respectively in the presence of external electric field $\vec{E}$. 3

Solution:

(a)



(b)

The work done in bringing charge q_1 from infinity to $\vec{r}_1$ is $q_1V(\vec{r}_1)$.

Work done on q_2 against external field = $q_2\ V(\vec{r}_2)$

Work done on q_2 against the field due to $q_1 = \dfrac{q_1q_2}{4\pi\varepsilon_o r_{12}}$

Where, r_{12} is the distance between q_1 and q_2.

By the superposition principle for fields,

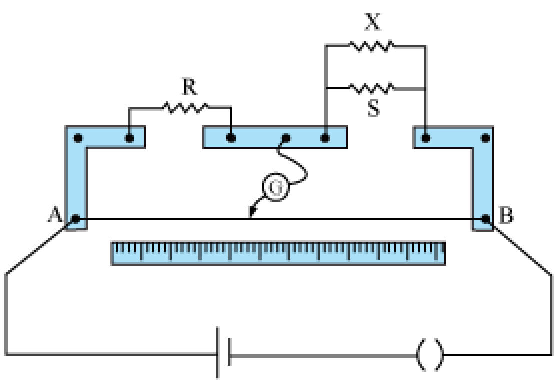
Work done in bringing q_2 to $\vec{r}_2$ is $\left(q_2V(\vec{r}_2)+\dfrac{q_1q_2}{4\pi\varepsilon_o r_{12}}\right)$.

Thus,

Potential energy of system = The total work done in assembling the configuration

$$= q_1V(\vec{r}_1)+q_2V(\vec{r}_2)+\frac{q_1q_2}{4\pi\varepsilon_o r_{12}}$$

20. In a meter bridge, the null point is found at a distance of l_1 cm from A. If now a resistance of X is connected in parallel with S, the null point occurs at l_2 cm. Obtain a formula for X in terms of l_1, l_2 and S. 3



Solution:

Initially, when X is not connected

$$\frac{R}{S}=\frac{l_1}{100-l_1}\ \text{Condition for balance}\quad ---(i)$$

The equivalent resistance (R_{eq}) of the combination of X and S is

$$\frac{1}{R_{eq}} = \frac{1}{X} + \frac{1}{S}$$

$$R_{eq} = \frac{SX}{X+S}$$

$$\frac{R}{R_{eq}} = \frac{l_2}{100-l_2}$$

$$\frac{R(X+S)}{SX} = \frac{l_2}{(100-l_2)} \quad ---(ii)$$

On dividing (i) by (ii), we obtain

$$\frac{R}{R(X+S)} \times \frac{SX}{X} = \frac{l_1}{l_2}\frac{(100-l_2)}{(100-l_1)}$$

$$\frac{X}{X+S} = \frac{l_1}{l_2}\frac{(100-l_2)}{(100-l_1)}$$

$$Xl_2(100-l_1) = (X+S)l_1(100-l_2)$$

$$Xl_2(100-l_1) = Xl_1(100-l_2) + Sl_1(100-l_2)$$

$$X = \frac{Sl_1(100-l_2)}{l_2(100-l_1) - l_1(100-l_1)}$$

This is the expression for X in terms of S, l_1 and l_2.

21. What is space wave propagation? Give two examples of communication system which use space wave mode.
A TV tower is 80 m tall. Calculate the maximum distance upto which the signal transmitted from the tower can be received. 3

Solution:
Space wave propagation is the propagation of waves whose frequencies lie above 40 MHz.
Examples of communication systems which use space wave mode are
(i) Television broadcast
(ii) Microwave links
(iii) Satellite communication
(Any two examples can be taken)

The maximum distance up to which signals can be received, $d = \sqrt{2R_E h_T}$

$$= \sqrt{2 \times 6400000 \times 80}$$
$$= 32000 \text{ m}$$
$$= 32 \text{ km}$$

Hence, the maximum distance up to which the transmitted signal can be received is 32 km.

22. (i) Define 'activity' of a radioactive material and write its S.I. units.
(ii) Plot a graph showing variation of activity of a given radioactive sample with time.
(iii) The sequence of stepwise decay of a radioactive nucleus is

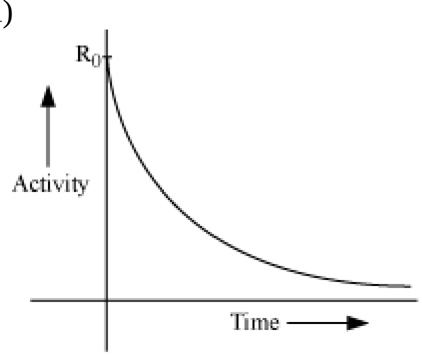
$$D \xrightarrow{\alpha} D_1 \xrightarrow{\beta^-} D_2$$

If the atomic number and mass number of D_2 are 71 and 176 respectively, what are their corresponding values of D? 3

Solution:

(i) The activity of a radioactive material is defined as the decay rate of a sample containing one or more radio nuclides.
The SI unit of radioactivity is becquerel (B).

(ii)



(iii)

$$D \xrightarrow{\alpha} D_1 \xrightarrow{\beta^-} {}^{176}_{71}D_2$$

Therefore,

$$D \xrightarrow{\alpha} {}^{176}_{72}D_1 \xrightarrow{\beta^-} {}^{176}_{71}D_2$$

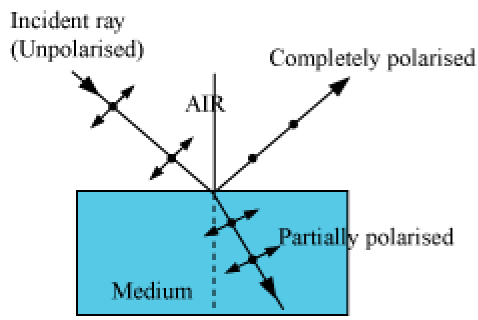
Therefore,

$${}^{180}_{74}D \xrightarrow{\alpha} {}^{176}_{72}D_1 \xrightarrow{\beta^-} {}^{176}_{71}D_2$$

So, the corresponding values of atomic number and mass number for D are 74 and 180.

23. What is an unpolarized light? Explain with the help of suitable ray diagram how an unpolarized light can be polarized by reflection from a transparent medium. Write the expression for Brewster angle in terms of the refractive index of denser medium. 3

Solution:

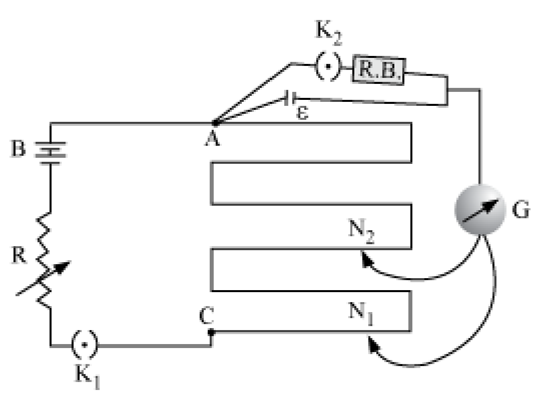


An unpolarised light is one in which the vibration of electric field vector is not restricted in one particular plane.
When an unpolarised light falls on the surface, the reflected light is such that the vibration of its electric field vector is confined to one particular plane. The direction of this plane is parallel to the surface of reflection. A component of electric field vector is absent from the refracted light. Therefore, the refracted light is partially polarised.

The expression for Brewster angle in terms of the refractive index of denser medium is $\tan i_B = \mu$
Where, μ is the refractive index of the denser medium with respect to the rarer medium.

24. Write the principle of working of a potentiometer. Describe briefly, with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a given cell. 3

Solution:
The working principle of a potentiometer is based on Kirchhoff's voltage law. According to this rule, *the algebraic sum of changes in voltage around any closed loop involving resistors and cells in the loop is zero*.

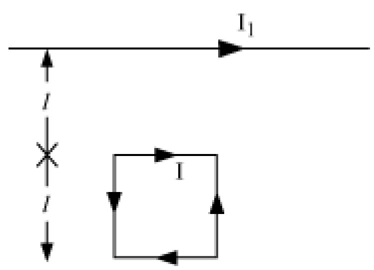


Let ϕ be the potential drop per unit length in the potentiometer wire

When only a cell is connected, the balance point is N_1.
Appling Kirchhoff's voltage law,
$\varepsilon = \phi l_1$ [l_1 = Length at which the balance point is achieved]
When some current is drawn using the resistance box, the balance point is achieved at N_2.
$V = \phi l_2$
This gives,
$$\frac{\varepsilon}{V} = \frac{l_1}{l_2}$$
$\varepsilon = I(r + R)$ [R = Resistance of the resistance box]
$V = IR$
This gives,
$$\frac{\varepsilon}{V} = \frac{r + R}{R}$$
$$r = R\left(\frac{l_1}{l_2} - 1\right)$$
The internal resistance of the cell can be determined by plugging-in the measured values of l_1 and l_2.

25. Write the expression for the magnetic moment $(\vec{m})$ due to a planar square loop of side 'l' carrying a steady current I in a vector form. 3

In the given figure this loop is placed in a horizontal plane near a long straight conductor carrying a steady current I_1 at a distance l as shown. Give reason to explain that the loop will experience a net force but no torque. Write the expression for this force acting on the loop.



Solution:
The expression for the magnetic moment $(\vec{m})$ due to a planar square loop of side 'l' carrying a steady current I in a vector form is given as
$\vec{m} = I\vec{A}$
Therefore,
$\vec{m} = I(l)^2\hat{n}$
Where, $\hat{n}$ is the unit vector along the normal to the surface of the loop.

The attractive force per unit length on the loop is

$$\frac{F_a}{l}=\frac{\mu_0}{2\pi}\frac{I_1 I}{l}$$

$$F_a=\frac{\mu_0}{2\pi}I_1 I$$

The repulsive force per unit length on the loop is

$$\frac{F_r}{l}=\frac{\mu_0}{2\pi}\frac{I_1 I}{2l}$$

$$F_r=\frac{\mu_0}{2\pi}\frac{I_1 I}{2l}$$

$$F_{net}=F_a-F_r$$

$$=\frac{\mu_0}{2\pi}I_1 I\left(1-\frac{1}{2}\right)$$

$$\left|F_{net}=\frac{\mu_0}{4\pi}I_1 I\right|$$

Since the attractive force is greater than the repulsive force, a net force acts on the loop.
The torque on the loop is given as

$$\tau=\vec{m}\times\vec{B}$$

$$=mB\sin\theta$$

$$=IAB\sin\theta$$

$\theta = 0°$ ($\because$ Area vector is parallel to the magnetic field)

$\tau = IAB\ \sin 0°$

$\tau = 0$

$\therefore$ The torque acting on the loop is zero.

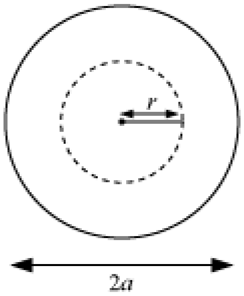
26. A long straight wire of a circular cross-section of radius ‘a’ carries a steady current ‘I’. The current is uniformly distributed across the cross-section. Apply Ampere’s circuital law to calculate the magnetic field at a point ‘r’ in the region for (i) r < a and (ii) r > a.

OR

State the underlying principle of working of a moving coil galvanometer. Write two reasons why a galvanometer can not be used as such to measure current in a given circuit. Name any two factors on which the current sensitivity of a galvanometer depends. 3

Solution:

(i) **For *r* < *a***



$$\oint \vec{B}\cdot\vec{dl} = \mu_0 I_{\text{enclosed}}$$

$$\frac{I_{\text{enclosed}}}{\pi a^2} = \frac{I}{\pi r^2}$$

$$I_{\text{encolsed}} = I\frac{r^2}{a^2}$$

$$\vec{B}\cdot\vec{dl} = Bdl \qquad \because \cos\theta = 1$$

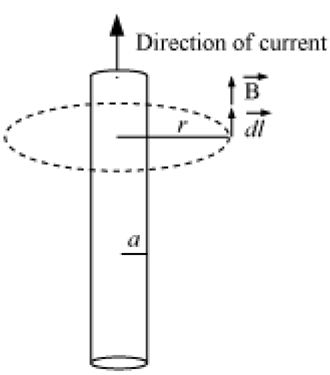
$$\therefore \oint Bdl = \mu_0 I\frac{r^2}{a^2}$$

$$B\oint dl = \mu_0 I\frac{r^2}{a^2}$$

$$B(2\pi r) = \mu_0 I\frac{r^2}{a^2}$$

$$B = \frac{\mu_0}{2\pi}\frac{I}{a^2}r$$

(ii) **For *r* > *a***



From Ampere's circuital law,

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_{\text{enclosed}}$$

$$\vec{B} \cdot \vec{dl} = Bdl \cos\theta$$

$$\theta = 0^\circ$$

$$\vec{B} \cdot \vec{dl} = Bdl$$

$$I_{\text{enclosed}} = I$$

$$\oint Bdl = \mu_0 I$$

$$B\oint dl = \mu_0 I$$

$$B(2\pi r) = \mu_0 I$$

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

OR

The underlying principle for the working of a moving coil galvanometer is that when a current-carrying conductor is placed inside a magnetic field, it experiences a magnetic force.
The two reasons why a galvanometer cannot be used for measuring current are

- The high resistance of galvanometer can disturb the original current flowing through the circuit
- The high current present in the circuit can destroy the coil windings present in the galvanometer

The factors on which the current sensitivity of a galvanometer depends are

- Number of turns in the coil
- Torsional spring constant
- Area of the coil
- Strength of the magnetic field

(Any two can be taken as the answer)

27. A parallel-plate capacitor is charged to a potential difference V by a dc source. The capacitor is then disconnected from the source. If the distance between the plates is doubled, state with reason how the following change: 3
(i) electric field between the plates
(ii) capacitance, and
(iii) energy stored in the capacitor

Solution:
(i)

$$Q = CV$$

$$Q = \left(\frac{\varepsilon_0 A}{d}\right)(Ed)$$

$$Q = \varepsilon_0 AE$$

$$\therefore E = \frac{Q}{\varepsilon_0 A}$$

Therefore, the electric field between the parallel plates depends only on the charge and the plate area. It does not depend on the distance between the plates.

Since the charge as well as the area of the plates does not change, the electric field between the plates also does not change.

(ii)
Let the initial capacitance be C and the final capacitance be C'.
Accordingly,

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

$$C' = \frac{\varepsilon_0 A}{2d}$$

$$\frac{C}{C'} = 2$$

$$C' = \frac{C}{2}$$

Hence, the capacitance of the capacitor gets halved when the distance between the plates is doubled.

(iii)

Energy of a capacitor, $U = \frac{1}{2}\frac{Q^2}{C}$

Since Q remains the same but the capacitance decreases,

$$U' = \frac{1}{2}\frac{Q^2}{\left(\frac{C}{2}\right)}$$

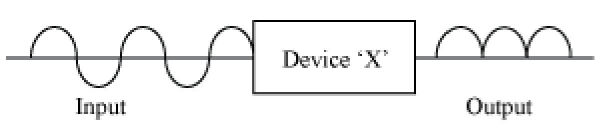
$$\frac{U}{U'} = \frac{1}{2}$$

$$U' = 2U$$

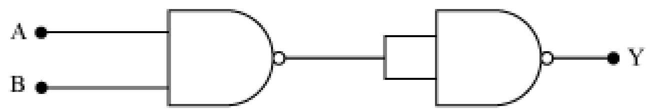
The energy stored in the capacitor gets doubled when the distance between the plates is doubled.

28. (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.



(c) Identify the logic gate represented by the circuit as shown and write its truth table.



OR

(a) With the help of circuit diagram explain the working principle of a transistor amplifier as an oscillator.

(b) Distinguish between a conductor, a semiconductor and an insulator on the basis of energy band diagrams. 3

Solution:

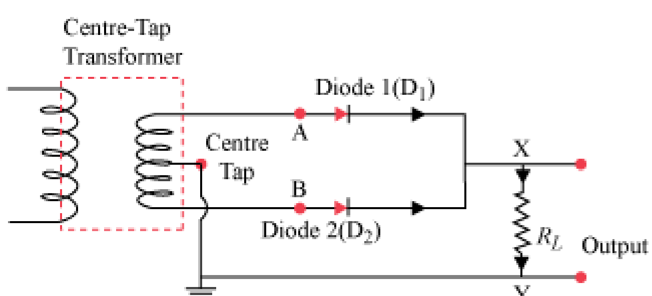
(a) In a *p*–*n* junction, a *p*-type and an *n*-type material are joined together. The concentration of holes is higher in *p*-type material as compared to that in *n*-type material. Therefore, there is a concentration gradient between the *p*-type and *n*-type materials. As a result of this concentration gradient, holes move from *p*-side to *n*-side ($p \rightarrow n$) by the process of diffusion. Similarly, electrons move from *n*-side to *p*-side ($n \rightarrow p$).

As the holes diffuse from *p*-side, they leave ionised spaces (negatively charged) on *p*-side near the junction. These ionised spaces are immobile. Hence, a negative space-charge region is formed on the *p*-side near the junction. Similarly, a positive space-charge region is formed on the *n*-side. These two space-charge regions on either sides of the junction constitute what is called a depletion layer.

Since the *n*-side loses electrons and *p*-side gains electrons, a potential difference is developed across the junction of the two regions. This potential difference tends to oppose further motions of electron from the *n*-region into the *p*-region. The same happens for holes too. The reverse polarity of this potential opposes further flow of carriers and is thus called the barrier potential.

(b) The device is a full-wave rectifier.

The circuit diagram of a full-wave rectifier is represented as



(a)

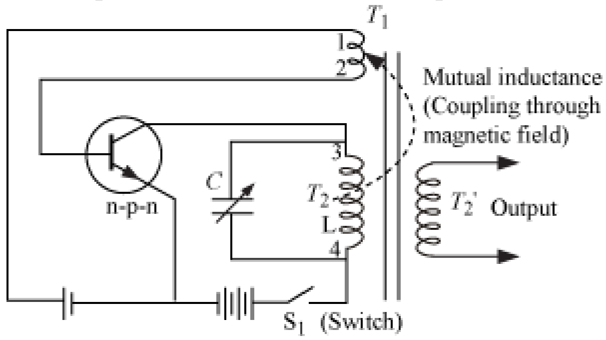
(c) The logic gate represented by the circuit is an AND gate.

The truth table of the AND gate is represented as

A	B	A.B
0	0	0
1	1	1
1	0	0
0	1	0

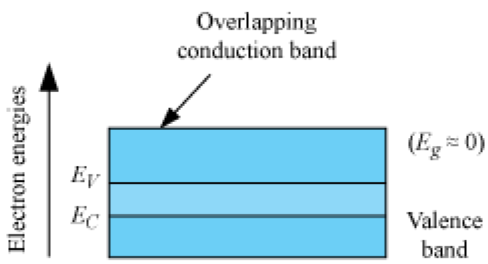
OR

(a)
The circuit diagram for a transistor amplifier as an oscillator is represented as

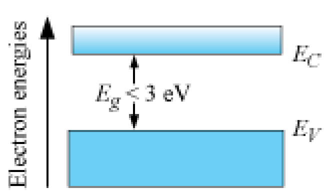


In an oscillator, a sustained A.C. output is obtained without any input oscillation. For this to happen, the output of a transistor amplifier is fed back into its input. This is achieved by coupling the winding T_1 to winding T_2.
When key S_1 is closed, the collector current begins to increase, which supports the forward bias of the emitter–base circuit. Collector current increases until it reaches saturation. When the saturation is reached, the magnetic flux linked to winding T_1 becomes steady. Hence, the forward bias of the emitter–base circuit is no longer supported. The transistor is now driven into cut-off. This cycle repeats itself and an oscillating output is obtained.

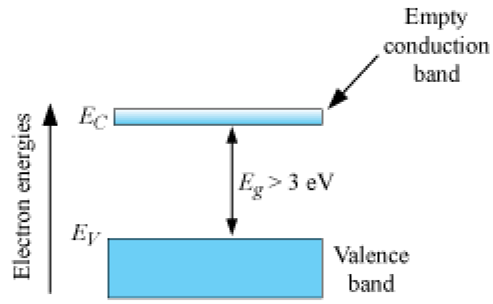
(b) The energy-band diagram of a conductor is represented as



The energy-band diagram of a semiconductor is represented as



The energy-band diagram of an insulator is represented as



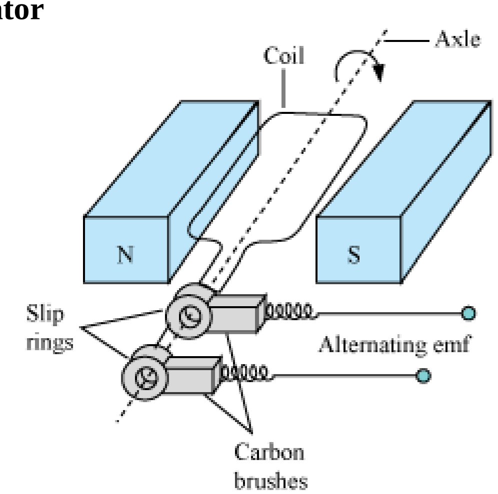
29. Describe briefly, with the help of a labelled diagram, the basic elements of an A.C. generator. State its underlying principle. Show diagrammatically how an alternating emf is generated by a loop of wire rotating in a magnetic field. Write the expression for the instantaneous value of the emf induced in the rotating loop.

OR

A series LCR circuit is connected to a 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. Define 'power factor'. State the conditions under which it is (i) maximum and (ii) minimum. 5

Solution:
Basic elements of an A.C. generator

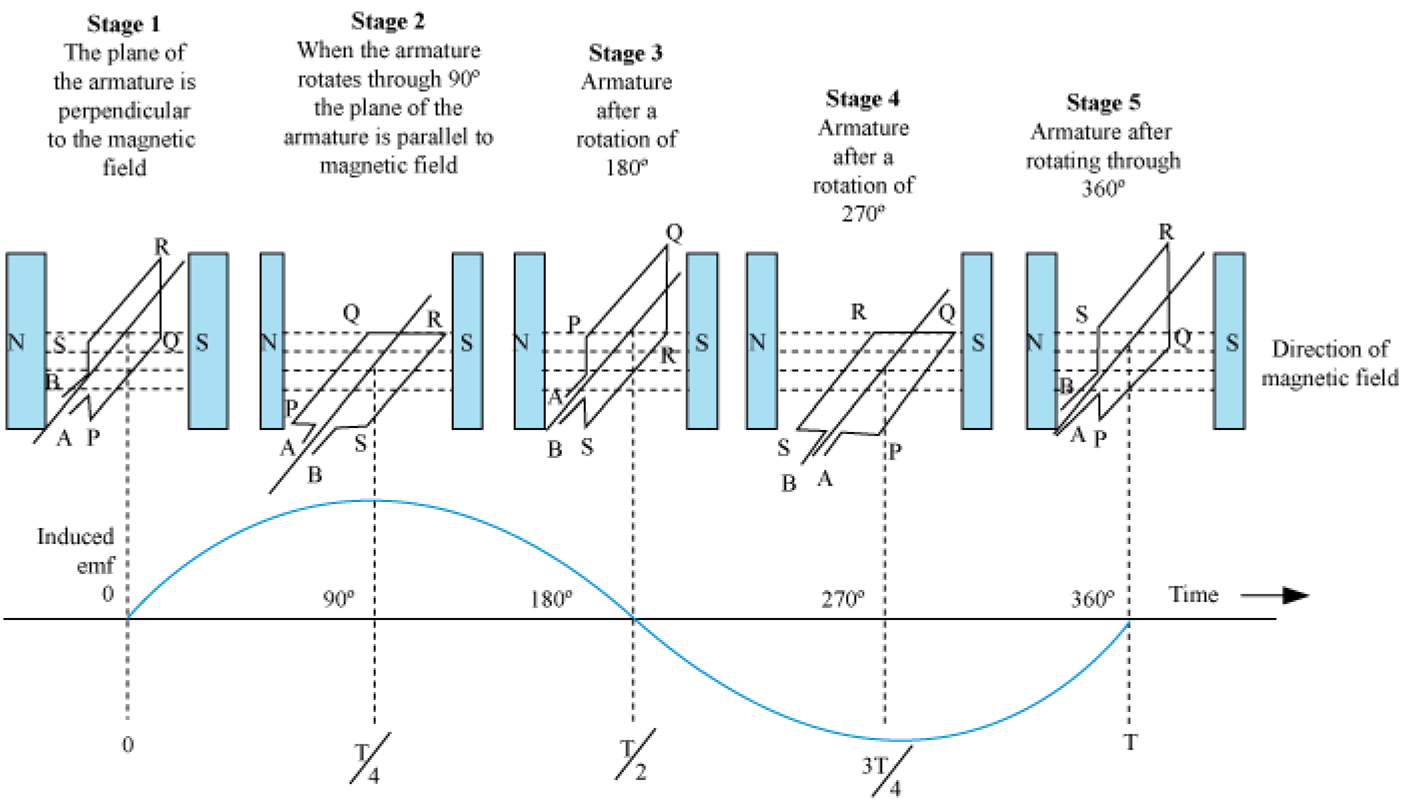


An A.C. generator consists of a rotor shaft on which a coil is mounted. A magnetic field is created around an armature coil with the help of permanent magnets.
The terminals of the coil are connected to two slip rings. Carbon brushes are attached to slip rings so as to make connection with an external circuit.

Underlying principle of an A.C. generator

The underlying principle responsible for the working of an A.C. generator is electromagnetic induction. According to this principle, if a conductor is placed in a varying magnetic field, then current is induced in the conductor.

Generation of an alternating e.m.f. by a loop of wire rotating in a magnetic field



Expression of the instantaneous value of the induced e.m.f. in a rotating loop

$\varepsilon = NBA\omega \sin\omega t$

Where N = number of turns in armature coil

B = Magnetic field vector

A =Area vector of the coil

ω = Angular speed

OR

$v = v_m \sin \omega t$

Let the current in the circuit be led the applied voltage by an angle ϕ.

$i = i_m \sin(\omega t + \phi)$

The Kirchhoff's voltage law gives $L\frac{di}{dt} + Ri + \frac{q}{C} = v$.

It is given that $v = v_m \sin \omega t$ (applied voltage)

$$L\frac{d^2q}{dt^2} + R\frac{dq}{dt} + \frac{q}{C} = v_m \sin\omega t \qquad \text{... 1}$$

On solving the equation, we obtain

$$q = q_{\mathrm{m}} \sin(\omega t + \theta)$$

$$\frac{dq}{dt} = q_{\mathrm{m}}\omega \cos(\omega t + \theta)$$

$$\frac{d^2q}{dt^2} = -q_{\mathrm{m}}\omega^2 \sin(\omega t + \theta)$$

On substituting these values in equation (1), we obtain

$$q_m\omega \;\; R\cos(\omega t + \theta) + (X_{\mathrm{C}} - X_{\mathrm{L}})\sin(\omega t + \theta) \;\; = v_{\mathrm{m}} \sin \omega t$$

$$X_{\mathrm{C}} = \frac{1}{\omega \mathrm{C}} \, X_{\mathrm{C}} = \omega L$$

$$Z = \sqrt{R^2 + (X_{\mathrm{C}} - X_{\mathrm{L}})^2}$$

$$q_m\omega Z\left[\frac{R}{Z}\cos(\omega t + \theta) + \frac{(X_{\mathrm{C}} - X_{\mathrm{L}})}{Z}\sin(\omega t + \theta)\right] = v_{\mathrm{m}} \sin \omega t \qquad \ldots\ 2$$

Let $\cos\phi = \frac{R}{2}$ and $\frac{X_{\mathrm{C}} - X_{\mathrm{L}}}{Z} = \sin\phi$

This gives

$$\tan\phi = \frac{X_{\mathrm{C}} - X_{\mathrm{L}}}{R}$$

On substituting this in equation (2), we obtain

$$q_m\omega Z \cos(\omega t + \theta - \phi) = v_{\mathrm{m}} \sin \omega t$$

On comparing the two sides, we obtain

$$v_{\mathrm{m}} = q_m\omega Z = i_{\mathrm{m}} Z$$

$$i_{\mathrm{m}} = q_m\omega$$

and $(\theta - \phi) = -\frac{\pi}{2}$

or $\theta = -\frac{\pi}{2} + \phi$

$$i = \frac{dq}{dt} = q_m\omega \cos(\omega t + \theta)$$

$$= i_{\mathrm{m}} \cos(\omega t + \theta)$$

Or

$$i = i_m \sin(\omega t + \theta)$$

Where, $i_m = \frac{v_{\mathrm{m}}}{Z} = \frac{v_{\mathrm{m}}}{\sqrt{R^2 + (X_{\mathrm{C}} - X_{\mathrm{L}})^2}}$

And

$$\phi = \tan^{-1}\left(\frac{X_{\mathrm{C}} - X_{\mathrm{L}}}{R}\right)$$

The condition for resonance to occur

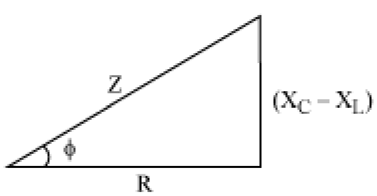
$$i_m = \frac{v_m}{\sqrt{R^2 + (X_C - X_L)^2}}$$

For resonance to occur, the value of i_m has to be the maximum.

The value of i_m will be the maximum when

$$X_C = X_L$$
$$\frac{1}{\omega C} = \omega L$$
$$\omega^2 = \frac{1}{LC}$$
$$\omega = \frac{1}{\sqrt{LC}}$$
$$2\pi f = \frac{1}{\sqrt{LC}}$$
$$\boxed{f = \frac{1}{2\pi\sqrt{LC}}}$$

Power factor = cos ϕ



Where, $\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_C - X_L)^2}}$

(i) Conditions for maximum power factor (i.e., cos ϕ = 1)

- $X_C = X_L$

  Or

- $R = 0$

(ii) Conditions for minimum power factor

- When the circuit is purely inductive
- When the circuit is purely capacitive

30. State Huygens's principle. Show, with the help of a suitable diagram, how this principle is used to obtain the diffraction pattern by a single slit.

Draw a plot of intensity distribution and explain clearly why the secondary maxima becomes weaker with increasing order (n) of the secondary maxima.

OR

Draw a ray diagram to show the working of a compound microscope. Deduce an expression for the total magnification when the final image is formed at the near point.

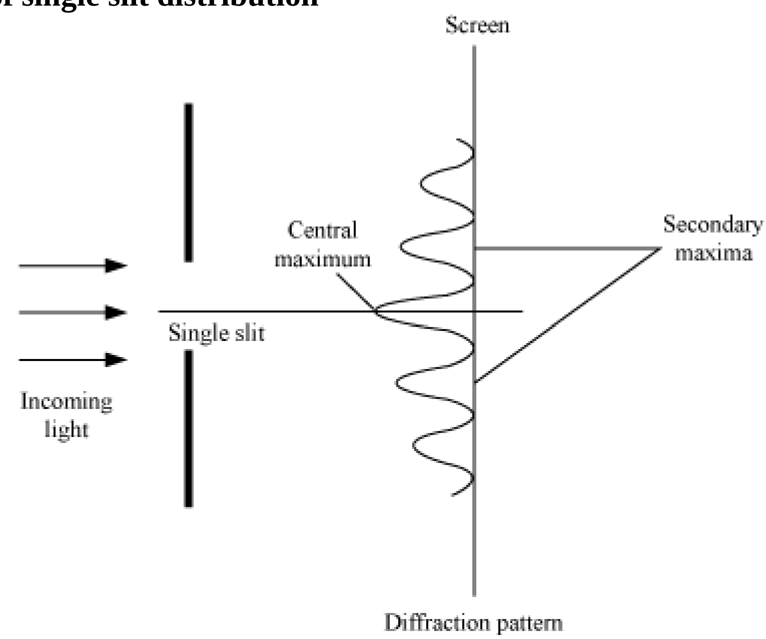
In a compound microscope, an object is placed at a distance of 1.5 cm from the objective of focal length 1.25 cm. If the eye piece has a focal length of 5 cm and the final image is formed at the near point, estimate the magnifying power of the microscope. 5

Solution:

Huygen's principle states that

- Each point on a wave front behaves as a source of secondary wavelets
- The secondary wavelets travel with the speed of light in that medium
- The position of new wave front at a later time can be found out by drawing a common tangent to all these secondary wavelets

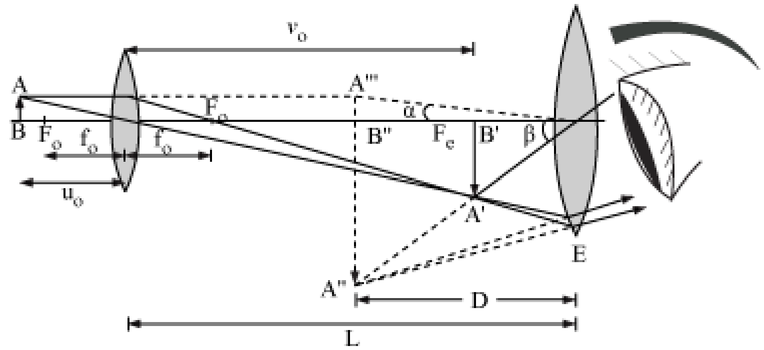
Intensity distribution of single slit distribution



For the first secondary maxima (n = 1), only one-third of the slit contributes to its intensity.
Secondly, for n = 2, only one-fifth of the slit contributes to the intensity.
Therefore, with increasing n, the intensity decreases.

OR

Ray diagram for a compound microscope



Total angular magnification, $m = \frac{\beta}{\alpha}$

β → Angle subtended by the image

α → Angle subtended by the object

Since α and β are small,

$\tan\alpha \approx \alpha$ and $\tan\beta \approx \beta$

$$m = \frac{\tan\beta}{\tan\alpha}$$

$$\tan\alpha = \frac{\text{AB}}{D}$$

And

$$\tan\beta = \frac{\text{A}''\text{B}''}{D}$$

$$m = \frac{\tan\beta}{\tan\alpha} = \frac{\text{A}''\text{B}''}{D} \times \frac{D}{\text{AB}} = \frac{\text{A}''\text{B}''}{\text{AB}}$$

On multiplying the numerator and the denominator with A′B′, we obtain

$$m = \frac{\text{A}''\text{B}'' \times \text{A}'\text{B}'}{\text{A}'\text{B}' \times \text{AB}}$$

Now, magnification produced by objective, $m_0 = \frac{\text{A'B'}}{\text{AB}}$

Magnification produced by eyepiece, $m_e = \frac{\text{A}''\text{B}''}{\text{AB}}$

Therefore,

Total magnification, $(m) = m_0 m_e$

$$m_0 = \frac{v_0}{u_0} = \frac{\text{(Image distance for image produced by objective lens)}}{\text{(Object distance for the objective lens)}}$$

$$m_e = \left(1 + \frac{D}{f_e}\right)$$

f_e → Focal length of eyepiece

$$m = m_0 m_e$$

$$= \frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

$v_0 \approx$ L (Separation between the lenses)

$u_0 \approx -f_0$

$\therefore m = \dfrac{-L}{f_0}\left(1+\dfrac{D}{f_e}\right)$

$u_0 = -1.5 \text{ cm}$

$f_0 = +1.5\,\text{cm}$

$\dfrac{1}{f_0} = \dfrac{1}{v_0} - \dfrac{1}{u_0}$

$\dfrac{1}{1.25} = \dfrac{1}{v_0} + \dfrac{1}{1.5}$

$\dfrac{1}{v_0} = \dfrac{1}{1.25} - \dfrac{1}{1.5}$

$= \dfrac{100}{125} - \dfrac{10}{15}$

$= \dfrac{1500-1250}{1875}$

$\dfrac{1}{v_0} = \dfrac{250}{1875}$

$v_0 = +7.5 \text{ cm}$

$f_e = +5 \text{ cm}$

$m = \dfrac{v_0}{u_0}\left(1+\dfrac{D}{f_e}\right)$

$= \dfrac{7.5}{-1.5}\left(1+\dfrac{25}{5}\right)$

$= -\dfrac{7.5}{1.5}\times 6$

$\boxed{m = -30}$