UACE PHYSICS PAPER 2002 GUIDE

Instructions to the candidates:

Answer **five** questions taking at least one from each of the sections **A, B, C** and **D**, but not more than one question should be chosen from either section **A** or **B**

Any additional question (s) will not be marked.

Mathematical tables and squared paper will be provided

Non programmable calculators may be used.

Assume where necessary

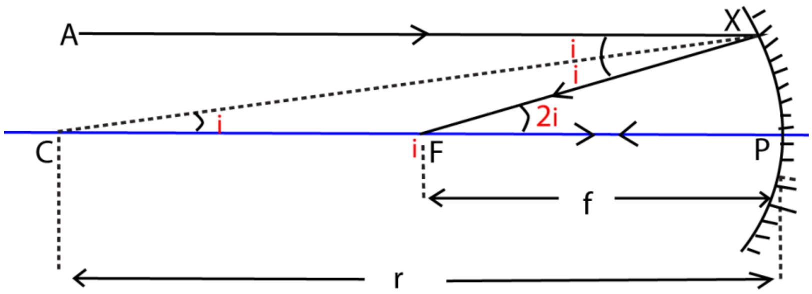
Acceleration due to gravity, g	$9.81ms^{-2}$
Electron charge, e	$1.6 \times 10^{-19}C$
Electron mass	$9.11 \times 10^{-31}kg$
Plank's constant, h	$6.6 \times 10^{-34}Js$
Speed of light in the vacuum, c	$3.0 \times 108ms^{-1}$
Specific heat capacity of water	$4.200Jkg^{-1}K^{-1}$
Avogadro's number, N_A	$6.02 \times 10^{23}mol^{-1}$
The constant, $\frac{1}{4\pi\varepsilon_0}$	$9.0 \times 10^{9}F^{-1}m$
Permittivity of free space, μ_0	$4.0\pi \times 10^{-7}Hm^{-1}$
Permittivity of free space, ε_0	$8.85 \times 10^{-12}Fm^{-1}$
One electron volt	$1.6 \times 10^{-19}J$
Resistivity of Nichrome wire at 25^0C	$1.2 \times 10^{-6}\Omega m$

SECTION A

1. (a) (i) State the laws of reflection of light. (02marks)
   - Incident ray reflected ray and the normal at the point of incidence all lie in the same plane
   - The angle incidence is equal to the angle of reflection.

   (ii) Show, with the aid of a ray diagram, that the radius of curvature of a concave mirror is twice the focal length of the mirror. (05marks)

   Consider the reflection of a paraxial ray, AX, parallel to the principal axis of a concave mirror as shown.



Taking FP = focal length and C = centre of curvature, then, CX, is the normal to the mirror surface and, CP, is the radius of curvature.
tan 2i ≈ 2i

If, X, is close to P, then tan 2i ≈ 2 i $= \frac{XP}{FP}$---------------- (for small angles)

$\Rightarrow \quad 2i = \frac{XP}{FP}$ --(i)

Similarly tan i ≈ i = $\frac{XP}{CP}$

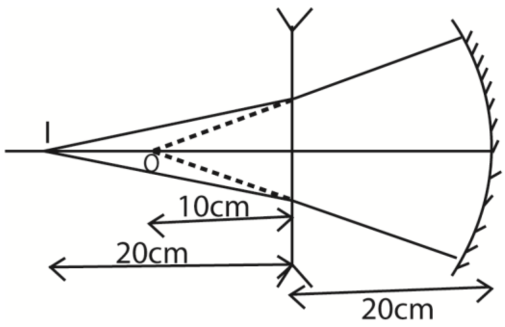
i = $\frac{XP}{CP}$ --- (ii)

Combining equations (i) and (ii) gives,
$2\frac{XP}{CP} = \frac{XP}{FP}$

Canceling XP throughout and simplifying for CP gives
CP = 2FP where CP = r, FP = f
∴r = 2f.

(b) An object is placed 20cm in from of a diverging lens place coaxially with a concave mirror of focal length 15cm. When the concave mirror is 20cm from the lens, the final image coincides with the object.

(i) Draw a ray diagram to show how the final image is formed. (02marks)



(ii) Determine the focal length of the diverging lens. (04marks)

Action of the diverging lens, u = -10cm

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{f} = \frac{1}{-10} + \frac{1}{20}$$

f = -20cm

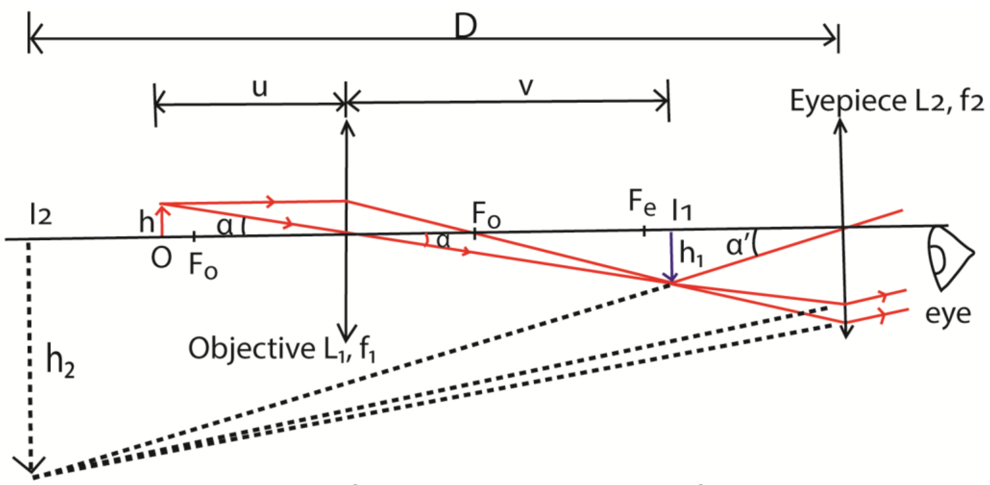
(c) (i) Define angular magnification of an optical instrument. (01mark)

Angular magnification is the ration of the angle subtended by the final image when using an instrument to the angle subtended by the object at the unaided eye

(ii) What is meant by exit pupil of a compound microscope? (02marks)

The exit pupil is the image of objective passes through the exit pupil (assuming no loss at the lens surfaces)

(iii) Describe with the aid of a diagram, the structure and action of a compound microscope in normal adjustment. (04marks)



Compound microscope in normal use

The objective forms a real magnified image of the object at a distance less than f_e from the eye piece.

The eye piece form a virtual magnified image of the intermediate image at nearest distance of distinct vision (D=25 cm)

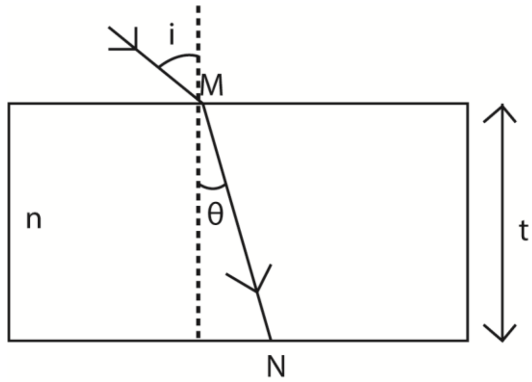
2. (a) (i) What is meant by a refractive index of a material? (01marks)

Refractive index of a material is the ratio of the speed of light in the vacuum to the speed of light in the medium

Or

It is the ratio of sine of an angle of incidence in the vacuum to sine of angle of refraction in the medium for light entering the medium from the vacuum

(ii) Mono chromatic light incident on a block of material placed in a vacuum is refracted through an angle θ. If the block has a refractive index, n and is of thickness, t, show that light takes a time $\frac{nt\sec\theta}{c}$ to emerge from the block where c is the speed of light in the vacuum. (03marks)



Let T be the time spent in the medium

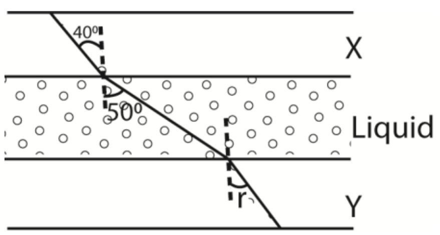
V = $\frac{MN}{T}$

But $\frac{t}{MN} = cos\theta$ => MN = tsecθ

V = $\frac{tsec\theta}{T} = \frac{c}{n}$

T = $\frac{ntsec\theta}{c}$

(b)



In the figure above, a layer of liquid is confined between two transparent plates X and Y of refractive indices1.54 and 1.44 respectively. A ray of monochromatic light making an angle of 40^0 with the normal to the interface between X and the liquid is refracted through an angle of 500 by the liquid. Find the

(i) Refractive index of the liquid (03marks)

nsini = constant

1.54sin 40^0 =nsin50^0

n = 1.29

(ii) Angle of refraction, r, in the medium, Y. (02marks)

$1.44\sin r = 1.54\sin 40^0$

$r = 43.4^0$

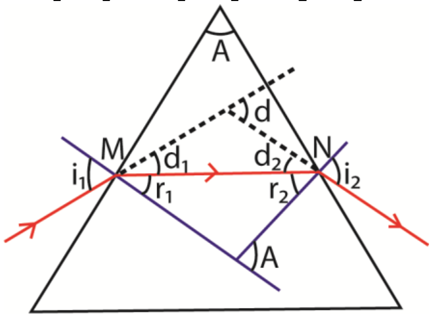
(iii) Minimum angle of incidence in medium X for which the light will not emerge in Y (04marks)

$1.54\sin i = 1.44\sin 90^0$

$i = 40.5^0$

(c) (i) A ray of monochromatic light is incident at a small angle of incidence on a small angle prism in air. Obtain the expression, d = (n-1)A for deviation of light by the prism (05marks)

The small refracting angle of this prism causes the angle $\mathbf{i_1, r_1, r_2}$ and $\mathbf{i_2}$ to be small such that $\mathbf{\sin i_1 \approx i_1, \sin r_1 \approx r_1 \sin r_2 \approx r_2}$ and $\mathbf{\sin i_2 \approx i_2}$.



From the diagram, $d = d_1 + d_2$

but $d_1 = i_1 - r_1$ and $d_2 = i_2 - r_2$

⇨ $d = (i_1 - r_1) + (i_2 - r_2)$

On simplifying $d = i_1 + i_2 - (r_1 + r_2)$

but $r_1 + r_2 = A$

$d = i_1 + i_2 - A$ ----------------------(a)

At M Snell's law becomes.

$n_a \sin i_1 = n \sin r_1$

For small angles this gives $i_1 = nr_1$ ---------------------------------(b)

Similarly at N Snell's law becomes $i_2 = nr_2$ --------------------------------(c)

Substituting equation (b) and (c) in (a) gives

$d = nr_1 + nr_2 - A$

$d = n(r_1 + r_2) - A$

but $r_1 + r_2 = A$

⇨ $d = nA - A$

$\therefore$ $\mathbf{d = (n-1)A}$

(ii) Light of two wavelengths is incident at a small angle on a thin prism of refractive angle 50 and refractive indices 1.52 and 1.50 for the two wavelength. Find the angular separation of the two wavelengths after refraction by the prism. (03marks)

$d_1 = (n_1-1)A = (1.52 - 1)5^0 = 2.60^0$

$d_2 = (n_2-1)A = (1.50 - 1)5^0 = 2.50^0$

Angular dispersion $= d_1 - d_2 = 2.60 - 2.50 = 0.10^0$

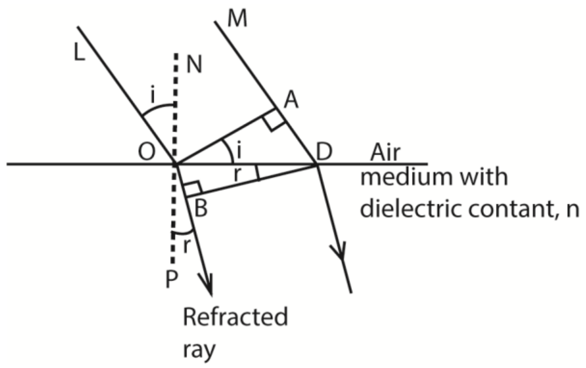
3. (a) Why is light referred to as a transverse wave? (01mark)

Light is referred as transverse waves because the vibrations of the magnetic and electric vectors are perpendicular to the direction of propagation of light wave.

(b) (i) State Huygens' Principle. (02marks)

(ii) Use Huygens' Principle to show that refractive index of medium 2 relative to medium 1 is given by

${}_1n_2 = \frac{v_1}{v_2}$ where v_1 and v_2 are the velocities of light in medium 1 and 2 respectively. (07marks)



In figure above, each point between O, D becomes a new centre of disturbance as the wave front advances to the surface of the medium, and the wave front changes in direction when the disturbance enters the medium.

Suppose that t is the time taken by the light to travel from A to D. The disturbance from O travels a distance OB, or V_2t, in the medium in a time t, where v is the velocity of light in medium.

At the end of the time t, the wave fronts in the medium from the other secondary centres between O, D reach the surfaces of spheres to each of which DB· is a tangent.

Thus DB is the new wave front in the water, and the ray OB which is normal to the wave front is consequently the refracted ray.

Since c is the velocity of light in air, AD = v_1t.

Now

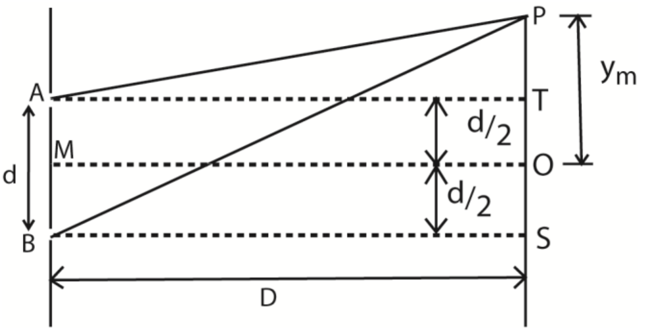
$$\frac{Sin\ i}{\sin r} = \frac{sin\ LON}{sin\ BOP} = \frac{sin\ AOB}{sin\ ODB}$$

$${}_1n_2 = \frac{Sin\ i}{\sin r} = \frac{AD}{OD} \div \frac{OB}{OD} = \frac{AD}{OD}\ x\ \frac{OD}{OB} = \frac{AD}{OB} = \frac{v_1 t}{V_2 t} = \frac{v_1}{V_2}$$

(c) (i) What is meant by division of wave fronts as applied to interference of waves (02marks)

This a process of getting two coherent waves from a single wave front

(ii) Two slits A and B are separated by a distance d and illuminated with light of wavelength, λ. Derive an expression for separation between successive fringes on a screen placed a distance D from slits, (05marks)



Suppose waves from A and B superpose at P to form a bright fringe

For triangle ATP; $AP^2 = AT^2 + TP^2$

$$= D^2 + \left(y_m - \frac{d}{2}\right)^2$$

$$= D^2 + y_m^2 - y_m d + \frac{d^2}{4} \text{ .... (i)}$$

For triangle BSP; $BP^2 = BS^2 + SP^2$

$$= D^2 + \left(y_m + \frac{d}{2}\right)^2$$

$$= D^2 + y_m^2 + y_m d + \frac{d^2}{4} \text{ .... (ii)}$$

Eqn. (ii) – eqn. (i); $BP^2 - AP^2 = 2y_m d$

$$(BP + AP)(BP - AP) = 2y_m d$$

Since $d \ll D$, $BP \approx AP \approx OM = D$

Thus, $BP + AP = 2D$

Then, $2D(BP - AP) = 2y_m d$

For bright fringe, $BP - AP = m\lambda$

$$2Dm\lambda = 2y_m d$$

$$y_m = \frac{m\lambda D}{d}$$

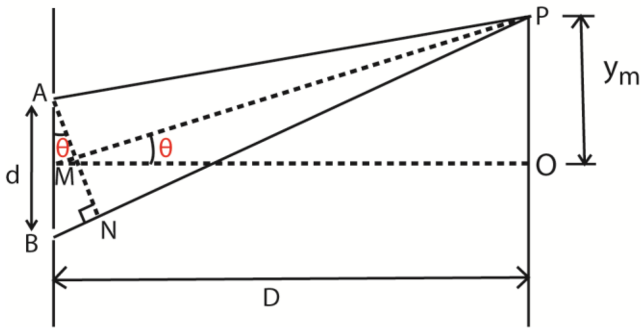
for the next bright fringe $(m+1)^{th}$

$$y_{m+1} = \frac{(m+1)\lambda D}{d}$$

$$y_{m+1} - y_m = \frac{\lambda D}{d}$$

∴ Fringe separation, $y = \frac{\lambda D}{d}$

Alternatively



A and B are coherent sources.

Suppose waves from A and B superpose at P to form bright fringe

Path difference, BN = BP – AP = dsinθ

For D>>d, θ is small that sinθ = dtanθ

⇨ BN = dtanθ = $\frac{dy_m}{D}$

For the mth bright fringe, BN = mλ, where λ is the wavelength

⇨ $\frac{dy_m}{D}$ = mλ

$$y_m = \frac{m\lambda D}{d}$$

For (m + 1)th bright fringe, $\frac{dy_{m+1}}{D}$ = (m + 1)λ

$$y_{m+1} = \frac{(m+1)\lambda D}{d}$$

Fringe separation, y = $y_{(m+1)}$ - y_m = $\frac{(m+1)\lambda D}{d} - \frac{m\lambda D}{d} = \frac{\lambda D}{d}$

(iii) In Young's double slit experiment, the 8th bright fringe is formed 5mm away from the center fringe system when the wavelength of light is 6.2 x 10^{-7}m. Calculate the separation of the two slits if the distance from slits to the screen is 80cm.

$$y_8 - y_0 = 8\frac{D\lambda}{d}$$

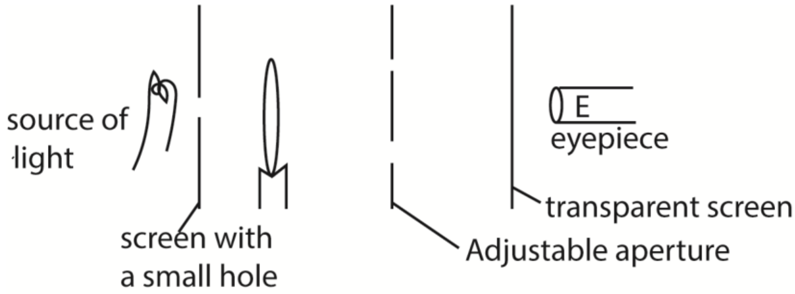
$$5 \, x \, 10^{-3} = 8\left(\frac{0.8 \, x \, 6.2 \, x \, 10^{-7}}{d}\right)$$

$$d = 8\left(\frac{0.8 \, x \, 6.2 \, x \, 10^{-7}}{5 \, x \, 10^{-3}}\right)$$ = 7.94 x 10^{-4}m

4. (a) Explain the term interference of light (04marks)

Interference of light is superposition of waves from coherent sources leading to alternate regions of maximum and minimum intensity.
If the path difference between the waves is an integral multiple of wavelength, constructive interference occurs (maximum intensity).
If the path difference between waves is an odd multiple of half the wavelength, destructive interference occurs (minimum intensity).

(b)



In the experiment to observe diffraction, the set up in figure 2 is used.

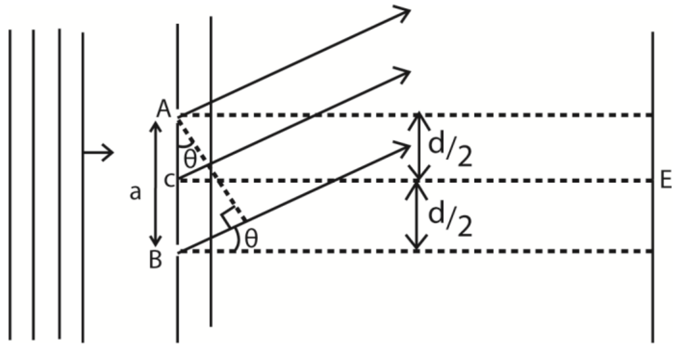
(i) Describe what you would see at E if the aperture is gradually reduced (04mark)

When the slit separation is large (a>>λ) a bright band of approximately the same width as the slit is observed

As the slit width is reduced so that a ≈ λ, a diffraction pattern is observed. A central white band having dark bands on either side is obtained. The dark bands have colored fringes running from blue to red; blue being nearest to the direct position.

As the slit width is reduced further, a<<λ, the central bright band widens and extends well into the geometrical shadows of the slit.
When the slit finally close, no light passes through.

(ii) Explain your observation in (b)(i) above.



Imagine the slit to consist of stripes of equal width parallel to the length of the slit.
Let c be the length of the slit.
The first dark band on either side of central bright band are formed at an angle θ to the incident beam.
The path difference for the secondary wavelets from the strips just below A and strip just below c is $\frac{\lambda}{2}$
Destructive interference will occur from this pair of strips since the crest from one strip reaches the observer with the trough from the other. This happens for all pairs of corresponding strips in AC and CB because the same path difference exists. The central bright band is formed at E. wavelets from all the imaginary strips in the slits arrive in phase.
For first minimum, CD= $\frac{a}{2}sin\theta = \frac{\lambda}{2}$

$$\sin\theta = \frac{\lambda}{a}$$

For white light, this condition occurs slightly different angles for component colors. This accounts for colored fringes at edges of the dark band.

(c) A diffraction grating has 550lines per mm. when illuminated normally by monochromatic light, the angle between the central maximum and the first maximum is 19.1^0. Find the

(i) wavelength of light (04marks)

$N\lambda = d\sin\theta$

$\lambda = \frac{1\ x\ 10^{-3}}{550}\ x \sin 19.1 = 5.95\ x\ 10^{-7} m$

(ii) number of diffraction maxima obtained (02marks)

$n_{max} = \frac{d}{\lambda} = \frac{\frac{1\ x\ 10^{-3}}{550}}{5.95\ x\ 10^{-7}} = 3$

(c) State two uses of diffraction of light. (02marks)

- Measurements of wavelength of light using diffraction grating
- For holography (making 3-dimensional images)

SECTION B

5. (a) Distinguish between self-induction and mutual induction. (03marks)

Self-induction is the process by which e.m.f is induced in a circuit due to changing current in the same circuit.
Mutual induction is the process by which e.m.f is induced in a circuit due change in current in the nearby circuit.

(b) (i) explain the factors which affect the efficiency of a transformer. (04marks)

- Joule heat loss in the winding. Current in the winding leads to dissipation of electrical energy as heat by I^2R mechanism.
- Eddy currents loss. When the magnetic flux linking the core of transformer changes, currents called eddy currents are induced in the core. The currents cause dissipation of electrical energy in form of heat.
- Hysteresis loss. When alternating currents flow in the primary coil, movement of magnetic domains in the core leads to dissipation of energy known as hysteresis loss.
- Loss of magnetic flux. Not all the magnetic flux linking the primary links the secondary which results in energy loss.

(ii) Power of 6000W is produced at 100V is to be transmitted over a distance of 2km through cables of resistance 0.2Ω. Determine the voltage at the output of transformer needed to transmit the power so that only 5% of it is lost.
(assume the transformer is 100% efficient) (05 marks)

Solution

Power = I^2R

= I2 x 0.2 x 2000

$= 400I^2$

Hence $\frac{400I^2}{6000} = \frac{5}{100}$

$\Rightarrow I^2 = \frac{60}{4} x \frac{5}{100} = 0.75$

$I = 0.866A$

Current in secondary of the transformer is 0.866A

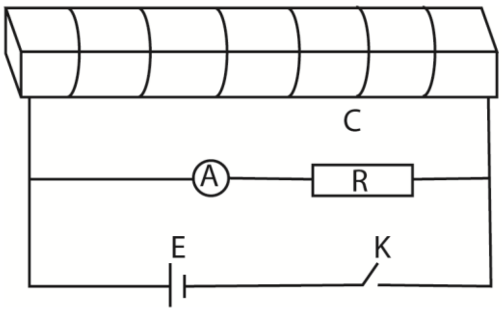
Assuming 100% efficient

$V_PI_P = V_SI_S$

$6000 = V_S (0.866)$

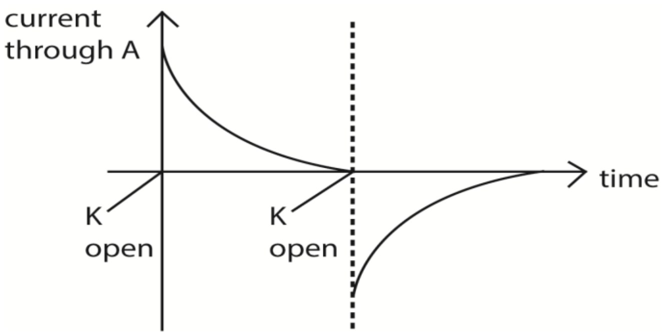
$V_S = 6930V$

(c)



In the diagram above, C is a coil of large number of turns connected in series with a center zero meter, A and a resistor R across cell E. The switch K is closed for some time and then opened.

(i) Sketch a graph to show the variation of current with time observed on the ammeter from the moment K was first closed. (01mark)



(ii) Explain the variation of current observed in in (c)(i) (05marks)

When the switch is first closed, growth of current in the coil causes varying magnetic flux and hence an induced e.m.f in the coil.

The direction of the induced e.m.f is such as to oppose the applied e.m.f. initially most of the current flows through the ammeter because the back e.m.f is very high.

As current in the coil increases, its rate of change decreases and the induced e.m.f decrease to zero and nearly all current flows through the coil. The current through the ammeter tends to zero.

When K is opened, the collapsing magnet field in the coil leads to an induced e.m.f in the coil which tends to maintain current in the coil. Current flows through the ammeter in opposite direction and in the coil current decays to zero as the magnetic field in the coil decays to zero.

(iii) Describe the effect of placing a bunch of soft iron wire inside the coil, on the observations in (c)(i) and (c)(ii) (02marks)

- The initial current flows in the ammeter at closing and opening the switch higher
- The time taken for the current through the ammeter to decay to zero is longer.

6. (a) (i) Write down the expression for the force on a charge q coulombs moving with velocity V at an angle, θ, to a uniform magnetic field of flux density, B.

F = qBVsinθ

(ii) Use the expression in (a)(i) above to deduce the force on a conductor carrying a current in magnetic field. (03marks)

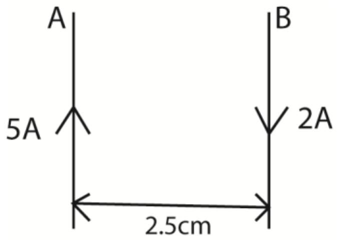
Suppose N electrons pass through the wire of length L in time t.

Force on the electrons = (Ne)B.$(\frac{L}{t})$sinθ

But $\frac{Ne}{t} = I$

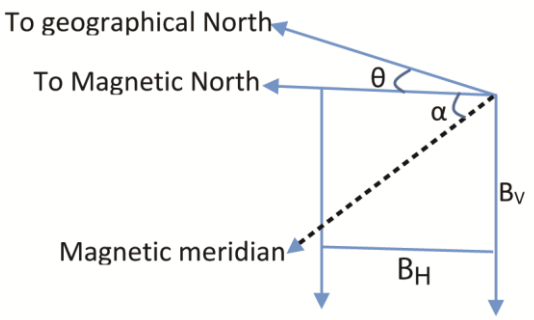
Force on the electrons and communicated to the wire= IBLsinθ

(iii) Two thin, long parallel wires A and B carry current of 5A and 2A respectively in opposite directions, if the wires are separated by a distance of 2.5cm in vacuum, calculate the force exerted by wire B on 1m of wire A (03 marks)



From F = $\frac{\mu_0 I_a I_b}{2\pi a} = \frac{4\pi \; x \; 10^{-7} \; x \; 5 \; x \; 2}{2\pi \; x \; 2.5 \; x \; 10^{-2}}$ = 8.0 x $10^{-5}Nm^{-1}$

(b) With the aid of a diagram, explain the terms angle of dip and magnetic meridian, as applied to earth's magnetic field. (04marks)



α = angle of dip

θ = angle of declination

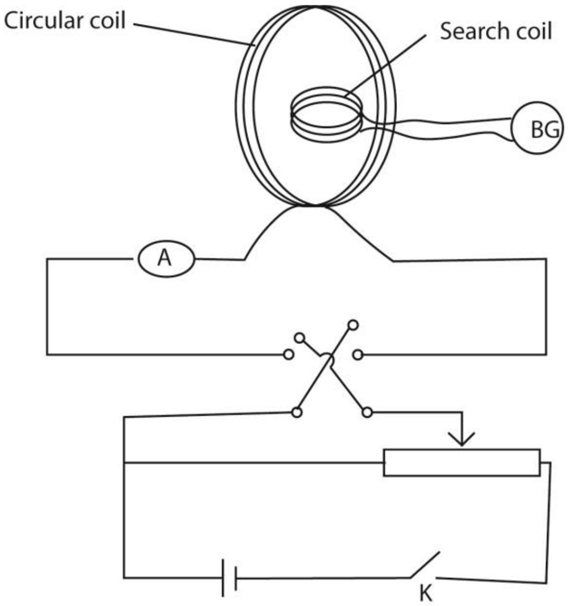
B_H = horizontal component of the earth's magnetic field

B_V = vertical component of magnetic field

Angle of dip (inclination) α: Angle of dip is the angle that the axis of a freely suspended bar magnet makes with the horizontal when the magnet settles

Magnetic meridian: This is the vertical plane containing the magnetic axis

(c)(i) Describe, using an appropriate circuit diagram, an expression to investigate the dependence of magnetic flux density at the center of circular coil on the current through the coil. (07mark)



The circuit is set up as above

The search coil is placed in the center of the coil such that their planes coincide.

Current in the circular coil is adjusted using a potential divider. K is closed. Current is reversed in the circular coil. The deflection θ of the BG is noted.

The procedure is repeated for several currents in the circular coil and corresponding angles θ of deflection in BG are noted.

A graph of θ against I is plotted and straight line graph through the origin is obtained.

Since θ is proportional to B, then B is proportional to I (current)

(ii) State two other factors on which the magnetic flus density in (c)(i) depends. (02marks)

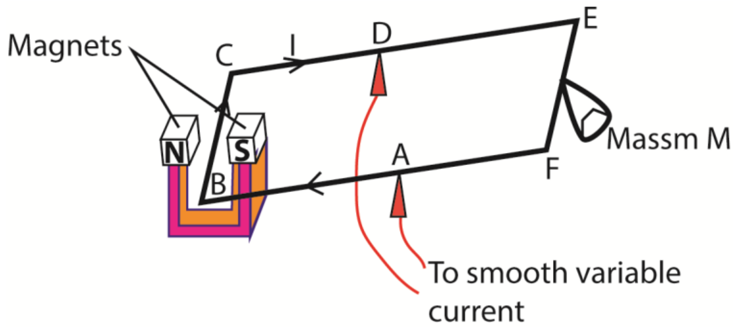
- Radius of the coil
- Number of turns of the coil

7. (a)(i) Define magnetic flux. (01mark)

Magnetic flux is thus, a product of magnitude of magnetic flux density and area of projection normal to magnetic field lines

(ii) Describe an experiment to investigate the relationship between the force on a current conductor situated in a uniform magnetic field and the current, using the ampere/current balance. (06marks)

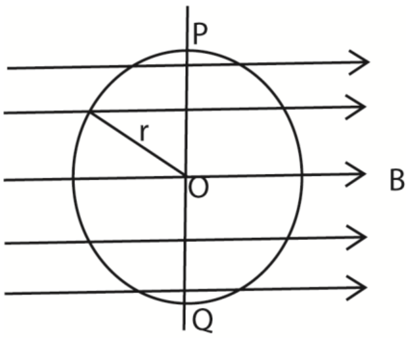
Solution



The apparatus setup is as above, AB = AF, length BC = L

- The Coil BCEF is adjusted to balance in a horizontal position
- Mass M is placed on the scale pan and the current required to restore the balance is determined.
- The mass is varied and corresponding currents to maintain the balance are determined.
- A plot of the graph of I against M gives a straight line showing that force on BC is proportional to current.

(b)



A circular loop of wire of radius, r, is placed in a uniform magnetic field of flux density, B, with the axis to the field as shown above. Explain what happens to the loop when current starts to flow in it a clockwise direction if the loop is pivoted about the axis POQ. (04marks)

Solution

The right hand side experiences an outward force. The left hand side experiences an equal but inward force.

The two forces constitute a couple which causes the coil to turn about PQ in an anticlockwise direction.

(c) A vertical square coil of the side 5cm has 100 turns and carries a current of 1A. Calculate the torque on the coil when it is placed in a horizontal magnetic field of flux density 0.2T with its plane making an angle of 30^0 to the field. (03marks)

$\tau = BANIcos30^0$

$= 0.2 \times (5 \times 5 \times 10^{-4}) \times 100 \times 1 \times cos30^0$

$= 4.33 \times 10^{-2}Nm$

(d) Explain why a moving coil galvanometer should have a radial magnetic field, fine springs and many turns. (06marks)

Radial magnetic field ensures that the Force, F, remains normal to the plane of the coil when it turns through an angle i.e.

Torque on the coil $\tau = BANIsin\alpha$, where α is the angle between the normal to the coil and magnetic field this is balanced by restoring torque = $k\theta$ due to current, where θ is the angle turned through

Thus, current sensitivity given by $\frac{\theta}{I} = \frac{BANIsin\alpha}{k}$

For a linear scale, sin α = 1 => radial field

For current sensitivity, k must be small; i.e. the springs must be fine

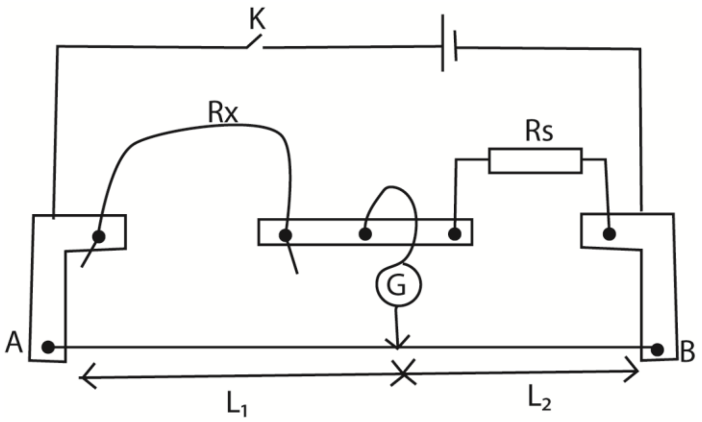
For current sensitivity, N, must be large

SECTION C

8. (a) State ohm's law (01mark)

Ohm's law states that the current flowing through a given conductor is directly proportional to the potential different difference between its ends provided the physical conditions remain constant.

(b) Describe with the aid a circuit diagram, an experiment to determine the relationship between the resistance and the length of the wire. (06marks)



A length Lx of the wire under test is connected in the left hand gap of the Meter Bridge and standard of resistance Rs in the right hand gap as shown above. Switch K is closed and the jockey tapped at different points along the uniform wire AB until a point is found where the galvanometer shows no deflection. Distance L_1 and L_2 are measured and recorded.

The procedure is repeated for different length of Lx and the results tabulated including the values of Rx = $\frac{L_1}{L_2} Rs$

A graph of Rx against Rx against Lx is plotted and a straight line is obtained showing that resistance is proportional to length.

(c) A dry cell gives a balance length of 84.8cm on a potentiometer wire. When a resistor of resistance 15Ω is connected across the terminals of the cell, a balance length of 75.0cm is obtained. Find the internal resistance of the cell. (04marks)

$$\frac{E_x}{V} = \frac{L_S}{L}$$

$$\frac{E_x}{V} = \frac{I(R+r)}{IR} = \frac{R+r}{R} = 1 + \frac{r}{R}$$

$$1 + \frac{r}{R} = \frac{L_S}{L}$$

$$r = R\left(\frac{L_S}{L} - 1\right) = 15\left(\frac{84.8}{75} - 1\right)$$

$$= 1.96\Omega$$

(d) A battery of e.m.f 18.0V and internal resistance 3.0Ω is connected a resistor of resistance 8Ω. Calculate the:

(i) Power generated (02marks)

$$P_{generated} = EI = E\left(\frac{E}{R+r}\right) = \frac{E^2}{R+r}$$

$$= \frac{18 \, x \, 18}{8+3}$$

$$= 29.45W$$

(ii) efficiency. (02marks)

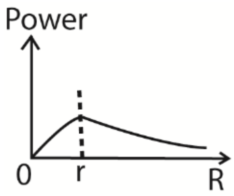
$$\eta = \frac{P_{out}}{P_{in}} = \frac{IV}{IE} = \frac{V}{E}$$

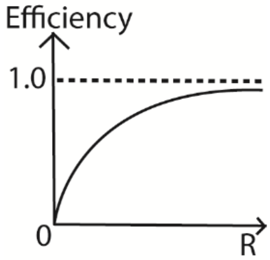
$$= \frac{IR}{I(R+r)} = \frac{R}{R+r}$$

$$= \frac{8}{8+3}$$

$$= 0.727 \text{ or } 72.7\%$$

(e) If the 8Ω resistor in (d) is replaced by a variable resistor, sketch graphs to show the variation of power and efficiency with the load. (03marks)





(a) Explain why a metal wire gets hot when current is passed through it. (02marks)

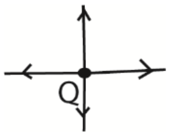
When a p.d is applied across a wire, the conduction electron gain kinetic energy from the applied field. As the electrons drift along the wire, in a direction opposite to the applied field, they collide with the ions and lose their kinetic energy to the ions.

The ions vibrate with larger amplitude as a result. This increases the temperature of the wire.

9. (a) Define electric potential. (01mark)

Electric potential is the work done n moving a positive charge of 1C from infinity to a point in electric field.

(b) Obtain an expression for the electric potential at a point a distance, r, from a point charge, Q, situated in a vacuum. (04marks)



δw = fδr

Electric force on a positive charge of 1C at a distance r from Q= $\frac{Q}{4\pi\varepsilon r^2}$

Work done to displace the positive charge through a distance δr towards Q = δw

δw =$\frac{-Q}{4\pi\varepsilon_0 r^2}\delta r$

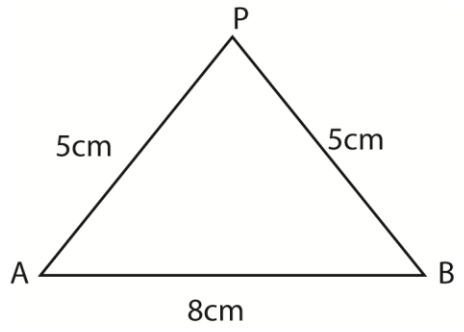
work done to move a positive charge of 1C from infinity to a point a distance r from Q

w = $\int_{\infty}^{r}\frac{-Q}{4\pi\varepsilon_0 r^2}\delta r$

=$\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{r}\right]_{\infty}^{r}$

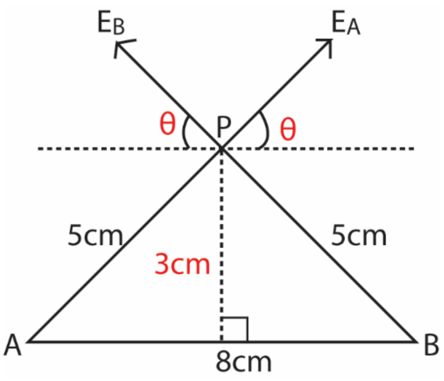
= $\frac{Q}{4\pi\varepsilon r}$

(c)



Two point charges A and B of charges +0.10μC and +0.05μC are separated by a distance of 8.0cm along the horizontal as shown in the figure above. Find the electric potential at P. (09marks)

Solution



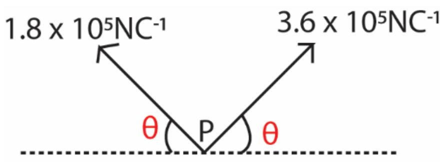
$\sin\theta^0 = \frac{3}{5} = 0.6;\ \cos\theta^0 = \frac{4}{5} = 0.8$

E at P due to charge at A

$E_{Q_1} = \frac{9\,x10^9\ x\ 0.1\ x\ 10^{-6}}{(5\ x\ 10^{-2})^2} = 3.6 \text{ x } 10^5 NC^{-1}$

E at A due to charge at B

$E_{Q_2} = \frac{9\,x10^9\ x\ 0.05\ x\ 10^{-6}}{(5\ x\ 10^{-2})^2} = 1.8 \text{ x } 10^5 NC^{-1}$



Resolving vertically

$E_y = 3.6 \text{ x } 10^5 \sin\theta + 1.8 \text{ x } 10^5 \sin\theta$

$= 5.4 \text{ x } 10^5 \sin\theta$

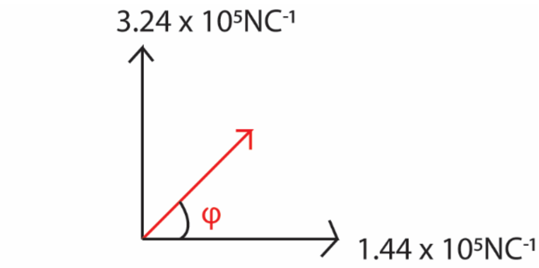
$= 5.4 \text{ x } 0.6 = 3.24 \text{ x } 10^5\ NC^{-1}$

Resolving horizontally

$E_x = 3.6 \text{ x } 10^5 \cos\theta - 1.8 \text{ x } 10^5 \cos\theta$

$= 1.8 \times 10^5 \times 0.8$

$= 1.44 \times 10^5\ NC^{-1}$



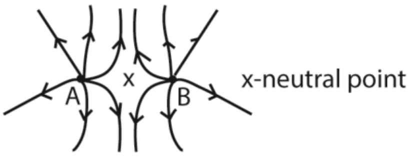
$R^2 = (1.44 \times 10^5)^2 + (3.24 \times 10^5)^2$

$R = 3.55 \times 10^5\ NC^{-1}$

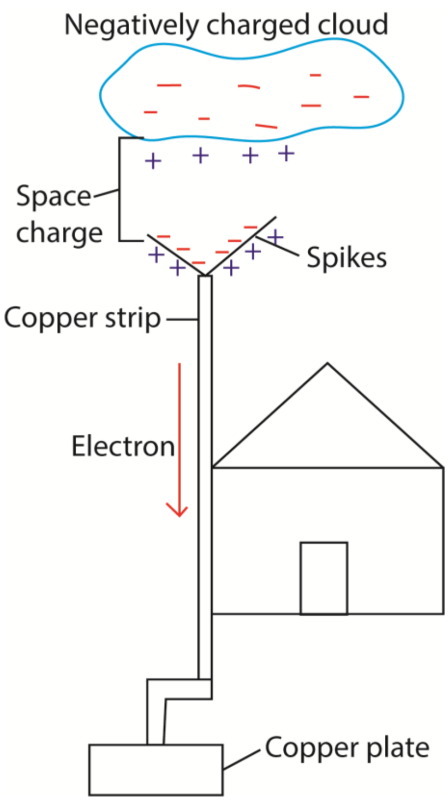
$\tan\theta = \frac{3.24 \, x \, 10^6}{1.44 \, x \, 10^6}$

$\theta = 66^0$

(d) Sketch the electric field pattern due to the charge distribution in (c). (02marks)



(e) Explain how a lightning conductor works. (04marks)



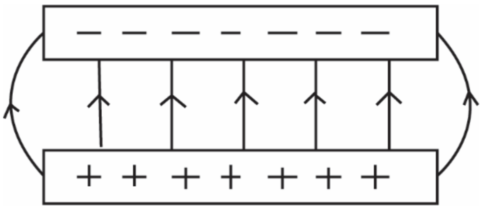
Action

(i) When a negatively charged cloud passes over lightning conductor, it induces positive charges on the spikes by repelling electrons to the grounds through copper conductor.

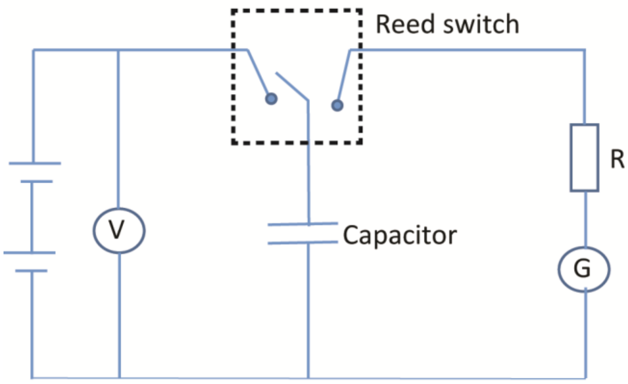
(ii) A high electric field concentration of positive ions on the spikes ionizes air around it causing positively charged ions and negatively ions.

(iii) The negatively charged ions are attracted and discharged at the spikes while the positively charged ions are repelled to form a space charges which neutralizes the negative charge on the cloud. In this way the harmful effect of the cloud is reduced.

10. (a) Sketch the electric field lines between two large parallel metal plates across which a p.d is applied. (01mark)

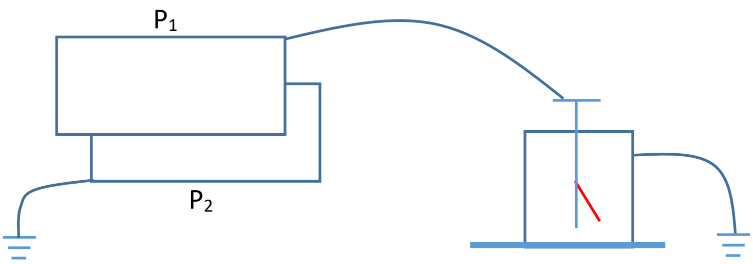


(b) (i) Describe, with aid of a diagram, how you would investigate the factors which affect the capacitance of a parallel plate capacitor. (07marks)



- The capacitor is alternatively charged through a sensitive light beam galvanometer G by the reed switch.
- Keeping the separation and the plate area constant, the capacitor is given charge Q for different p.ds, V. it is found that $Q \propto V$
- Keeping the p.d V and plate area constant, the deflection θ is measured for different separation, d. Results show that charge is proportional to deflection. $C \propto 1/d$
- Keeping the p.d V and the separation constant, the deflection θ is measured for different overlapping plate area A. The results show that $C \propto A$
- Keeping the area, separation of the plates, and p.d constant; the charge is measured with a dielectric constant. The results show that the charge increases, implying that C also increases. Thus **$C \propto \varepsilon$.**

Alternative experiments



P_1 and P_2 are capacitor plates initially with air between then. P_2 is earthed while P_1 is charged and connected to the cap of electroscope. Note that for this arrangement, the charges remain constant while the p.d between the plates varies.

(a) To show that C ∝ A

Plate P_2 is displaced sideways relative to P_1 to reduce the effective area A of the plates. The divergence of the leaf increase. This shows that the p.d. between the plates has increased since divergence is proportional to p.d between the plates. From C = Q/V, since Q is constant, c decreases. Thus **C ∝ A.**

(a) To show that C ∝ 1/d

Plate P_2 is restored to its initial position, and it is then moved closer to P_1. The divergence of the leaf is seen to decrease. This shows the p.d between the plates has decreased. From C = Q/V, this show that C has increased. Thus C increases as d decreases. Thus **C ∝ 1/d**

(b) To show that C ∝ε

The position of P2 is again restored and dielectric (an insulator) like paper is inserted between the plates. The divergence of the leaf decreases. This shows that V has decreased. From C = Q/V, C has increased. Thus **C ∝ε.**

(ii) Calculate the capacitance of parallel capacitor whose plates are 10cm by 10cm separated by an air gap of 5mmm. (02marks)

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.85 \ x\ 10^{-12} \ x\ 0.1\ x\ 0.1}{5\ x\ 10^{-3}} = 1.77\ x\ 10^{-11} F$$

(c) A hollow spherical conductor of diameter 21.4cm carrying a charge of 6.9 x 10^{-10}C is raised to a potential of 50V. Find the permittivity of surrounding medium.

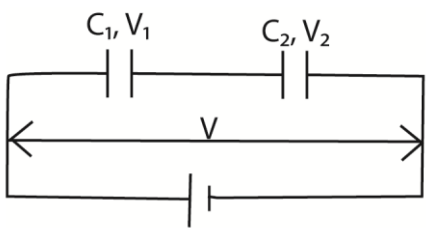
$$V = \frac{Q}{4\pi\varepsilon R}$$

$$\varepsilon = \frac{Q}{4\pi RV} = \frac{6.9\ x\ 10^{-10}}{4\pi\ x\ 0.107\ x\ 10} = 1.026\ x\ 10^{-11} Fm^{-1}$$

(d) (i) show that the effective capacitance, C, of two capacitances, C_1 and C_2, connected in series is given by

$$C = \frac{C_1 C_2}{C_1 + C_2}$$ (04marks)

Solution



If the charge on each capacitor is Q, then the total p.d across the network,

$V = V_1 + V_2$

$= \frac{Q}{C_1} + \frac{Q}{C_2}$

$= Q\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$

$= Q\frac{C_2 + C_1}{C_1 C_2}$

$Q = \frac{C_1 C_2}{C_1 + C_2}V$

But effective capacitance, $C = \frac{Q}{V}$

$\therefore C = \frac{C_1 C_2}{C_1 + C_2}$

(ii) A 20µF capacitor is charged to 40V and then connected across uncharged 60µF capacitor. Calculate the potential difference across the 60µF capacitor.
Charge on the capacitor before connection = charge on a capacitor after connection
$20 \times 10^{-6} \times 40 = (20 \times 10^{-6} + 60 \times 10^{-6})V$

$V = 10.0V$

END