

Current electricity and capacitor revision questions

1. (a) Define the following

(i) Temperature coefficient of resistance. (01mark)

Temperature coefficient of resistance is fractional change in resistance at 0°C per Kelvin rise in temperature.

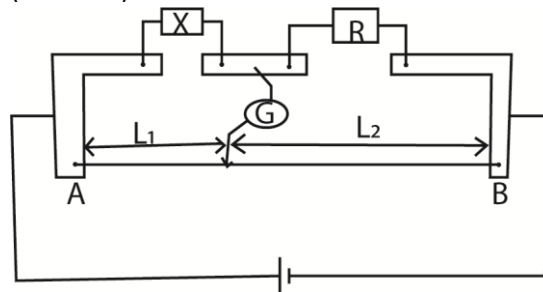
(ii) Electrical resistivity (01mark)

Resistivity is the resistance of a material of length 1m and cross sectional area of 1m^2 .

Or

Resistivity is the resistance across opposite faces of a cube of material of length 1m.

(b)(i) Describe an experiment to measure an unknown resistance using a meter bridge (05marks)



Unknown resistance X is connected in left hand gap of the bridge and standard resistance R is connected in right hand gap of the bridge as shown above. A balancing point is determined where the galvanometer G shows no deflection. The experiment is repeated with several values of R. The results are tabulated including values of $\frac{L_2}{L_1}$. A graph of R against $\frac{L_2}{L_1}$ is plotted. The resistance of unknown resistor X = slope of the graph S.

(iii) Explain why the balance point of a meter bridge should be close to the middle of the slide wire. (03marks)

When the balance point is near the middle, the ratio of the resistances in the two arms of the bridge remains closer to 1, leading to more consistent and proportional results. In

such a situation, the errors that occur in the measured value of the resistance would comparatively be smaller.

- (c) A piece of wire of length 200cm and cross-sectional area 0.001cm^2 has a resistivity of $4.4 \times 10^{-7}\Omega\text{m}$. The ends of the wire are joined together to form a loop. Terminals T_1 and T_2 are fixed across the diameter of the loop and connected to two cells in parallel, each of e.m.f 1.5V and internal resistance 1Ω as shown in figure 4

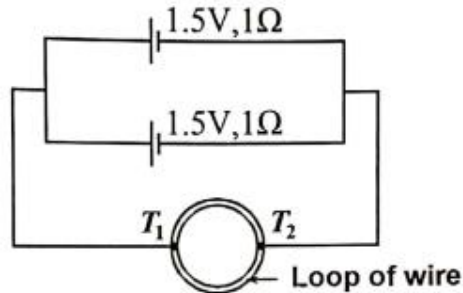


Fig. 4

Find the total current that flows in the circuit. (06 marks)

$$R = \frac{\rho l}{A} = \frac{4.4 \times 10^{-7} \times 200 \times 10^{-2}}{0.001 \times 10^{-4}} = 8.8\Omega$$

$$R_1 = R_2 = \frac{R}{2} = \frac{8.8}{2} = 4.4\Omega$$

$$\text{Total resistance in the circuit, } R_T = \frac{4.4 \times 4.4}{4.4 + 4.4} + \frac{1 \times 1}{1 + 1} = 2.2 + 0.5\Omega = 2.7\Omega$$

$$I = \frac{\text{e.m.f}}{R_T} = \frac{1.5}{2.7} = 0.556A$$

- (d) Show that a given source of e.m.f delivers maximum power for a load when the resistance of the load is equal to internal resistance of the source. (04 marks)

$$P = I^2 R$$

$$\text{But } I = \frac{E}{R+r}$$

$$P = \left(\frac{E}{R+r}\right)^2 \cdot R = \frac{E^2 R}{(R+r)^2}$$

$$\frac{dP}{dR} = \frac{E^2[(R+r)^2 - 2R(R+r)]}{(R+r)^3} = \frac{E^2(r-R)}{(R+r)^2}$$

$$\text{For maximum power, } \frac{dP}{dR} = 0 \text{ or } r - R = 0$$

$$\text{Thus } r = R$$

2. (a) Define the following:
(i) Dielectric constant (01mark)

Dielectric constant is the ratio of the capacitance of a capacitor with a dielectric material to capacitance of the same capacitor without dielectric material

Or

Dielectric constant is the ratio of permittivity of dielectric to permittivity of free space

- (ii) Dielectric strength (01 mark)

Dielectric strength is the maximum electric field intensity or potential gradient that a material can withstand without breaking down and losing its insulating properties.

(b) Explain using molecular theory, the effect of a dielectric material on the capacitance of a capacitor. (05 marks)

- when a dielectric is placed between the plates of a charged capacitor, its molecules get polarised.
- The charges inside the dielectric cancel each other and the surface of the dielectric acquires charges opposite to the charge of the plate near the surface.
- since these are bound charges then they cannot be neutralized
- an electric field intensity is developed between the surfaces of a dielectric in the direction opposite to that of the applied field.
- The resultant electric field intensity reduces i.e. from $E = \frac{V}{d}$; p.d, V reduces.

Also from $C = \frac{Q}{V}$; capacitance of capacitor increases.

(c) A capacitor of $50\mu\text{F}$ is charged fully to a p.d of 45V. The capacitor is disconnected and a dielectric material of dielectric constant 2 is inserted between its plates. If it is then connected across an uncharged capacitor of $60\mu\text{F}$, determine the;

(i) p.d across the combination (04marks)

$$\text{Charge stored, } Q = CV = 50 \times 10^{-6} \times 45 = 2.25 \times 10^{-3} \text{C}$$

$$\text{After inserting the dielectric, capacitance } C' = 2 \times 50 \mu\text{F} = 100 \mu\text{F}$$

$$\text{Total capacitance, } C_T = (100 + 60) \mu\text{F} = 160 \mu\text{F}$$

$$V = \frac{Q}{C_T} = \frac{2.25 \times 10^{-3}}{160 \times 10^{-6}} = 14.1 \text{V}$$

Or

$$V = \frac{C_0 V_0}{C_1 + C_2} = \frac{50 \times 10^{-6} \times 45}{100 + 60} = 14.1 \text{V}$$

Or

$$Q = C_1 V_1 = (C_1 + C_2) V_f$$

$$V_f = \frac{C_1 V_1}{C_1 + C_2} = \frac{50 \times 10^{-6} \times 45}{100 + 60} = 14.1 \text{V}$$

(ii) change in energy initially stored and in both capacitors. (04marks)

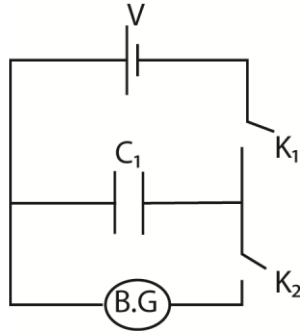
$$E_1 = \frac{1}{2} CV^2 = \frac{1}{2} \times 50 \times 10^{-6} \times 45^2 = 0.0506 \text{J}$$

Energy stored in combination

$$E_2 = \frac{1}{2} \times 160 \times 10^{-6} \times 14.1^2 = 0.0159 \text{J}$$

$$\text{Change in energy} = 0.0506 - 0.0159 = 0.0347 \text{J}$$

(d)(i) Describe how a ballistic galvanometer can be used to compare the capacitance of two capacitors. (04marks)



- The circuit is connected as shown with a capacitor of known capacitance C_1 .
- Switch K_1 is closed and K_2 is opened. The capacitor of capacitance C_1 is charged by the battery of e.m.f V .
- K_1 is opened and K_2 is closed to discharge the capacitor through the ballistic galvanometer, B.G. the first deflection of the B.G θ_1 is noted
- The capacitor is then replaced with the capacitor of unknown capacitance C_2 . the experiment is repeated and deflection θ_2 is noted
- Hence $\frac{c_2}{c_1} = \frac{\theta_2}{\theta_1}; c_2 = c_1 \frac{\theta_2}{\theta_1}$

(ii) State any two functions of a dielectric material in a capacitor. (01 mark)

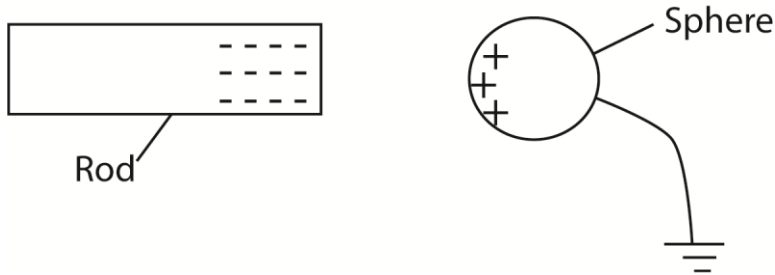
- **Increases Capacitance:** By introducing a dielectric material, the capacitor's ability to store charge increases. This is due to the dielectric constant (relative permittivity) of the material, which reduces the effective electric field and allows more charge to accumulate for a given voltage.
- **Prevents Short Circuiting:** The dielectric acts as an insulating layer between the capacitor's plates, preventing direct contact and ensuring that charge is stored safely without current flowing directly across the plates.
- **Enhances Energy Storage:** A dielectric material allows a capacitor to store more energy by enabling a higher charge storage for the same physical size. This makes capacitors more compact and efficient.
- **Reduces Electric Field Strength:** Through dielectric polarization, the internal electric field opposes the applied field, effectively reducing the net electric field. This helps maintain the capacitor's functionality under high voltage.
- **Enables High Voltage Operation:** Certain dielectric materials have high dielectric strength, allowing capacitors to operate at higher voltages without breakdown.

1. (a) State Coulomb's law of electrostatics (01marks)

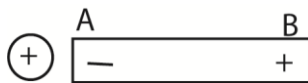
Coulomb's law states that the force between two point charges is directly proportional to the product of the magnitude of the charges and inversely proportional to the square of the distance between the charges.

(b) (i) Describe how a conductor may be positively charge but remains at zero potential(03marks)

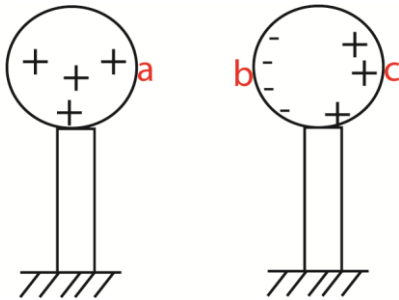
A negatively charged rod is brought near a neutral sphere. Distribution of charges occurs. The sphere is then earthed in the presence of the rod. Electrons flow to the earth. The sphere is positively charged and at zero potential. When the rod is removed the sphere remains positively charged.



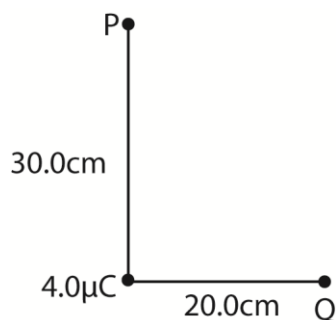
(ii) Explain how the presence of a neutral conductor near a charged conducting sphere may reduce the potential of the sphere.



When a positively charged insulated sphere A is placed close to a neutral insulated sphere B, negative charges are attracted to the side close to A while positive charges are repelled to the far end. Potential at a; $V = V_a + V_b + V_c$. Since V_b and V_c are of opposite sign and c is further from A, the negative charges at b effectively reduce the potential at a.



(c) In the figure below, points P and Q are at distances 30.0cm and 20.0cm from a point charge of $4.0\mu\text{C}$ respectively.



Calculate

(i) Electric potential difference between P and Q (05marks)

Electric potential at P

$$V_p = \frac{KQ_p}{r_p} = \frac{(9 \times 10^9)(4 \times 10^{-6})}{30 \times 10^{-2}} = 120,000V$$

$$V_p = \frac{KQ_Q}{r_Q} = \frac{(9 \times 10^9)(4 \times 10^{-6})}{20 \times 10^{-2}} = 180,000V$$

Potential difference between P and Q

$$V_{PQ} = 180000 - 120000 = 60000V$$

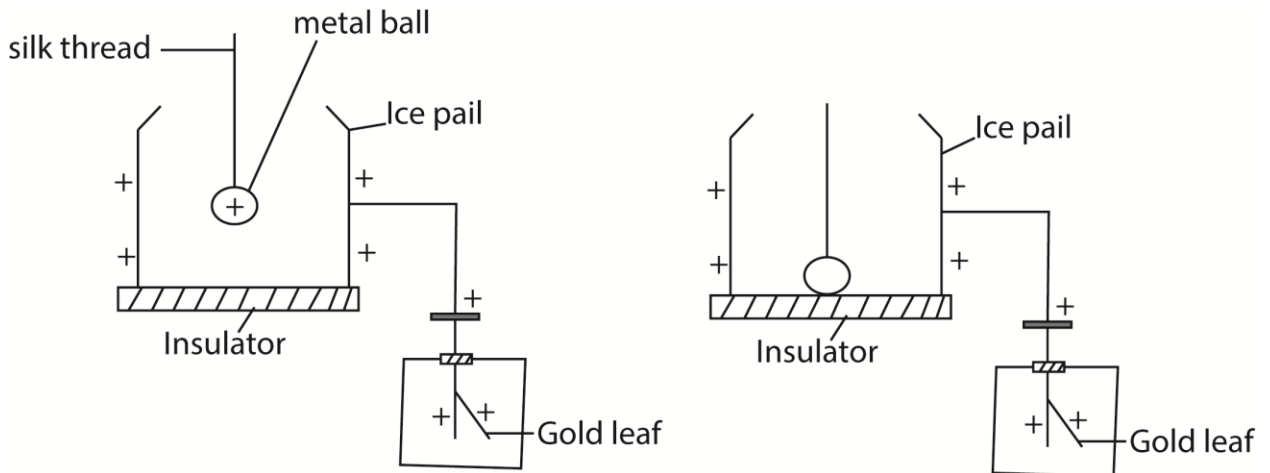
(ii) Energy required to bring a charge of $+1.0\mu\text{C}$ from infinity to Q. (03marks)

Energy, $E = QV$

$$= 1 \times 10^{-6} \times 180000 = 0.18J$$

(d) Describe with the aid of a diagram an experiment to show that excess charge resides only on outside of hollow conductor.

Experiment to show that excess charge resides only on the outside of a hollow conductor.



- Ice pail is placed on an insulator and connected to a gold leaf electroscope
- A positively charged metal ball held on a long silk thread is lowered into the pail without touching the sides nor the bottom.
- Positive charges are induced on the outside of the pail and gold leaf diverges. The divergence does not change when the ball is moved about as long as it does not touch the pail.
- When the metal ball is allowed to touch the bottom, the divergence remains unchanged although it loses the charge.
- This shows that the charge induced inside the ice pail (hollow conductor) is of equal magnitude and opposite to the charge on the metal ball. Thus the total charge inside the hollow conductor is zero.
- Hence excess charge resides only on the outside of a hollow conductor.

2. (a)(i) Define e.m.f of a battery. (01marks)

E.m.f of a battery is energy supplied by the battery

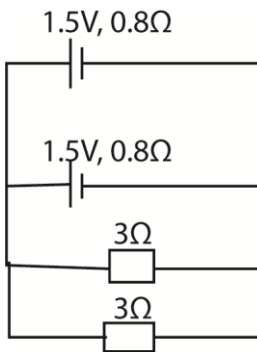
Or

It is the p.d across the terminals of the battery on an open circuit.

(ii) Explain why e.m.f of a battery left standing in a room for long decreases. (02marks)

Moisture in the room contains ions which allow electric conduction between the terminals of the battery and therefore the e.m.f of the battery reduces.

(b) The figure below shows a network resistors connected to show identical cells of e.m.f 1.5V and internal resistance 0.8Ω.



Calculate the current supplied by the cells (04marks)

From $E = I(R+r)$

The effective e.m.f of cells in parallel = e.m.f of one cell = 1.5V

Effective internal resistance, $r = \frac{0.8}{2} = 0.4\Omega$

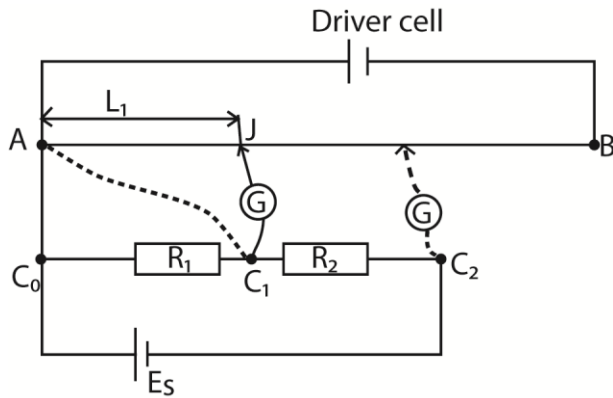
$$1.5 = I\left(\frac{3 \times 3}{3+3} + 0.4\right)$$

$$I = 0.789A$$

The current flowing is 0.789A

(c) Describe an experiment which can be carried out to determine the resistance of a wire using a potentiometer. (06marks)

An experiment to determine resistance of a wire using a potentiometer



R_1 = known resistor

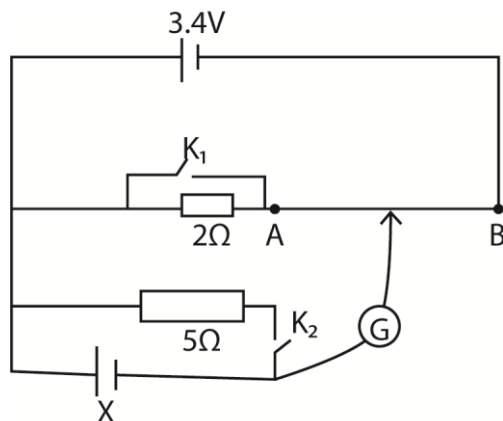
R_2 = wire of unknown resistance

AB – Uniform resistance slide wire

E_s – standard cell

- The balance length L_1 from A is recorded
- A is disconnected from C_0 and galvanometer is disconnected from C_1
- A is connected to C_1 and galvanometer to C_2
- The balance length L_2 from A is recorded.
- The resistance $R_2 = \frac{L_2}{L_1} \times R_1$

(d) The figure below shows a uniform resistance wire AB, 100cm long and resistance 4.0Ω connected with a 2.0Ω resistor through switch K_2 . When K_1 is closed and K_2 open, the balance length is 53cm.



Find the

- (i) Balance length when K_1 and K_2 are both open (04marks)

$$L_{AB} = 100\text{cm}, R_{AB} = 4\Omega, E_d = 3.4\text{V}, r = 0\Omega, L_{AJ} = 53\text{cm}$$

Considering upper circuit

$$E_d = I_d (R + r)$$

$$3.4 = I_d(4 + 2 + 0)$$

$$I_d = \frac{3.4}{6} A$$

e.m.f of cell X = p.d across the balance length

$$E_x = kL \text{ where } k \text{ is p.d per centimeter of AB}$$

$$= \frac{3.4}{100} \times 53 = 1.802V$$

At balance

e.m.f of cell X = p.d across 2Ω + p.d across balance length

$$1.802 = I_d \times 2 + I_d \times \frac{4}{100} \times L$$

$$1.802 = \frac{3.4}{6} \times 2 + \frac{3.4}{6} \times \frac{4}{100} \times L$$

$$L = 29.4\text{cm}$$

- (ii) Internal resistance of cell X if the balance length is 44.1cm when both K_1 and K_2 are closed (01marks)

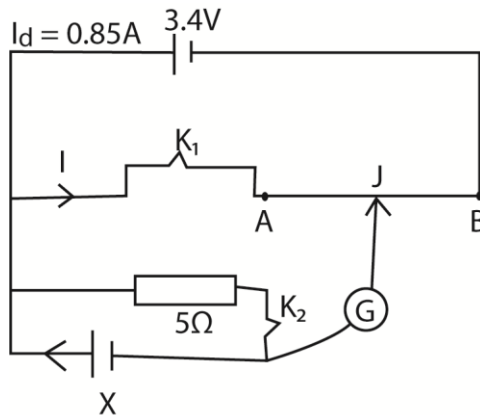
$$L_{AJ} = 44.1\text{cm}$$

Using upper circuit

$$E_d = I_d(R+r)$$

$$3.4 = I_d(4 + 0)$$

$$I_d = 0.85$$



At balance point

p.d across 5Ω = p.d across balance length AJ

$$I \times 5 = I_d k L_{AJ}$$

$$5I = 0.85 \times \frac{4}{100} \times 44.1$$

$$I = 0.3A$$

Using lower circuit

$$E_x = I(R + r)$$

$$1.802 = 0.3(5 + r)$$

$$r = 1.0\Omega$$

the internal resistance of a cell = 1.0Ω

or

$$r = R_S \left(\frac{L_1}{L} - 1 \right) = 5 \left(\frac{53}{44.1} - 1 \right) = 1.0\Omega$$

3. (a)(i) Define farad. (01mark)

A faraday is the capacitance of a capacitor when a charge stored is 1C and potential difference is 1V.

(ii) Describe briefly the energy transformations that take place when charging a capacitor using a dry cell. (02marks)

Chemical energy in the cell → electrical energy → electrostatic potential energy when the charge is being stored on the capacitor plates + heat

(b)(i) What is meant by dielectric constant? (02marks)

Dielectric constant is the ratio of capacitance of a capacitor with a medium between its plates to the capacitance of the same capacitor with a vacuum between its plates.

Or

Dielectric constant is the ratio of permittivity of a medium to permittivity of space.

(ii) A parallel plane capacitor is connected to 100V and then isolated. When a sheet of a dielectric is inserted between the plates, the p.d. decreased to 30V. Calculate the dielectric constant of the dielectric. (03marks)

Let the capacitance of a capacitor be C

Charge stored, $Q = CV$

$$= C \times 100 = 100C$$

When a material is inserted between the plates of the capacitor

$$Q = C'V'$$

$$= E_r C_x 30$$

By conservation of charge

$$100C = E_r C_x 30$$

$$E_r = \frac{100}{30} = 3.33$$

(c) A 60 μF is charged from a 120V supply. It is then connected across the terminals of a 20 μF capacitor. Calculate the

(i) final p.d. across the combination (03marks)

Total charge = total charge after combination;

When the capacitors are joined, the p.d, V , across is the same

$$C_1V_1 = C_1V + C_2V = (C_1 + C_2)V$$

$$60 \times 10^{-6} \times 120 = (20 \times 10^{-6} + 20 \times 10^{-6})V = 80 \times 10^{-6}V$$

$$V = 90V$$

The final p.d = 90V

(ii) Difference in the initial and final energies stored in the capacitor and comment on the difference. (05marks)

$$\text{Energy} = \frac{1}{2} CV^2$$

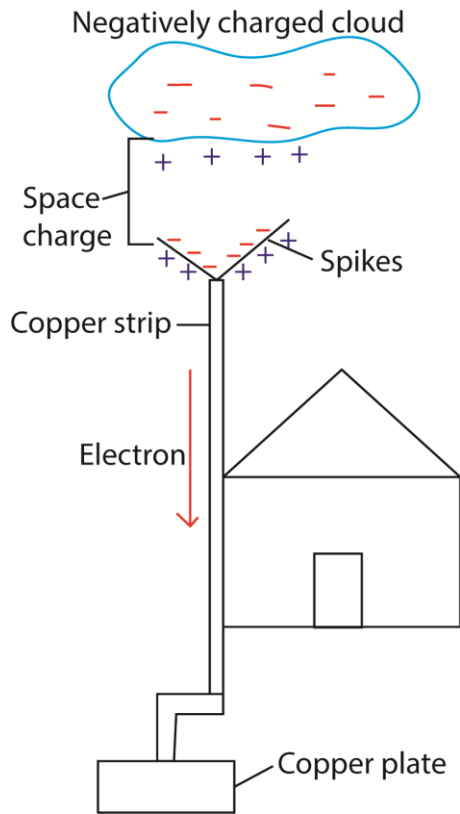
$$\text{Initial energy} = \frac{1}{2} C_1 V_1^2 = \frac{1}{2} \times 60 \times 10^{-6} \times 120^2 = 0.432J$$

$$\text{Final energy} = \frac{1}{2} (C_1 + C_2)V^2 = \frac{1}{2} (60 \times 10^{-6} + 20 \times 10^{-6}) \times 90^2 = 0.324J$$

$$\text{Energy difference} = 0.432 - 0.324 = 0.108J$$

Comment: Energy after is less because some energy is lost as heat in the connecting wires

(d) Explain the principles of operation of a lightning conductor. (05marks)



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.

4. (a) Define the following as applied to a battery:

(i) Electromotive force

It is the energy supplied by the battery to transfer 1C of charge a round a complete circuit which includes the battery.

Or

It is the ratio of the power the source generated to the current it delivers

(ii) Internal resistance

This is the opposition to the flow of current with the battery due to its chemical composition.

- (b) A battery of e.m.f E and internal resistance, r , is connected across a load of resistance, R . Derive an expression for maximum power delivered to the load. (04marks)

Power delivered to the load, $P = I^2 R$

$$\text{But } I = \frac{E}{R+r}$$

$$\Rightarrow P = \frac{E^2 R}{(R+r)^2}$$

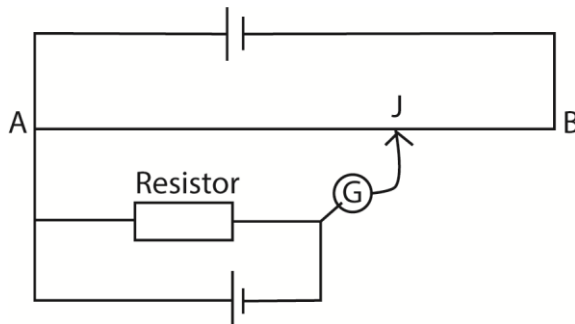
For maximum power, $\frac{dP}{dR} = 0$

$$\frac{dP}{dR} = \frac{E^2(R+r)^2 - E^2 R \cdot 2(R+r)}{(R+r)^4} = 0$$

$$R = r$$

$$P_{\max} = \frac{E^2 R}{(2R)^2} = \frac{E^2 r}{4r^2} = \frac{E^2}{4r}$$

- (c) Determine how resistance of a resistor may be determined using a slide wire potentiometer (05marks)

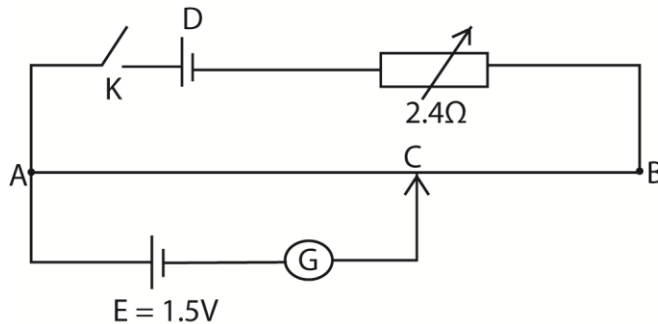


- A balance point $AJ = L_s$ is determined with a standard resistor, R_s .
- A balance point $AJ = L$ is determined with unknown resistor, R
- The unknown resistor, $R = \frac{L}{L_s} \times R_s$

- (d) Explain why the potentiometer is more suitable for measuring small resistance than Wheatstone bridge (02marks)

At balance point the current in a potentiometer wire is zero thus the resistance of the connecting wires does not affect the reading

- (e) In the figure below, AB is a uniform resistance wire of resistance 2.0Ω , and length 100cm , E is a cell of e.m.f 1.5V and D is a driver cell of negligible internal resistance. When switch K is closed the balance length AC is 82.5cm .



- (i) Find e.m.f of D (03marks)

$$E_D = I(R_{AB} + R)$$

$$= I(2 + 2.4)$$

$$I = \frac{E_D}{4.4}$$

$$\text{p.d. across AB} = IR_{AB} = \frac{E_D}{4.4} \times 2 = \frac{E_D}{2.2}$$

$$\text{p.d/cm, } k = \frac{E_D}{2.2} \times \frac{1}{100} = \frac{E_D}{220}$$

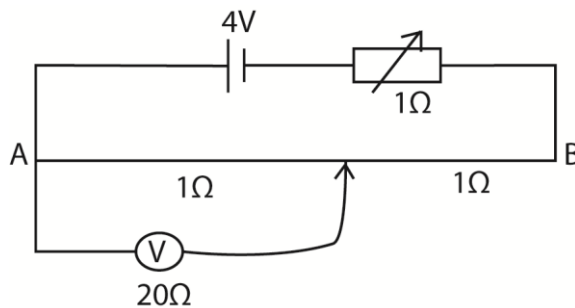
$$\text{At balance p.d across AC} = 1.5\text{V}$$

$$kL_{AB} = 1.5$$

$$\frac{E_D}{220} \times 82.5 = 1.5$$

$$E_D = 4\text{V}$$

- (ii) If E and the galvanometer are replaced by a voltmeter of resistance 20.0Ω , find the reading of the voltmeter when contact C is placed at the mid-point of AB and the value of R is 1.0Ω .



$$\text{Combined resistance in parallel, } R_C = \frac{20 \times 1}{20+1} = 0.95238\Omega$$

$$\text{Effective resistance, } R_E = 0.95238 + 1 + 1 = 2.95238\Omega$$

$$\text{Total current, } I = \frac{V}{R} = \frac{4}{2.95238} = 1.355\text{A}$$

p.d across the parallel combination, $V = IR = 1.355 \times 0.95238 = 1.29V$

\therefore voltmeter reading = 1.29V

Or

Combined resistance in parallel, $R_C = \frac{20 \times 1}{20+1} = 0.95238\Omega$

Effective resistance, $R_E = 0.95238 + 1 + 1 = 2.95238\Omega$

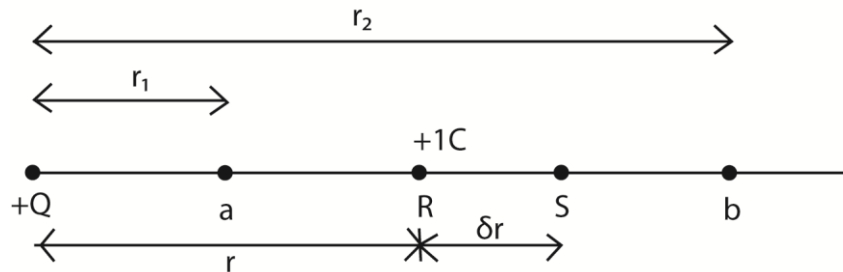
p.d across the parallel combination, $V_C = \frac{R_C}{R_E} \times V = \frac{0.95238}{2.95238} \times 4 = 1.29V$

5. (a) (i) Define electric field intensity and potential difference. (02marks)

Electric field intensity at a point is the force exerted on positive charge of 1C placed a point in an electric field.

The potential difference between two points is the work done to move 1C of positive charge from one point to another in electric field.

- (ii) Derive an expression for electric potential difference between two points a and b in the field of a single point charge +Q (04marks)



The force exerted on +1C charge at R

$$F = \frac{Q}{4\pi\epsilon_0 r^2}$$

The work done to move +1C of charge from S to R through a small distance, δr is

$$\delta w = \frac{-Q}{4\pi\epsilon_0 r^2} \delta r$$

Over a small distance, δr , F is assumed to remain constant.

Total work done to move +1C from b to a is

$$w = \int_{r_2}^{r_1} \frac{-Q}{4\pi\epsilon_0 r^2} \delta r = \frac{-Q}{4\pi\epsilon_0} \left[\frac{1}{r} \right]_{r_2}^{r_1}$$

$$= \frac{Q}{4\pi\epsilon_0} \left[\frac{1}{r_1} - \frac{1}{r_2} \right]$$

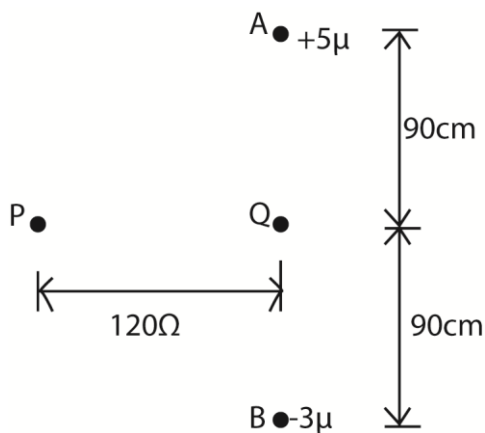
∴ p.d between a and b

$$V_{ab} = \frac{Q}{4\pi\epsilon_0} \left[\frac{1}{r_1} - \frac{1}{r_2} \right]$$

(b) Describe an experiment to show that when two dissimilar dielectrics are rubbed together, they acquire equal but opposite charge.

- Wool is wrapped round on end of a polythene rod and several turns of thread wound over wool. The loose end of the thread is pulled so that the wool rubs the polythene making sure that the hands do not touch the wool.
- The end of the rod with wool is inserted in the metal can place on neutral electroscope. No divergence is observed.
- When the polythene is carefully pulled out to leave the wool, a divergence of the leaf of electroscope is observed.
- The wool is then withdrawn and the electroscope discharged, when the rod is placed inside the can, the electroscope is observed to diverge to the same extent as before.
- Therefore two dissimilar dielectric have acquired equal but opposite charges.

(c) Two point charges of $+5\mu\text{F}$ and $-3\mu\text{F}$ are placed at points A and B as shown in the figure below.



Calculate the

- (i) Electric potential at P (03marks)
- $$AP = BP = \sqrt{(120^2 + 90^2)} = 150\text{cm}$$
- Potential at P = $\frac{kQ}{r}$

$$V_p = k \left[\frac{Q_A}{r_1} + \frac{Q_B}{r_2} \right] = 9 \times 10^9 \left[\frac{5 \times 10^{-6}}{150 \times 10^{-2}} - \frac{3 \times 10^{-6}}{150 \times 10^{-2}} \right] = 12,000V$$

(ii) Work done in moving a charge $-3\mu C$ from P to Q. (04marks)

$$\text{Potential at Q} = k \left[\frac{Q_A}{r_a} + \frac{Q_B}{b} \right] = 9 \times 10^9 \left[\frac{5 \times 10^{-6}}{90 \times 10^{-2}} - \frac{3 \times 10^{-6}}{90 \times 10^{-2}} \right] = 20,000V$$

Potential difference between P and Q

$$V_{QP} = 20000 - 12000 = 8000V$$

$$\text{Work done, } w = QV_{QP} = -3 \times 10^{-6} \times 8000 = 0.024J$$

(d) State any two characteristics of an equipotential (02marks)

- The work done to move a charge along the surface is zero
- The field lines are perpendicular to the surface.

6. (a) Define the following

(i) Capacitance (01mark)

It is the ratio of the magnitude of a charge on either plates of a capacitor to the potential difference between the plates.

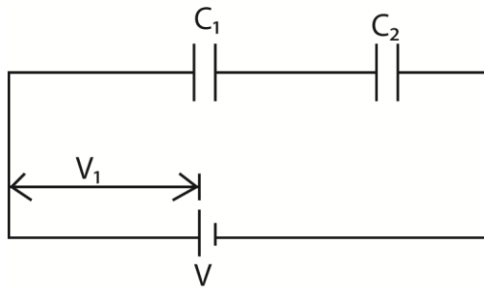
Or

It is the magnitude of charge on a conductor to potential of the conductor.

(ii) Relative permittivity (01mark)

It is the ratio of the permittivity of a material to permittivity of free space.

(b) Two capacitors of capacitances C_1 and C_2 are connected in series with a battery of e.m.f V as shown below.



If the p.d across the capacitor of capacitance C_1 is V_1 show that

$$\frac{1}{V_1} = \left(\frac{1}{C_1} + \frac{1}{C_2} \right) \frac{C_1}{V}$$

Proof

Let the charge on each capacitor plates be Q and $V_2 =$ p.d across C_2 .

$$\text{Total p.d } V = V_1 + V_2$$

$$V_1 = \frac{Q}{C_1} \text{ and } V_2 = \frac{Q}{C_2}$$

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} = Q \left[\frac{1}{C_1} + \frac{1}{C_2} \right]$$

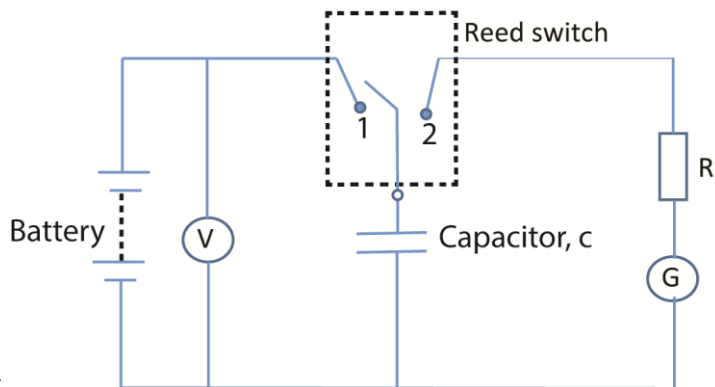
$$\text{Charge on } C_1 = Q_1 = C_1 V_1$$

$$V = C_1 V_1 \left[\frac{1}{C_1} + \frac{1}{C_2} \right]$$

Dividing through by $V V_1$ gives

$$\frac{1}{V_1} = \frac{C_1}{V} \left[\frac{1}{C_1} + \frac{1}{C_2} \right]$$

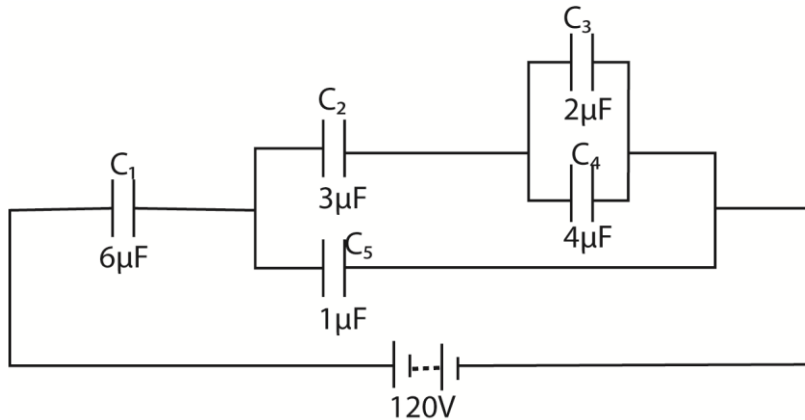
(c) Describe an experiment to determine the capacitance of a capacitor using a vibrating reed



circuit.

- The test capacitor of capacitance, C , to be determined is connected to the circuit as shown above
- The capacitor is alternatively charged and discharged through a sensitive light beam galvanometer, G by the reed switch.
- The frequency, f , of the reed switch, the voltmeter reading, V and ammeter reading I are recorded
- The capacitance of the capacitor is given by $C = \frac{I}{fV}$

(d) A battery of e.m.f. 120V is connected to a network of capacitors as shown in the figure below



Calculate the

(i) Charge on C_1 (04marks)

Combined capacitor C' of C_3 and C_4 in parallel

$$C' = C_3 + C_4 = 2 + 4 = 6\mu\text{F}$$

Equivalent capacitance C'' of C' and C_2 in series

$$C'' = \frac{C'C_2}{C' + C_2} = \frac{3 \times 6}{3 + 6} = 2\mu\text{F}$$

Combine capacitance, C''' of C'' and C_5 in parallel

$$C''' = 2 + 1 = 3\mu\text{F}$$

Equivalent capacitance C'''' of C''' and C_6 in series

$$C'''' = \frac{C'''C_6}{C''' + C_6} = \frac{3 \times 6}{3 + 6} = 2\mu\text{F}$$

$$\text{Total charge } Q = CV = 120 \times 2 \times 10^{-6} = 2.4 \times 10^{-4}\text{C}$$

$$\text{Charge on } C_1 = 2.4 \times 10^{-4}\text{C}$$

(ii) Energy stored in C_5 (03marks)

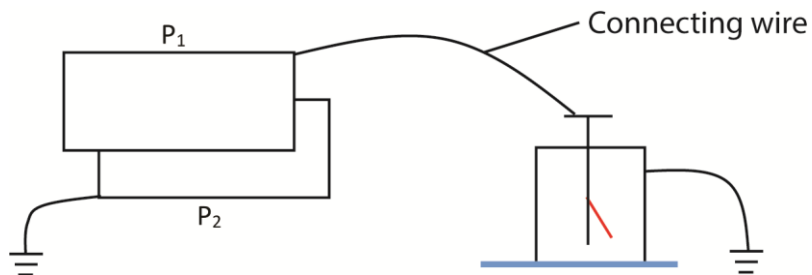
$$\text{p.d across parallel network, } V' = \frac{Q}{C''''} = \frac{2.4 \times 10^{-4}}{3 \times 10^{-6}} = 80\text{V}$$

$$\text{Energy stored in } C_5 = E = \frac{1}{2} C V^2$$

$$= \frac{1}{2} \times 1 \times 10^{-6} \times 80^2$$

$$= 3.2 \times 10^{-3}\text{J}$$

(e) Describe how the effect of a dielectric medium on the capacitance of a capacitor may be determined. (03marks)



- Two metal plates P₁ and P₂ are set close to each other but not touching.
- P₂ is earthed while P₁ is given charge Q and connected to the cap of electroscope.
- The divergence of the leaf is noted
- A dielectric (e.g. sheets of glass) is placed between the plates keeping the separation of P₁ and P₂ and area constant.
- The divergence of the leaf is seen to decrease implying a reduction of p.d across the plates.
- From $C = \frac{Q}{V}$, the capacitance increases in presence of dielectric.

7. (a)(i) State the law of conservation of current at a junction in an electric circuit. (01marks)

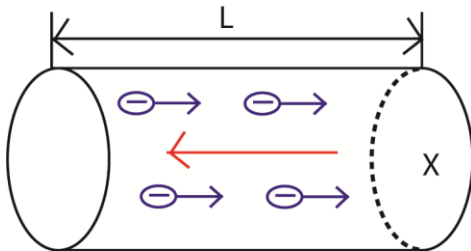
Law of conservation of current at a point/junction states that the total current flowing through a junction is equal to the total current flowing out of a junction.

(ii) Explain why current from a battery is greater when bulbs are connected in parallel than when they are in series across a battery. (03marks)

The effective resistance across the bulbs is smaller when the bulbs are in parallel than when they are in series. Since the current is a ratio of p.d to resistance the current is higher when the bulbs are connected in parallel than when connected in series.

(b) A conductor of length L and cross sectional area A has n free electrons per unit volume. The average drift velocity of the electrons is v and each electron carries charge e.

Derive an expression for the current which flows (03marks)



Number of free electrons in section of the wire = nAL

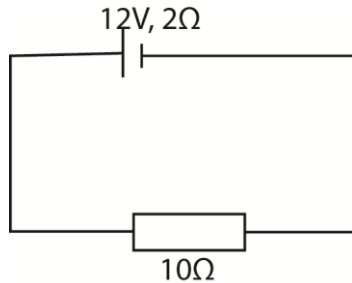
Total charge Q in the section is given by $Q = nALe$

Time taken for all electrons to flow through X, $t = \frac{L}{v}$

But current $I = \frac{Q}{t} = \frac{nALe}{L/v} = nAve$

(c) A battery with an e.m.f of 12V and internal resistance 2Ω is connected to a wire of resistance 10Ω .

(i) Calculate the p.d across the wire. (02marks)

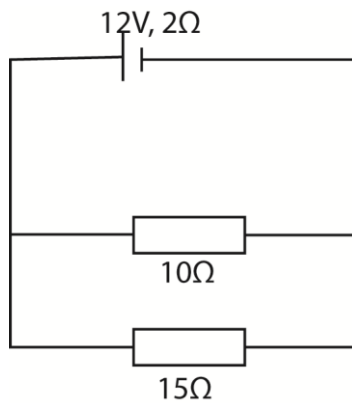


Total resistance in series = $10 + 2 = 12\Omega$

But Current $I = \frac{V}{R} = \frac{12}{12} = 1A$

p.d across 10Ω resistor = $IR = 1 \times 10 = 10V$

(ii) What is the p.d across the wire become if a 15Ω resistor is connected parallel to it? (03marks)



Combined resistance for 10Ω and 15Ω in parallel = $\frac{15 \times 10}{15+10} = 6\Omega$

Total resistance in the circuit = $6 + 2 = 8\Omega$

Current $I = \frac{V}{R} = \frac{12}{8} = 1.5A$

p.d across the parallel resistors = $IR = 1.5 \times 6 = 9V$

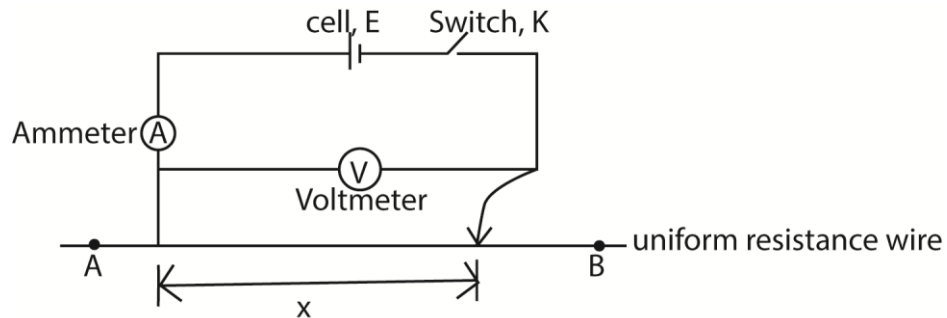
Hence, the p.d across 10Ω resistor = $9V$

(d)(i) Define electrical resistivity and state its units (02marks)

Electrical resistivity of a material is the resistance across 1m cube of the material

Units is Ohm-meter (Ωm)

(ii) Describe an experiment to determine the resistivity of the material of a wire using an ammeter, meter rule and voltmeter



- The setup is shown above
- Various values of x , V and I are obtained and tabulated including values of $R = \frac{V}{I}$
- A graph of R against x is plotted and slope s is obtained
- Given that the diameter of the wire is d ; the resistivity of the wire, ρ is given by

$$\rho = s \left(\frac{\pi d^2}{4} \right)$$

8. (a) (i) Define temperature coefficient of resistance and state its units. (02marks)

The temperature coefficient of resistance is the fractional change in resistance at 00C for very degree Celsius rise in temperature.

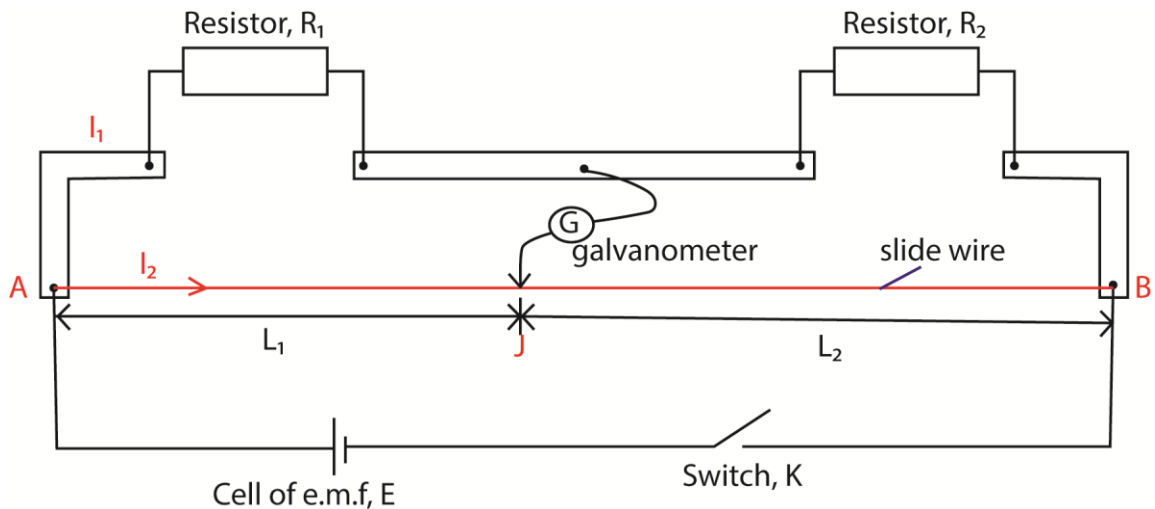
Units is K^{-1}

(ii) Explain why temperature coefficient of resistance is positive for metals. (03marks)

The resistance of a metal increases with increase in temperature because when the temperature increases, the atoms of the metal vibrate with higher amplitude reducing the mean free path for conduction of electrons.

The charge flow per second (or current) is reduced. This implies that resistance has increased. Hence fractional change in temperature is positive.

(b) (i) Derive the conditions for balance of meter bridge. (05marks)



- The setup is as shown above, J is the balancing point.
- At balance the current through R_1 = current through R_2 and current through AJ = current through JB
- \therefore p.d across R_1 = p.d across AJ
- $I_1 R_1 = I_2 R_{AJ}$
- If r is the resistance per meter of wire AB,
- Then, $I_1 R_1 = I_2 r L_1$ (i)
- P.d across R_2 = p.d across JB
- $I_1 R_2 = I_2 R_{JB}$
- Then, $I_1 R_2 = I_2 r L_2$ (ii)
- Dividing (i) by (ii)
- $\frac{R_1}{R_2} = \frac{L_1}{L_2}$

(ii) Explain why the meter bridge is unsuitable for comparison of low resistances. (02marks)

When the resistances are very low, the resistance of the connecting wire or the resistance of end error become significant.

(c) A standard resistor is connected across the right hand gap of a meter bridge and a coil X across the left hand gap of meter bridge. When the coil is heated to a temperature of 40°C , the balance length is 525mm from left-hand end of the bridge.

When the temperature of X is raised to 100°C , the balance point is 546mm from the left end.

(i) Calculate the temperature coefficient of resistance of the coil X (06marks)

$$\text{At } 40^\circ, \frac{X_{40}}{R} = \frac{52.5}{47.5} = 1.105 \text{ (i)}$$

$$\text{At } 100^\circ, \frac{X_{100}}{R} = \frac{54.6}{45.4} = 1.203 \text{ (ii)}$$

$$\text{Hence } \frac{X_{100}}{X_{40}} = \frac{1.203}{1.105} = 1.089$$

$$\text{Using } R_{\theta} = R_0(1 + \alpha\theta)$$

$$X_{100} = X_0(1 + 100\alpha)$$

Also,

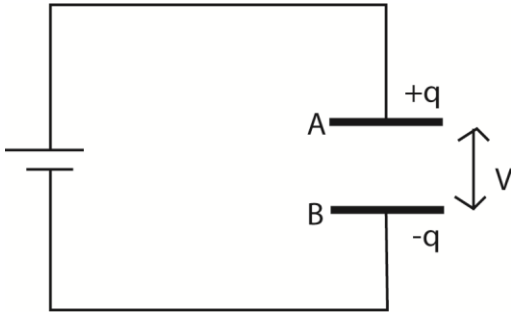
$$X_{40} = X_0(1 + 40\alpha)$$

$$\frac{X_{100}}{X_{40}} = \frac{(1+100\alpha)}{(1+40\alpha)} = 1.089$$

$$\alpha = 1.57 \times 10^{-3} K^{-1}$$

- (ii) Why are standard resistors made of alloys such as constantan and magnesium? (02marks)
 The temperature coefficient of constantan and magnesium are small, thus, there negligible change in resistance with moderate change temperature

9. (a) Derive an expression for energy stored in a capacitor of capacitance, C, charged to voltage, V. (04marks)



When a small amount of charge δq is transferred from B to A

$$\text{Total charge} = q + \delta q$$

$$\text{Total p.d} = V + \delta V$$

$$\text{Work done, } \delta w = (V + \delta V)\delta q$$

$$\therefore \delta w = V\delta q, \text{ but } q = CV$$

$$\delta w = \frac{q}{C} \delta q$$

$$\text{Work done, } W = \int_0^Q \frac{q}{C} \delta q$$

$$= \frac{1}{2} \times \frac{Q^2}{C}$$

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

Alternatively

$$\delta q = \delta(CV) = C\delta V$$

$$\delta w = CV\delta V$$

$$\text{Work done} = \int_0^V CV\delta V = \frac{1}{2} CV^2$$

- (b) A parallel plate capacitor with plate area of $2 \times 10^{-2} \text{m}^2$ and plate separation of $5.0 \times 10^{-3} \text{m}$ is connected to a 500V supply.

- (i) Calculate the energy stored in the capacitor (04marks)

$$\text{Charge } Q = CV \text{ but } C = \frac{\epsilon_0 A}{d}$$

$$= \frac{\epsilon_0 A V}{d}$$

$$= \frac{8.85 \times 10^{-12} \times 2 \times 10^{-2} \times 500}{5 \times 10^{-3}}$$

$$\begin{aligned}
 &= 1.77 \times 10^{-8} \text{C} \\
 \text{Energy stored} &= \frac{1}{2} QV \\
 &= \frac{1}{2} \times 1.77 \times 10^{-8} \times 500 \\
 &= 4.4 \times 10^{-6} \text{J}
 \end{aligned}$$

(ii) If the space between the plates is completely filled with oil and the total charge in the capacitor becomes $4.42 \times 10^{-8} \text{C}$. Find the dielectric constant of the oil (03marks)

Capacitance, $C' = \epsilon_r C$, where ϵ_r = electric field

From $Q = C'V$

$$\begin{aligned}
 \Rightarrow Q &= \epsilon_r V \frac{\epsilon_0 A}{d} \\
 \epsilon_r &= \frac{Qd}{\epsilon_0 Av} = \frac{4.42 \times 10^{-8} \times 5 \times 10^{-3}}{8.85 \times 10^{-12} \times 2 \times 10^{-2} \times 500} = 2.5
 \end{aligned}$$

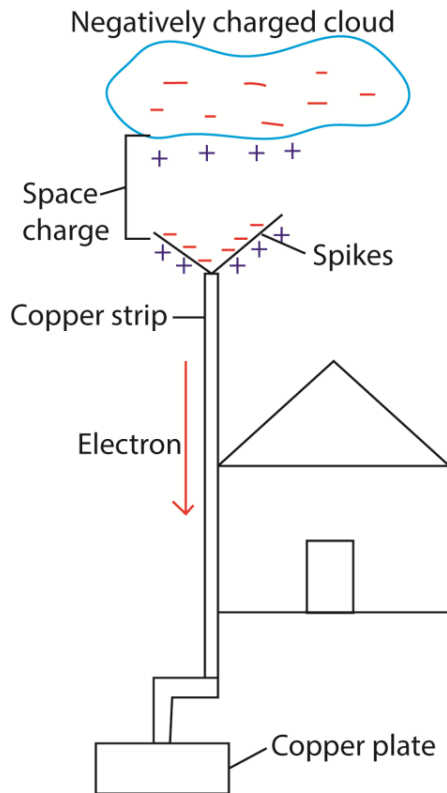
Or

$Q = CV$

$$= 4.42 \times 10^{-8} = \epsilon_r \times 3.54 \times 10^{-11} \times 500$$

$$\epsilon_r = \frac{4.42 \times 10^{-8}}{3.54 \times 10^{-11} \times 500} = 2.5$$

(c) Explain how a lightning conductor may protect a building from damage by lightning. (05marks)

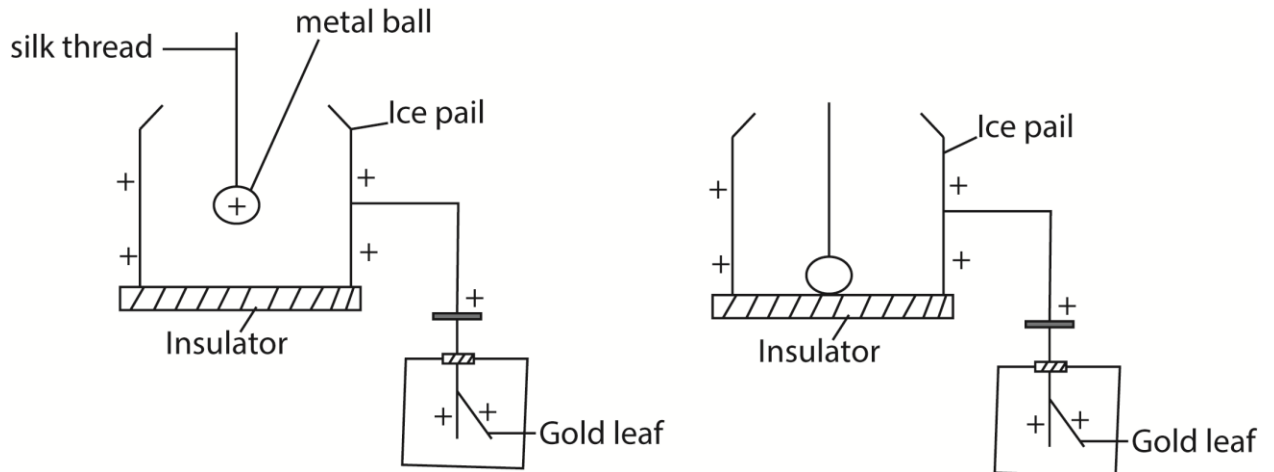


Action

- (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.

(d) Describe an experiment to show that charge on a hollow conductor resides on the outer surface. (04marks)

Experiment to show that excess charge resides only on the outside of a hollow conductor.



- Ice pail is placed on an insulator and connected to a gold leaf electroscope
- A positively charged metal ball held on a long silk thread is lowered into the pail without touching the sides nor the bottom.
- Positive charges are induced on the outside of the pail and gold leaf diverges. The divergence does not change when the ball is moved about as long as it does not touch the pail.
- When the metal ball is allowed to touch the bottom, the divergence remains unchanged although it loses the charge.
- This shows that the charge induced inside the ice pail (hollow conductor) is of equal magnitude and opposite to the charge on the metal ball. Thus the total charge inside the hollow conductor is zero.
- Hence excess charge resides only on the outside of a hollow conductor.

10. (a)(i) Define electrical resistivity. (01mark)

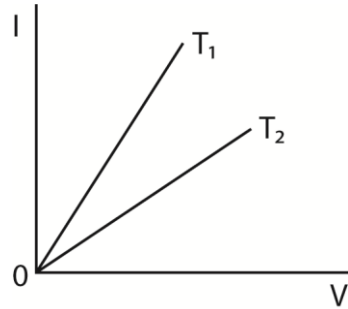
Electric resistivity is the resistance across opposite faces of 1m cube of material.

(ii) Explain how length and temperature of a conductor affect its resistance. (04marks)

Length: Increase in length leads to longer path of electrons. This means more collision will occur with the metal ions. This leads to a reduction in current and hence increase in resistance.

Temperature- increase in temperature increases the amplitude of vibrations of ions. This increases the rate of collision between the electrons and the ions. This will reduce the amount of current flowing and hence increase in resistance.

(iii) The figure below shows a circuit-voltage graphs for a metallic wire at two different temperatures T_1 and T_2 .

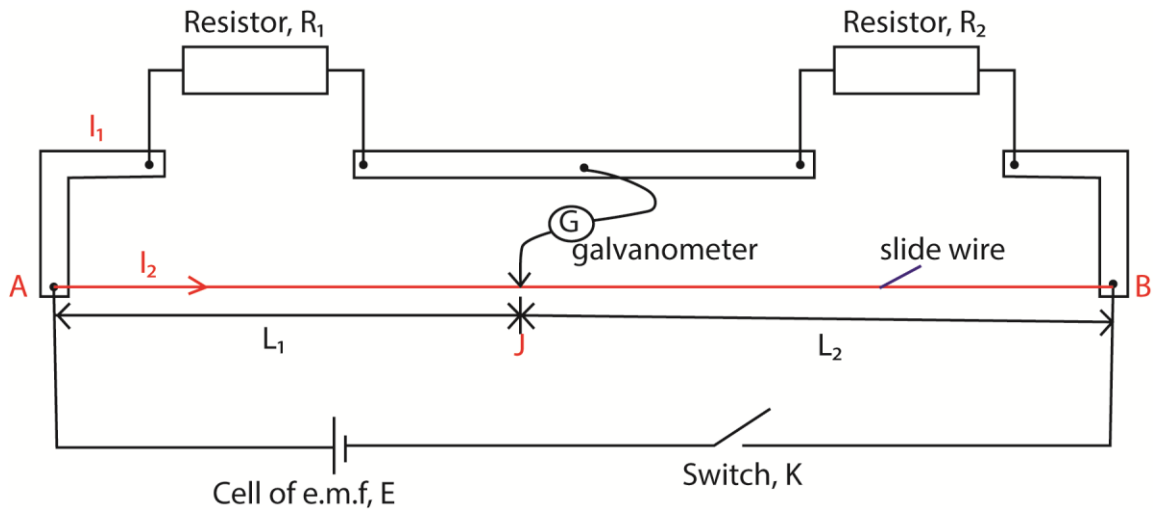


State in which of the two temperatures resistance is greater and explain your answer (03marks)

$$T_2 > T_1$$

At T_1 the gradient is higher than at T_2 (or at each voltage the current flowing at temperature T_1 is higher than at temperature T_2). This implies that the resistance at T_1 is lower than the resistance at T_2 .

(b) (i) Derive the balance condition when using a meter bridge to measure resistance. (03marks)



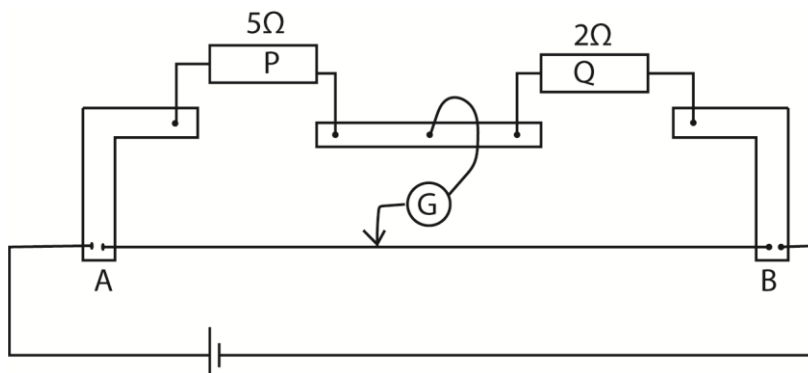
- The setup is as shown above, J is the balancing point.
- At balance the current through R_1 = current through R_2 and current through AJ = current through JB
- \therefore p.d across R_1 = p.d across AJ
- $I_1 R_1 = I_2 R_{AJ}$
- If r is the resistance per meter of wire AB,
- Then, $I_1 R_1 = I_2 r L_1$ (i)
- P.d across R_2 = p.d across JB
- $I_1 R_2 = I_2 R_{JB}$
- Then, $I_1 R_2 = I_2 r L_2$ (ii)
- Dividing (i) by (ii)

$$\frac{R_1}{R_2} = \frac{L_1}{L_2}$$

(ii) State **two** precautions taken to achieve an accurate measurement. (02marks)

- The slide wire should have uniform resistance
- The resistors should be chosen such the balance point is approximately in the middle of slide wire.
- The resistors should be interchanged to use average values.

(c) The figure below shows two resistors P and Q of resistance 5Ω and 2Ω respectively connected in the two gaps of the meter bridge.



A resistor X of cross-sectional area 1mm^2 is connected across P so that the balance point is 66.7cm from A. If the resistivity of wire X is $1.0 \times 10^{-5}\Omega\text{m}$ and the resistance wire AB of the meter bridge is 100cm long, calculate the length of X. (04marks)

Let the combined resistance of P and X be R

$$\frac{R}{Q} = \frac{L_1}{L_2}$$

$$\frac{R}{2} = \frac{66.7}{33.3}$$

$$R = 4\Omega$$

Since P and X are in parallel

$$R = \frac{5X}{5+X} = 4$$

$$X = 20\Omega$$

$$\text{From } L_x = \frac{XA}{\rho} = \frac{20 \times 1.0 \times 10^{-6}}{1 \times 10^{-5}} = 2.0\text{m}$$

(d) Explain how electrons attain a steady drift velocity when current flows through a conductor. (02marks).

When a p.d is supplied across a conductor, the free electrons are accelerated in the direction of the field. As they move, they collide with the metal ions until they attain a steady drift velocity.

11. (a) (i) Explain equipotential surface. (04marks)

Equipotential surface is one on which the electric potential is the same (or constant) at all points. The work done to move a charge from one point to another along the surface is zero. This implies that the electric field is perpendicular to the surface.

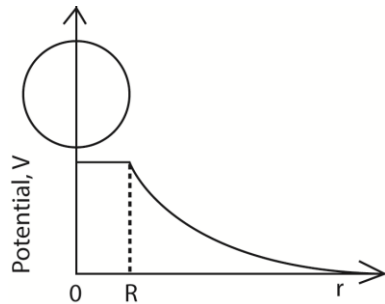
(ii) Give an example of an equipotential surface (01mark)

- the surface of the earth
- the surface of charged conductor.
- An imaginary surface containing points equidistant from a point charge

(b) (i) State coulomb's law. (01 marks)

Coulomb's law states that the force between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance between them.

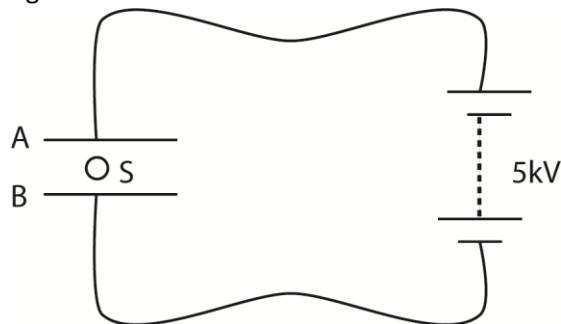
(ii) With the aid of a diagram, explain the variation of electric potential with distance from the center of charged metal sphere (03marks)



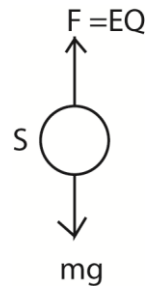
Within the sphere, electric potential is constant. There is no charge inside.

Outside the sphere, the potential is inversely proportional to the distance r from the center of the sphere.

(iii) Two metal plates A and B, 30cm apart are connected to a 5kVdc supply as shown in the figure below.



When a small charged sphere, s , of mass $9.0 \times 10^{-3} \text{ kg}$ is placed between the plates, it remains stationary. Indicate the forces acting on the sphere and determine the magnitude of the charge on the sphere. (04marks)



Since the sphere is stationary, $F = mg$

$EQ = mg$ where Q is the charge on the sphere

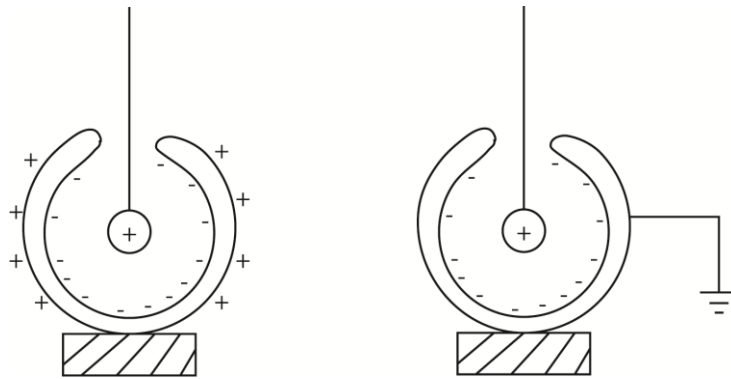
$$E = \frac{V}{d};$$

$$\therefore Q = \frac{mgd}{V} = \frac{9 \times 10^{-3} \times 9.81 \times 30 \times 10^{-2}}{500} = 5.3 \times 10^{-6} \text{ C or } 5.3 \mu\text{F}$$

(c) (i) Define electric field intensity. (01marks)

Electric field intensity at a point is the force exerted on positive charge of 1C placed at a point in an electric field.

(ii) With the aid of a diagram, explain electrostatic shielding. (04marks)



- The test material is suspended in an almost enclosed conducting can.
- It includes an equal and opposite charge inside the can and similar charge to it on the outer wall such that the net charge inside the can is zero.
- An external field only affects charge distribution on the outer surface of the can.
- Hence the material is shielded from the external field.

NB. Electrostatic shielding is the act of protecting material from the influence of an electric field or creating an electrically neutral space in an electric field.

(d) Explain briefly why a neutral metal body is attracted to a charged body when brought near it. (02marks)

- When a neutral metal is brought near a charged material, opposite charge is induced the side of the metal and the charge similar to that of the charged body on the far side.
- Since opposite charges are now closer to each other, the attraction force between the material is greater than the repulsion force. Hence the metal body is attracted.

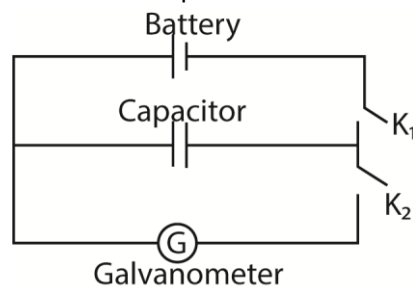
12. (a) (i) What is meant by capacitance of a capacitor? (01mark)

Capacitance of a capacitor is the ratio of the magnitude of charge on either plates of a capacitor to the potential difference between the plates

(ii) A parallel plate capacitor is connected across a battery and charged fully. When a dielectric material is now inserted between its plates, the amount of charge stored in the capacitor changes. Explain the change. (04marks)

- When a dielectric is inserted between the plates of a charged capacitor, its molecules get polarized. The surfaces of the dielectric thus develop charges opposite to those on adjacent capacitor plates.
- Electric field intensity develops between the faces of the dielectric in the opposition of the applied field and this reduces the electric field between the plates.
- Since the p.d is now less than the terminal p.d of the battery, more charges are conducted to the capacitor until the p.d is again equal to that of the battery. Hence charge on the capacitor increases.

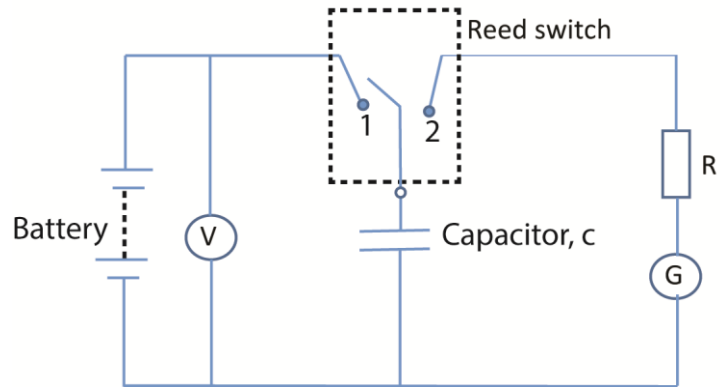
(iii) Describe an experiment to determine the relative permittivity of a dielectric. (04marks)



- The circuit is set up as shown above,
- Switch K_1 is closed for some time and opened, then switch K_2 is closed and the deflection θ_1 of the ballistic galvanometer is noted.
- The procedure is repeated when the capacitor contains a dielectric and θ_2 is noted
- The relative permittivity, $\epsilon_r = \frac{\theta_2}{\theta_1}$

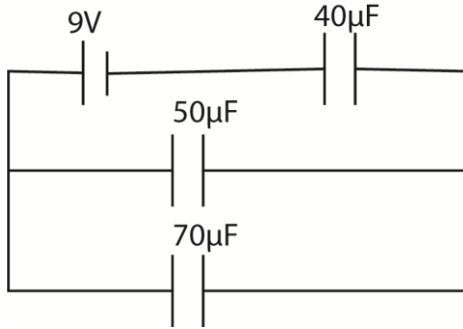
Alternatively

The circuit is as shown below



- The capacitor is alternatively charged and discharged through a sensitive light beam galvanometer, G by the reed switch at reasonable frequency, f and steady current I_1 is noted.
- The procedure is repeated when the capacitor contains a dielectric and steady current I_2 is noted
- Relative permittivity, $\epsilon_r = \frac{\epsilon}{\epsilon_0} = \frac{I_1}{I_2}$
- Thus ϵ_r is the ratio of respective currents in G with and without the dielectric between plates.

(b) A network of capacitors of capacitances $40\mu\text{F}$, $50\mu\text{F}$ and $70\mu\text{F}$ is connected to a battery of 9V as shown in the figure below



Calculate

- (i) Charge stored in the 50μF capacitor. (05marks)

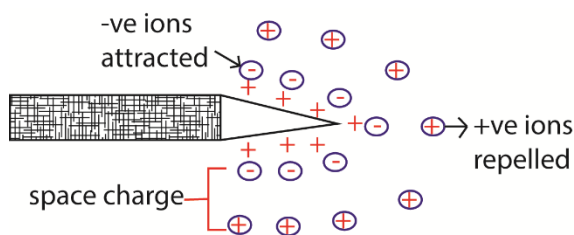
Effective capacitance in parallel = $50 + 70 = 120\mu\text{F}$
 Net capacitance in the network = $\frac{120 \times 40}{120+40} = 30\mu\text{F}$
 Total charge in the network = $CV = 30 \times 10^{-6} \times 9 = 270 \times 10^{-6}\text{C}$
 p.d across the parallel combination = $\frac{Q}{C_{eff}} = \frac{270 \times 10^{-6}}{120 \times 10^{-6}} = 2.25\text{V}$
 charge on 50μF capacitor = $CV = 50 \times 10^{-6} \times 2.25 = 1.125 \times 10^{-4}\text{C}$

- (ii) Energy stored in the 40μF (03marks)

$$E = \frac{Q^2}{2C} = \frac{(270 \times 10^{-6})^2}{2 \times 40 \times 10^{-6}} = 9.11 \times 10^{-4}\text{J}$$

(c) Explain corona discharge

Corona Discharge



- On a pointed charged conductor, there is high charge density and thus high electric field at the sharp point.
- This causes air molecules around the sharp point to ionize and form positive and negative ions.
- The similar charges to those on the conductor are repelled while those opposite are attracted to neutralize some of the charges on the conductor.
- The apparent loss of charge from the conductor in this way is called **Corona discharge**.

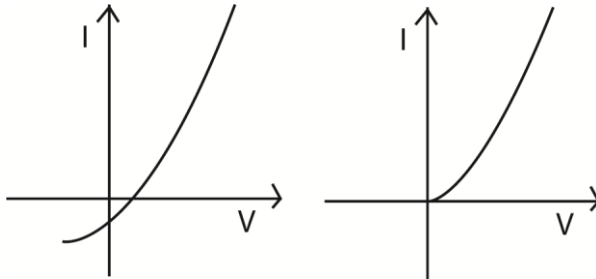
13. (a)(i) Define temperature coefficient of resistance (01mark)

Temperature coefficient of resistance is the fractional change in resistance at 0°C for every degree Celsius rise in temperature.

(ii) Explain the origin of the heating effect of electric current in metal conductor. (03marks)

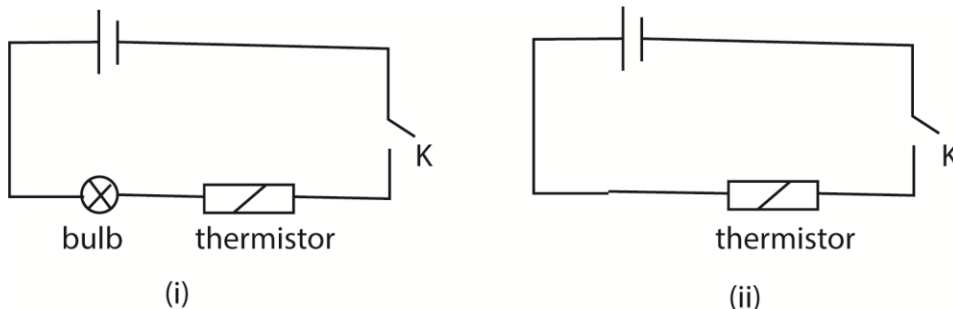
During the flow of current, electrons moving through the metal conductor may collide with the positive ions in the metallic lattice. On collision, the kinetic energy possessed by electron is transferred into heat.

(iii) Describe with the aid of an I-V sketch the variation of current with p.d across a semiconductor diode. (02marks)



When the diode is forward biased, the current increases rapidly as the p.d is increased.
When the reversed biased little or no current flows

(b) A cell, a bulb, a switch and a thermistor with negative temperature coefficient of resistance are connected as shown in the figures (i) and (ii) below



(i) Explain what would happen when in figure (i) switch K is closed (04marks)

At room temperature, the resistance of thermistor is high, current flowing is thus small and bulb lights dimly. As current flows, the thermistor heats up (temperature increases) and the resistance decreases leading to increase in current and brightness of the bulb.

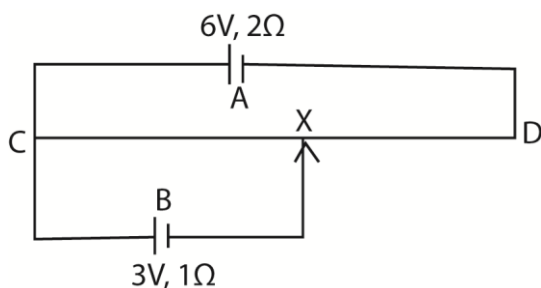
(ii) If the bulb in figure (i) is removed and the circuit connected as shown in figure (ii), explain what would happen when switch K is closed (03marks)

On closing K, the thermistor heats up and its resistance reduces. The reduction in resistance causes high current through the cell. High current in the cell and due to internal resistance, overheating occurs destroying the cell

(c) State the law of conservation of current at the junction (01mark)

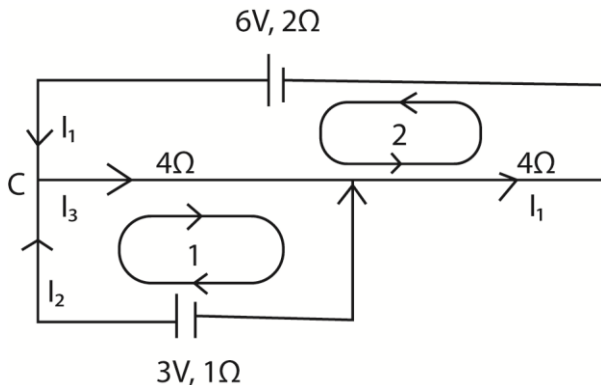
The law of conservation of current at a junction states that the algebraic sum of current at the junction is zero

(d) Two cells A of e.m.f 6V and internal resistance 2Ω and B of e.m.f 3V and internal resistance 1Ω respectively are connected across a uniform resistance wire CD of resistance 8Ω as shown in the figure below



If X is exactly in the middle of the wire CD, Calculate the

(i) Power dissipated in CX. (04marks)



$$I_3 = I_1 + I_2 \dots\dots\dots (i)$$

Consider loop 1

$$3 = I_2 + 4I_3 \dots\dots\dots (ii)$$

Consider loop 2

$$6 = 2I_1 + 4I_3 + 4I_1$$

$$6 = 6I_1 + 4I_3 \dots\dots\dots (iii)$$

Eqn. (ii) and eqn. (i)

$$3 = I_2 + 4(I_1 + I_2)$$

$$= 5I_2 + 4I_1 \dots\dots\dots (iv)$$

Eqn. (iii) and eqn. (i)

$$6 = 6I_1 + 4(I_1 + I_2)$$

$$= 10I_1 + 4I_2$$

$$3 = 5I_1 + 2I_2 \dots\dots\dots (v)$$

Eqn. (v) x 5 – eqn. (iv) x 2

$$9 = 17I_1$$

$$\therefore I_1 = 0.55A$$

Substituting I_1 in equation (iii)

$$6 = 6 \times \frac{9}{17} + 4I_3$$

$$I_3 = \frac{12}{17} = 0.71A$$

$$\text{Power} = I^2R = \left(\frac{12}{17}\right)^2 \times 4 = 1.993W$$

(ii) P.d across the terminals of cell A. (02marks)

$$\text{Terminal p.d} = 6 - 2I_1$$

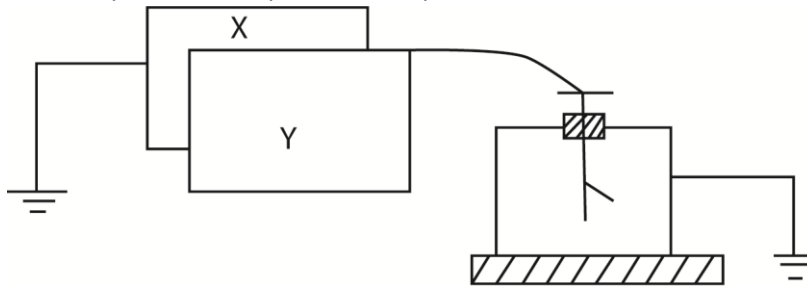
$$= 6 - 2 \times \frac{9}{17}$$

$$= 4.94V$$

14. (a)(i) Define capacitance of a capacitor (01mark)

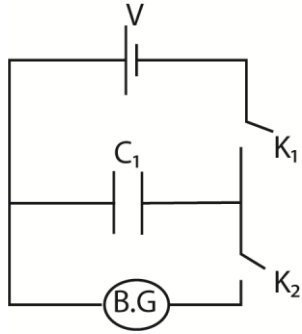
Capacitance of a capacitor is the ratio of the magnitude of charge on either plate of the capacitor to the potential difference across the plates.

(ii) Describe briefly an experiment to show the effect of placing a sheet of glass or mica between the plates of a capacitor on capacitance. (05marks)



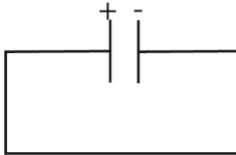
- Two plates X and Y are placed close to each other but not touching as shown above.
- Plate Y is given a charge, Q, by means of an electrophorus and divergence of the leaf of the electroscope noted.
- A sheet of glass or mica is placed between the plates; the divergence of the leaf is observed to decrease, implying that the new p.d between the plates has decreased and the capacitance has increased since $C = \frac{Q}{V}$ and Q is constant.

(b) Describe how the unknown capacitance of a capacitor can be determined using a ballistic galvanometer. (04marks)



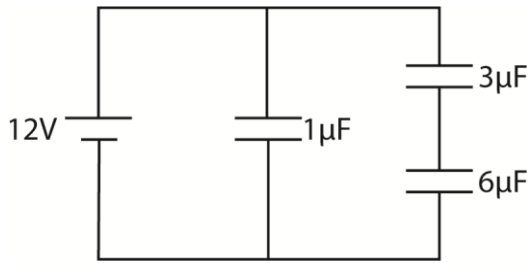
- The circuit is connected as shown with a capacitor of known capacitance C_1 .
- Switch K_1 is closed and K_2 is opened. The capacitor of capacitance C_1 is charged by the battery of e.m.f V .
- K_1 is opened and K_2 is closed to discharge the capacitor through the ballistic galvanometer, B.G. the first deflection of the B.G θ_1 is noted
- The capacitor is then replaced with the capacitor of unknown capacitance C_2 , the experiment is repeated and deflection θ_2 is noted
- Hence $\frac{C_2}{C_1} = \frac{\theta_2}{\theta_1}$; $C_2 = C_1 \frac{\theta_2}{\theta_1}$

(c) Explain briefly how a charged capacitor can be fully discharged. (02marks)



The wire is connected from the positive plate to the negative plate. Electrons flow from the negative plate to the positive plate neutralizing the positive charges. The flow of electrons continues until all the capacitor is fully neutralized.

(d) A $3\mu\text{F}$ capacitor is connected in series with a $6\mu\text{F}$ capacitor. The combination is then connected in parallel with $1\mu\text{F}$ capacitor to 12V battery as shown in the figure below



Calculate

- (i) Charge stored on each capacitor (05marks)

Charge stored on $1\mu\text{F}$

$$Q = CV = 1 \times 10^{-6} \times 12 = 10 \times 10^{-6}\text{C}$$

Total capacitance in series

$$C = \frac{6 \times 3}{6+3} = 2\mu\text{F}$$

\therefore The charge stored in combination

$$Q = CV = 2 \times 10^{-6} \times 12 = 2.4 \times 10^{-6}\text{C}$$

The charge on either $6\mu\text{F}$ or $3\mu\text{F}$ capacitor is $2.4\mu\text{C}$

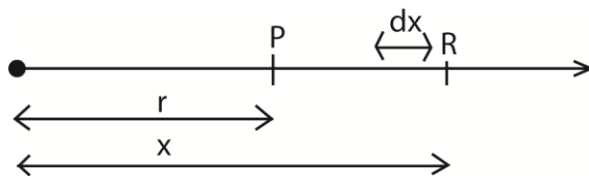
- (ii) Energy stored in the $6\mu\text{F}$ capacitor when fully charged (03marks)

$$E = \frac{Q^2}{2C} = \frac{(2.4 \times 10^{-6})^2}{2 \times 6 \times 10^{-6}} = 4.8 \times 10^{-5}\text{J}$$

15. (a) (i) Define the following; electric field intensity and electric potential at a point (02marks)

- Electric field intensity at a point is the force exerted on positive charge of 1C placed a point in an electric field.
- Electric potential is the work done in bringing 1C of positive charge from infinity to a point against an electric field.

- (ii) Show that the electric field intensity at a point is equal to the negative potential gradient at that point. (04marks)



The force experienced by the charge of $+1\text{C}$ placed at R, $F = K\frac{Q \times 1}{x^2}$

The work done to move the charge a distance dx towards a fixed charge,

$$\Delta w = f \cdot dx$$

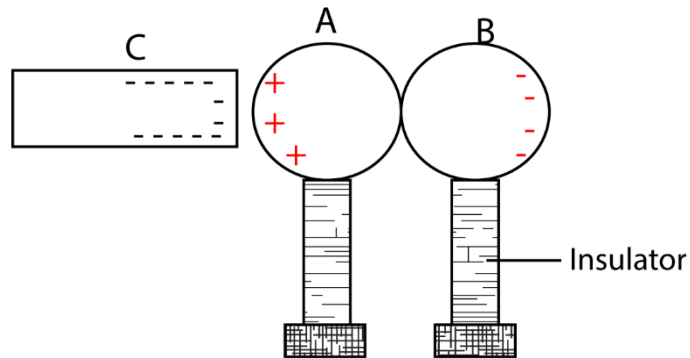
$$= \frac{KQ}{x^2} dx$$

The total work done to bring the charge to a point a distance r from a fixed charge

$$w = \int_{\infty}^r -\frac{KQ}{x^2} dx = KQ \left[\frac{1}{x} \right]_{\infty}^r = \frac{KQ}{r}$$

- (b) (i) Explain with the aid of a diagram, how an insulated metal sphere can be charged by induction using a negatively charged rod. (03marks)

- Two insulated metal spheres A and B, arranged such that they touch one another.
- A negatively charged rod C is brought near A.



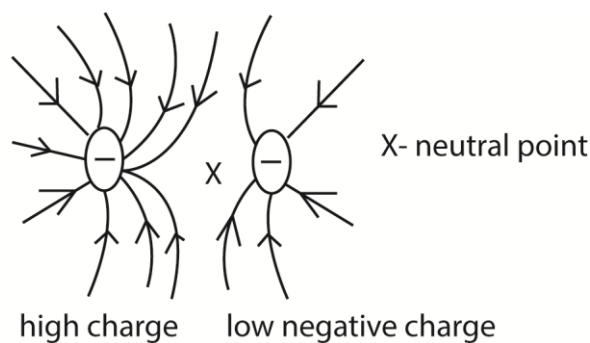
When the spheres are separated while C in position, A will be positively charged while B will be negatively charged.

- (ii) Describe how a gold leaf electroscope can be used to detect the presence of a charge on the body
- A gold leaf electroscope is first charged positively or negatively by bring either a negatively or positively charged rod close to the cap and the then earthed by touching.
 - When a body with similar charge as that on the gold leaf electroscope is brought close to the cap the leaf diverges more.

- (c) (i) Write down the equation for the electrostatic force between two isolated point charges in a vacuum. (01mark)

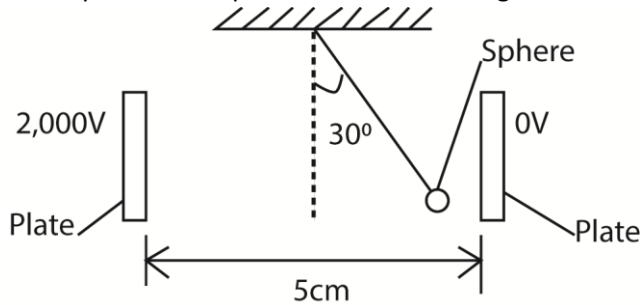
$$F = \frac{1}{4\pi\epsilon_0} \times \frac{Q Q_0}{r^2} \text{ where } \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \text{ and } Q \text{ and } Q_0 \text{ are charges of the point charges}$$

- (ii) Sketch the electric field lines between two negatively charged spheres carrying unequal charges and use the sketches to explain a neutral point. (02marks)

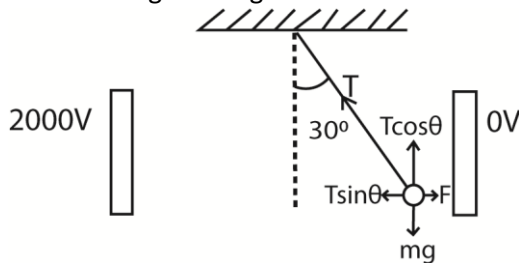


A neutral point in an electric field is a point where the resultant electric field intensity is zero.

(d) A charged polystyrene sphere of mass 2g is suspended by affine nylon thread between two plates 5cm apart as shown in the figure below



When a p.d of 2000V is supplied across the plates, the thread attached to a sphere deflects through an angle of 30° . Calculate the charge on the sphere.



Resolving the force vertically $T \cos \theta = mg$

$$T = \frac{2 \times 10^{-3} \times 9.81}{\cos 30^\circ} = 2.27 \times 10^{-2} \text{N}$$

Resolving horizontally

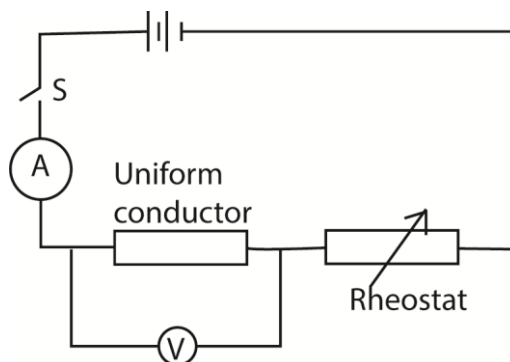
$$\begin{aligned} F &= T \sin 30^\circ \\ &= 2.27 \times 10^{-2} \sin 30^\circ \\ &= 1.13 \times 10^{-2} \text{N} \end{aligned}$$

Electric field intensity, $E = \frac{V}{d}$

But $F = EQ$, where $Q = \text{charge}$

$$Q = \frac{F}{E} = \frac{Fd}{V} = \frac{1.13 \times 10^{-2} \times 5 \times 10^{-2}}{2000} = 2.825 \times 10^{-7} \text{C}$$

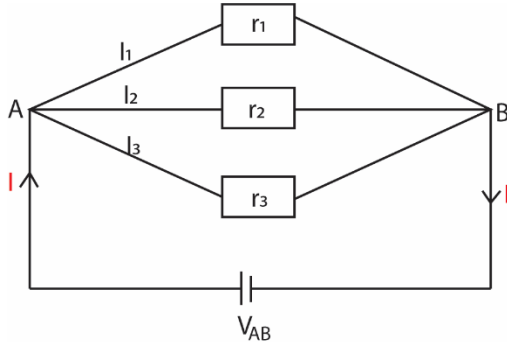
16. (a) Describe an experiment to verify Ohm's law, (04marks)



- The circuit is shown above

- The switch, s is closed
- The Rheostat is adjusted to read suitable values of I and V of ammeter and voltmeter respectively
- The several values of I with corresponding values V are recorded.
- A graph of I against V is plotted.
- A straight line graph through the origin is obtained, hence Ohm's law is verified.

(b) Derive an expression for combined resistance of three resistors in parallel. (04marks)



The p.d. across each resistor is the same = V_{AB}

By conservation of current, $I = I_1 + I_2 + I_3$

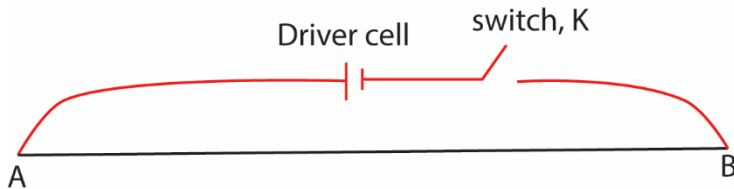
From Ohm's law, $I = \frac{1}{R}$, where R is combined resistance of the resistors

$$\begin{aligned} \therefore I &= \frac{V_{AB}}{r_1} + \frac{V_{AB}}{r_2} + \frac{V_{AB}}{r_3} \\ &= V_{AB} \left[\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \right] \\ \frac{1}{R} &= \frac{I}{V_{AB}} = \left[\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \right] \end{aligned}$$

(c)(i) Explain the principle of operation of a slide wire potentiometer. (04marks)

Potentiometer

It consists of a uniform slide wire which can be of any length (but usually 1m) connected in series with an accumulator or driver cell which maintains a steady current through the wire.



The driver cell supplies a uniform p.d across the wire and hence the p.d across any length of the wire is directly proportional to the length of the section.

Consequently, the p.d per unit length of the slide wire is constant.

By knowing the knowing the p.d per unit length of the slide wire, any p.d can be determined by balancing it against a known length of a wire.

If the p.d per unit length is k and the balance length is L , then the required p.d = kL

- (ii) Two cells A and B connected in series give a balance length of 80.0cm along a potentiometer wire. When Cell B is reversed, the balance length falls to 15.0cm. If the e.m.f of cell A is 1.5V, calculate the e.m.f of cell B. (04marks)

$$E_A + E_B = kL$$

$$\Rightarrow 1.5 + E_B = 80k \dots\dots\dots (i)$$

$$\text{Also } 1.5 - E_B = 15k \dots\dots\dots (ii)$$

From Eqn. (i) and Eqn. (ii)

$$95k = 3$$

$$k = \frac{3}{95}$$

Substituting k in Eqn. (i)

$$E_B = 80 \times \frac{3}{95} - 1.5 = 1.0263V$$

- (d) A battery of e.m.f 20.0V and internal resistance 4.0Ω is connected to a resistor of resistance 10.0Ω . Calculate

- (i) Power generated (02marks)

$$\text{Power generated} = IE, \text{ but } I = \frac{E}{R+r}$$

$$\text{Thus, power} = \frac{E^2}{(R+r)} = \frac{20^2}{10.0+4.0} = 28.75W$$

- (ii) Efficiency of the circuit (02marks)

$$\begin{aligned} \text{Efficiency, } \eta &= \frac{I^2R}{IE} \times 100\% \\ &= \frac{IR}{E} \times 100\% = \frac{ER}{E(R+r)} \times 100\% \\ &= \frac{R}{(R+r)} \times 100\% \\ &= \frac{10}{10+4} \times 100\% \\ &= 71.4\% \end{aligned}$$

17. (a)(i) Define capacitance and dielectric constant. (02marks)

The capacitance of a capacitor is the ratio of the magnitude of charge on either plates of the capacitor to the potential difference between the plates

Dielectric constant of a material is the ratio of capacitance of a capacitor when the space between the plates is filled with a dielectric material to the capacitance of the same capacitor when the space between it plate is a vacuum.

- (ii) State the factors which affect the capacitance of a capacitor. (02marks)

- Separation of the plates
- Area of overlap of the plates
- Permittivity of the medium between the plates

(b) A capacitor of capacitance C_1 is charged by a battery of e.m.f, V_0 . The charging battery is then removed and the capacitor is connected to uncharged capacitor of capacitance, C_2 . Show that the loss of energy after connection is given by

$$E = \frac{1}{2} \left[\frac{C_1 C_2}{C_1 + C_2} \right] V_0^2 \quad (05\text{marks})$$

Energy stored in the capacitor, $E_0 = \frac{1}{2} C V^2$

Total charge before connection, $Q_0 = C_1 V_0$

Total charge after connection, $Q = (C_1 + C_2) V$

Total charge before connection = total charge after connection

Hence $Q = Q_0$

$$\Rightarrow C_1 V_0 = (C_1 + C_2) V$$

$$V = \frac{C_1 V_0}{(C_1 + C_2)}$$

Total energy before connection, $E_0 = \frac{1}{2} C_1 V_0^2$

Total energy after connection, $E = \frac{1}{2} (C_1 + C_2) \left(\frac{C_1 V_0}{(C_1 + C_2)} \right)^2$

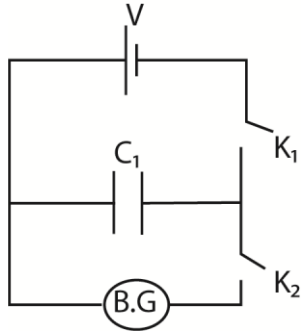
Energy loss = $E_0 - E$

$$= \frac{1}{2} C_1 V_0^2 - \frac{1}{2} (C_1 + C_2) \left(\frac{C_1 V_0}{(C_1 + C_2)} \right)^2$$

Solving

$$\text{Energy loss, } E = \frac{1}{2} \left[\frac{C_1 C_2}{C_1 + C_2} \right] V_0^2$$

(c) Describe an experiment to measure the capacitance of a capacitor using a ballistic galvanometer. (05marks)

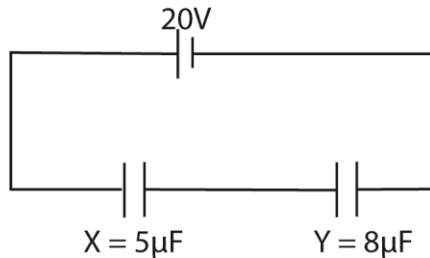


- The circuit is connected as shown with a capacitor of known capacitance C_1 .
- Switch K_1 is closed and K_2 is opened. The capacitor of capacitance C_1 is charged by the battery of e.m.f V .
- K_1 is opened and K_2 is closed to discharge the capacitor through the ballistic galvanometer, B.G. the first deflection of the B.G θ_1 is noted
- The capacitor is then replaced with the capacitor of unknown capacitance C_2 , the experiment is repeated and deflection θ_2 is noted
- Hence $\frac{C_2}{C_1} = \frac{\theta_2}{\theta_1}$; $C_2 = C_1 \frac{\theta_2}{\theta_1}$

(d) A capacitor, X of $5.0\mu\text{F}$ and another, Y of $8.0\mu\text{F}$ are connected in series with a 20V supply.

Calculate the;

(i) Charge on X (04marks)



For capacitors in series, overall capacitance, $C = \frac{C_1 C_2}{C_1 + C_2}$

$$C = \frac{5 \times 10^{-6} \times 8 \times 10^{-6}}{5 \times 10^{-6} + 8 \times 10^{-6}} = 3.08 \times 10^{-6} \text{F}$$

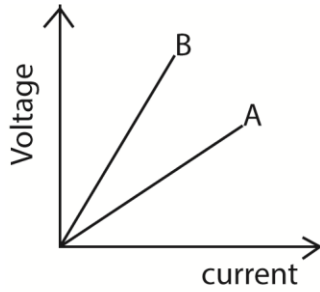
Since $Q = CV$

$$\text{Then } Q = 3.08 \times 10^{-6} \times 20 = 6.16 \times 10^{-5} \text{C}$$

(ii) Potential drop across X (02marks)

$$V = \frac{Q}{C} = \frac{6.16 \times 10^{-5}}{5 \times 10^{-6}} = 12.3 \text{V}$$

18. (a) The voltage versus current graphs for two wires A and B of the same material, same radii and at the same temperature are shown in the figure below



Account for the difference between the graphs

Current flowing through a homogenous conductor is proportional to the p.d. across.

The slope of the graph is equal to the resistance of the conductor.

This implies that the resistance of B is greater than that of A since B has a bigger slope than A

Since resistance is proportional to length, B is longer than A

(b) Three identical cells are connected in series with resistors of 3Ω and 5Ω . A current of 1.2A flows in the circuit. When the two resistors are connected in parallel across the three cells in series, the current in the circuit is 2.2A . Calculate the

(i) internal resistance of each cell (03marks)

For the resistors in series, $R_{\text{eff}} = 3 + 5 = 8\Omega$

$$\therefore 3E = 1.2(3r + 8) \dots\dots\dots (i)$$

When in parallel, $R_{\text{eff}} = \frac{3 \times 5}{3+5} = \frac{15}{8}\Omega$

$$\therefore 3E = 2.2\left(3r + \frac{15}{8}\right) \dots\dots\dots (ii)$$

From Eqn. (i) and Eqn. (ii)

$$1.2(3r + 8) = 2.2\left(3r + \frac{15}{8}\right)$$

$$r = 1.825\Omega$$

(ii) e.m.f of each cell (1mark)

$$3E = 1.2 (3 \times 1.825 + 8) = 5.39\text{V}$$

(iii) power dissipated in the 3Ω resistor for parallel connection (04marks)

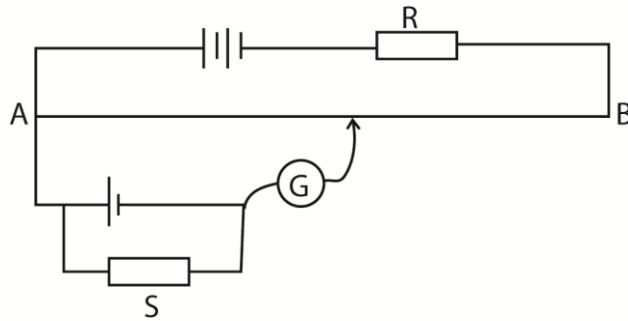
$$\begin{aligned} \text{p.d across } 3\Omega \text{ resistor} &= 3E - 3IR \\ &= 3 \times 5.39 - 3 \times 2.2 \times 1.8 \\ &= 4.12\text{V} \end{aligned}$$

$$\text{Power} = \frac{V^2}{R} = \frac{4.125^2}{3} = 5.72\text{V}$$

(c) Two students X and Y performed separate experiments using a potentiometer arranged as shown below and both obtained a balance point.

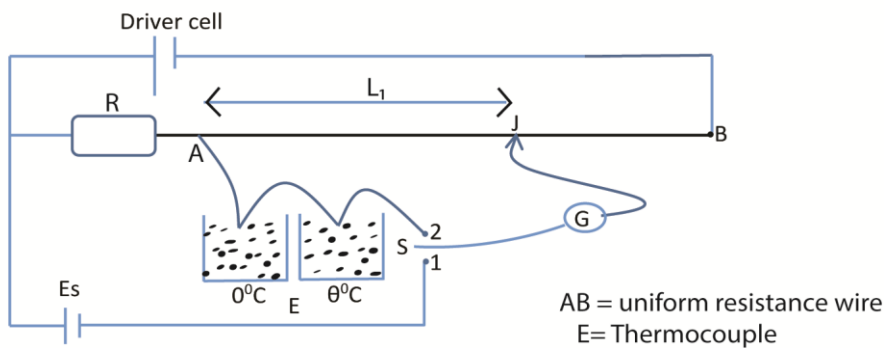
X increased the value of R

Y decreased the value of S



Explain what happened to the position of balance point when

- (i) X increases the value of R (02marks)
 Increasing R reduces the current in driver circuit. Therefore the p.d per cm reduces and therefore the balancing length also increases.
- (ii) Y decreases slightly the value of S from an initially large value (02marks)
 Decreasing the value of S slightly does not change the current in the circuit appreciably and hence the p.d across S remains nearly constant. The position of null deflection is almost unaffected.
- (d) Describe an experiment to determine the e.m.f of a thermocouple (06marks)



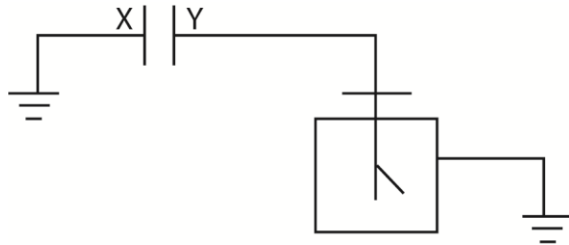
- With switch S in position 1, J is moved along AB until the galvanometer G shows no deflection. The balancing length L_1 is noted
- With switch S in position 2, J is moved along AB until the galvanometer G shows no deflection. The balancing length L_2 is noted
- The e.m.f of the thermocouple is $E = kL_2$
 While $E_S = I(kL_1 + R)$
 $\therefore E = \frac{E_S k L_2}{R + k L_1}$ where k is the resistance per cm of the uniform resistance wire

19. (a) Define the following

- (i) Capacitance (01mark)
The capacitance of a capacitor is the ratio of the magnitude of charge on either plates of the capacitor to the potential difference between the plates
- (ii) Dielectric (01mark)

Dielectric constant of a material is the ratio of capacitance of a capacitor when the space between the plates is filled with a dielectric material to the capacitance of the same capacitor when the space between its plates is a vacuum.

(b) Describe an experiment that can be used to show how capacitance of a capacitor depends on permittivity of dielectric. (04marks)



- The apparatus is set up as above, X and Y are capacitor plates
- Y is charged and the divergence of the leaf of electroscopes is noted.
- A dielectric material is placed between the plates and divergence of the leaf is seen to reduce. This implies that the p.d, V, between the plates has reduced and capacitance increased.
- Thus $C \propto \epsilon$ since permittivity of the material is greater than that of air.

(c) A capacitor of capacitance C, is fully charged from a 200V battery. It is then discharged through a small coil of wire embedded in thermally insulated block of heat capacity 250KJ^{-1} . If the temperature rose by 0.4K, Calculate C. (04marks)

$$\text{Energy stored} = \frac{1}{2}CV^2 = \text{heat dissipated in the coil} = C\theta$$

$$\frac{1}{2}C \times 200^2 = 250 \times 0.4$$

$$C = 5.0 \times 10^{-3}\text{F}$$

(d)(i) State three properties of an equipotential surface. (03marks)

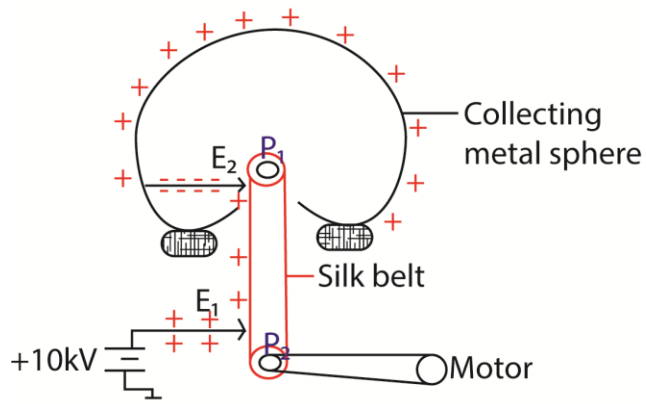
- All the parts at the surface are at the same potential
- Work done to transfer charge from point to another on the surface is zero
- Electric field is perpendicular to the surface

(ii) What is meant by charge quantization? (0marks)

Charge quantization is the product ne where e is the electronic charge and n is an integer.

(e) With the aid of a labelled diagram, describe the structure and action of a Van de Graaff generator. (06marks)

Van der Graaff generator



Main features

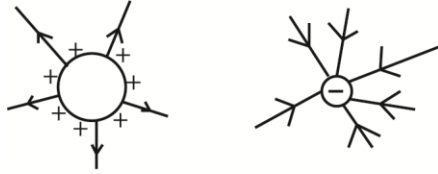
- It consists of a large hollow metal sphere (collecting sphere) supported on insulating stand.
- A silk belt inside the tube driven by an electric motor possesses the sharply pointed electrode metal E_1 , held at electric potential of about 10kV relative to the earth.
- As the belt moves up, it passes another sharply pointed metal electrode E_2 connected inside the hollow sphere.

Mode of operation

- The metal rod E_1 , is kept at a high positive potential of about 10kV with respect to the earth.
- The high positive charge at the sharp ends ionizes the air around.
- The positive ions are repelled to the silk belt carries then towards the collecting sphere.
- At E_2 , the silk belt induces negative charges on the sharp ends of E_1 and the positive charges on the outer of the sphere. The electric field at point ends E_2 ionizes the air around it.
- The negatively charged ions are repelled to the silk belt which is carrying positively charged ions
- The positive ions are neutralized before passing over the upper pulley P_1 .
- The process of silk belt charging up and dis charging is repeated many times per second and each time the belt passes, the sphere charges up positively until it has electric it has electric potential of about 10^6 V relative to the earth.

20. (a) (i) State Coulomb's law of electrostatics (01marks)

- The force between two point charges is directly proportional to the product of the magnitude of the charges and inversely proportional to the square of their separation
- (ii) Sketch the electric field pattern for positively charged metallic sphere and for negative point charge. (02marks)



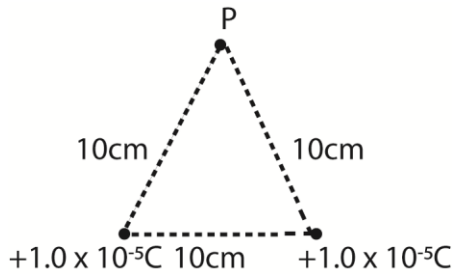
(b) (i) Define electric field intensity and electric potential at a point. (02marks)

- Electric field is the force acting on 1C of positive charge in an electric field.
- Electric potential at a point is the work done to bring 1C of positive charge from infinity to that point in the electric field.

(ii) What is the relationship between them? (01mark)

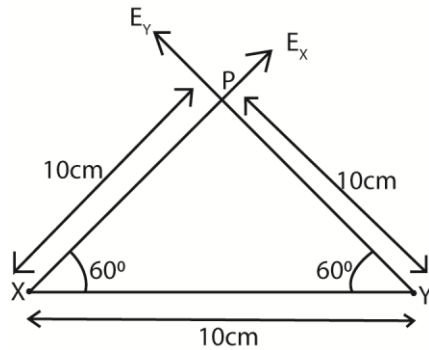
Electric field intensity is equal to the negative gradient of the electric potential.

(c) Two charges of $1.0 \times 10^{-5}\text{C}$ are placed 10cm apart as shown in the figure below



Calculate the

(i) Electric field intensity at P (06marks)



$$E_x = \frac{kQ}{r^2}$$

$$= \frac{9 \times 10^9 \times 10^{-5}}{0.1^2} = 9 \times 10^6 \text{NC}^{-1}$$

$$E_y = \frac{9 \times 10^9 \times 10^{-5}}{0.1^2} = 9 \times 10^6 \text{NC}^{-1}$$

The horizontal component, $E_H = E_x \cos 60^\circ - E_y \cos 60^\circ = 0$ (since $E_x = E_y$)

Vertical component $E_V = 2 \times 9.0 \times 10^6 \sin 60^\circ = 1.5 \times 10^6 \text{NC}^{-1}$

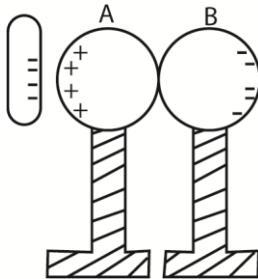
Electric potential at P, $E_R = 1.5 \times 10^6 \text{NC}^{-1}$ (vertically upwards)

(ii) Electric potential at P (03marks)

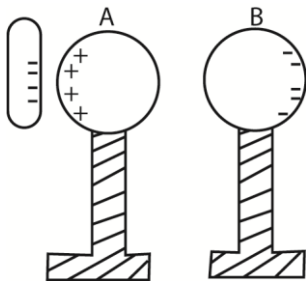
$$\begin{aligned} \text{From } V &= \frac{kQ}{R} \\ V_x &= \frac{9 \times 10^9 \times 10^{-5}}{0.1} = 9 \times 10^5 \text{V} \\ V_y &= \frac{9 \times 10^9 \times 10^{-5}}{0.1} = 9 \times 10^5 \text{V} \\ V &= V_x + V_y \\ &= (9 \times 10^5 + 9 \times 10^5) \text{V} \\ &= 1.8 \times 10^6 \text{V} \end{aligned}$$

(d) Two conducting spheres A and B supported on insulating stand are placed in contact. A negatively charged rod is then held near sphere A. The spheres are then separated after which the rod is removed. With the aid of suitable diagrams, explain the processes which occur. (05marks)

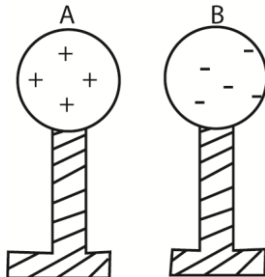
- When the spheres are placed in contact and the negatively charged rod brought near A, it repels negative charge to extreme end of B



- When the spheres are separated B moves with excess negative charges while A remains with excess positive charges



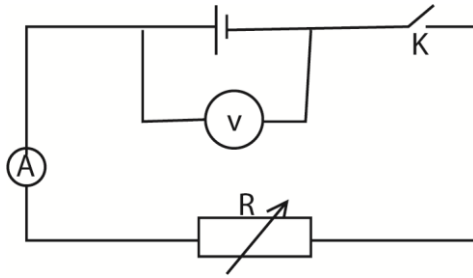
- When the charged body is removed, the charges on each sphere distributes uniformly



21. (a) What is meant by electromotive force of a cell? (01mark)

e.m.f is work done in moving a positive 1C charge around a circuit in which a cell is connected.

(b) Describe an experiment to determine e.m.f and internal resistance of a cell using ammeter, a resistance box and voltmeter. (05marks)



- The circuit is connected as above
- Switch K is closed, R is adjusted to suitable value of I. Ammeter reading I and voltmeter reading V are noted and recorded.
- The rheostat is varied for other four sets of value of I and V
- The values of I and V are tabulated
- A graph of V against I is plotted.
- The slope S is the internal resistance of the cell while intercept V_0 on the V axis is the e.m.f of the cell

Or

- The circuit is connected as above.
- With K open, the voltmeter reading V_0 is recorded.
- K is closed and a rheostat is adjusted to a suitable value
- The ammeter reading I and voltmeter reading V are recorded.
- Internal resistance, $r = \frac{V_0 - V}{I}$

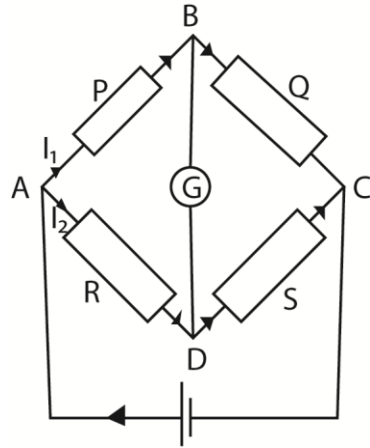
(c) (i) Define temperature coefficient of resistance (01mark)

Temperature coefficient of resistance is the fractional change in resistance at 0° per degree Celsius rise in temperature

(ii) Explain why the resistance of a thermistor reduces when current is passed through it. (02marks)

The current is passed through a thermistor heat is generated. As the temperature rises the loosely bound electrons are released for conduction which reduces resistance.

(d) (i) Derive the balance conditions for Wheatstone bridge. (04marks)



- The resistance P, Q, R, and S are adjusted until $I_G = 0$
- This implies that the potential at B = potential at D, hence p.d across P = p.d across R
 $I_1 P = I_2 R$ (i)
- Current through Q is therefore I_1 and through S is I_2
- P.d across Q = p.d across S
 $I_1 Q = I_2 S$ (ii)
- From equation (i) and (ii)

$$\frac{P}{Q} = \frac{R}{S}$$

(ii) Explain one reason other than faulty apparatus and poor electrical contact, why it may not be possible to obtain balance in a Wheatstone bridge in an experiment to compare two resistances. (02marks)

When the resistance of one resistor is too high or too low compared to others, more current flows through other resistors than that particular resistor and I_G fails to be zero. Thus the balance state cannot be achieved.

(e) In an experiment to investigate the variation of resistance with temperature, a nickel wire and a 10Ω standard resistor were connected in the left-hand gap and right-hand gap respectively of Meter Bridge. When the nickel wire was at 0°C , a balance point is 40cm from the end of the bridge adjacent to the nickel wire. When the nickel wire is at 100°C , the balance point is 50cm from the same end of the bridge.

Calculate the temperature of the nickel wire if the balance length is 42cm. (05marks)

From $\frac{R_0}{L_1} = \frac{R_s}{L_2}$

$$R_0 = \frac{40}{60} \times 10 = \frac{20}{3}$$

$$R_{100} = \frac{50}{50} \times 10 = 10\Omega$$

$$R_\theta = \frac{42}{58} \times 10 = \frac{420}{58}$$

$$\theta = \left(\frac{R_\theta - R_0}{R_{100} - R_0} \right) \times 100$$

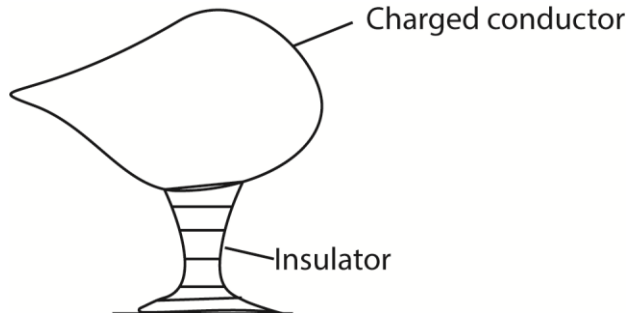
$$= \left(\frac{\frac{420}{58} - \frac{20}{3}}{10 - \frac{20}{3}} \right) \times 100$$

$$= 18.2^0$$

22. (a) (i) What is meant by electric field intensity at a point? (01mark)

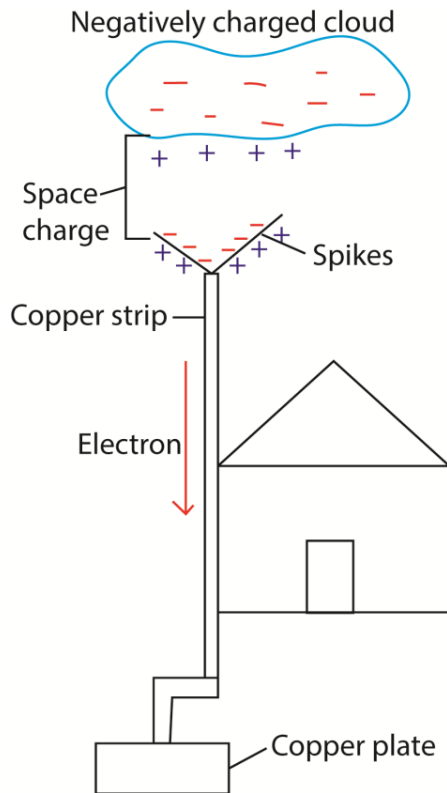
Electric field intensity is the force acting on 1C of positive charge placed at a point in electric field.

(ii) Describe how distribution of charge on a charged conductor of the shape shown below can be investigated.



- An insulated metal can is connected to the cap of a gold leaf electroscope.
 - Then proof planes that fit different parts of the charge conductor are pressed on the corresponding parts of the conductor and then lowered into the can one at a time.
 - The deflection of the gold leaf for each case is noted.
- It is observed that the deflection is greatest for the proof plane pressed at the sharpest point of the charged conductor.
Hence the charge concentration is greatest at the sharpest points.

(iii) Explain how a lightning conductor protects a house from lightning. (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.

(b) (i) what is electric field line?

It is the path (or direction) taken by a small positive charge placed in a field.

- (ii) Derive an expression for electric potential at a point a distance, a , from an isolated charge of magnitude Q in air.

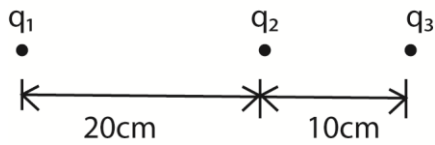
The force on 1C of a charge, $F = \frac{Q}{4\pi\epsilon x^2}$

Work done to move the charge through Δx against the field $\Delta w = -F\Delta x$

Total work done to bring the charge from infinity to a point a distance a from charge Q

$$\begin{aligned}
 w &= \int_{\infty}^a -F dx \\
 &= \int_{\infty}^a \frac{-Q}{4\pi\epsilon x^2} dx \\
 &= \frac{-Q}{4\pi\epsilon} \left[\frac{-1}{x} \right]_{\infty}^a \\
 &= \frac{Q}{4\pi\epsilon a}
 \end{aligned}$$

(c) The figure below shows charges q_1 , q_2 and q_3 of $+46.3\mu\text{F}$, $-34.7\mu\text{F}$ and $+23.4\mu\text{F}$ respectively, placed in straight line in air.



Find the force on q_3 .

From $F = \frac{kQ_1Q_2}{r^2}$, where $k = 9.0 \times 10^9 \text{F}^{-1}\text{m}$

$$F_1 = \frac{9.0 \times 10^9 \times (46.3 \times 10^{-6}) \times (23.4 \times 10^{-6})}{(30 \times 10^{-2})^2} = 108.34\text{N i.e. to the right}$$

$$F_2 = \frac{9.0 \times 10^9 \times (-34.7 \times 10^{-6}) \times (23.4 \times 10^{-6})}{(10 \times 10^{-2})^2} = -730.78\text{N i.e. to the left}$$

Resultant force $F = F_1 + F_2$

$$= 108.34 - 730.78 = -622.44\text{N}$$

So the resultant force on q_3 is 622.44N towards the left

23. (a) Define the following terms

(i) The farad (01mark)

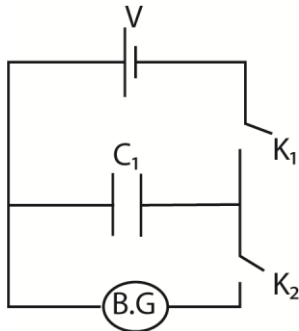
A farad is the capacitance of a capacitor when 1C of charge changes its potential difference by 1V

(ii) Relative permittivity (01mark)

Relative permittivity is the ratio of the capacitance of a capacitor with a dielectric material between its plates to the capacitance of the same capacitor with vacuum between the plates.

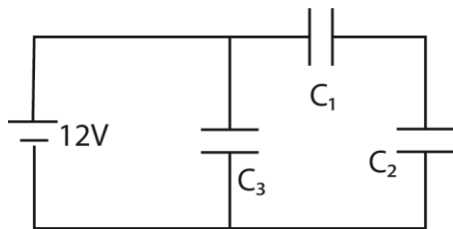
(b) You are provided with the following apparatus, a battery, two switches, a capacitor of known capacitance, a ballistic galvanometer and connecting wires.

Describe an experiment that can be carried out using the above apparatus to determine the unknown capacitance of a capacitor (05marks)



- The circuit is connected as shown with a capacitor of known capacitance C_1 .
- Switch K_1 is closed and K_2 is opened. The capacitor of capacitance C_1 is charged by the battery of e.m.f V .
- K_1 is opened and K_2 is closed to discharge the capacitor through the ballistic galvanometer, B.G. the first deflection of the B.G θ_1 is noted
- The capacitor is then replaced with the capacitor of unknown capacitance C_2 , the experiment is repeated and deflection θ_2 is noted
- Hence $\frac{C_2}{C_1} = \frac{\theta_2}{\theta_1}$; $C_2 = C_1 \frac{\theta_2}{\theta_1}$

(c) The diagram below shows arrangement of three capacitors C_1 , C_2 , and C_3 of capacitance $8\mu\text{F}$, $2\mu\text{F}$ and $6\mu\text{F}$ respectively.



Calculate the total energy stored;

- (i) In all capacitors when fully charged. (04marks)
- Effective capacitance, C_4 , of C_1 and C_2 in series $= \frac{C_1 C_2}{C_1 + C_2} = \frac{8 \times 2}{8 + 2} = 1.6\mu\text{F}$
- Effective capacitance C_4 and C_3 in parallel $= C_4 + C_3 = 1.6\mu\text{F} + 6\mu\text{F} = 7.6\mu\text{F}$
- Total energy stored in the network $= \frac{1}{2} CV^2 = \frac{1}{2} \times 7.6 \times 10^{-6} \times 12^2 = 5.472 \times 10^{-4} \text{J}$
- (ii) When the space between the plates of C_2 is filled with a dielectric of constant 1.25. (04marks)
- New capacitance $C_2' = \epsilon r C_2 = 1.25 \times 2 \times 10^{-6} \text{F} = 2.5\mu\text{F}$
- Effective capacitance, C_5 , of C_1 and C_2' in series $= \frac{C_1 C_2'}{C_1 + C_2'} = \frac{8 \times 2.5}{8 + 2.5} = 1.905\mu\text{F}$
- Effective capacitance C_5 and C_3 in parallel $= C_5 + C_3 = 1.905\mu\text{F} + 6\mu\text{F} = 7.905\mu\text{F}$
- Total energy stored in the network $= \frac{1}{2} CV^2 = \frac{1}{2} \times 7.905 \times 10^{-6} \times 12^2 = 5.69 \times 10^{-4} \text{J}$

- (d) A capacitor of capacitance, C , is charged by a battery and then later isolated. When the plates of the capacitor are taken apart, deduce what happens to the potential difference between the plates. (03marks)

$$\text{From } C = \frac{\epsilon A}{d} \text{ and } V = \frac{Q}{C}; \text{ it implies that } C \propto \frac{1}{d} \text{ and } V \propto \frac{1}{C}.$$

Since ϵ , A and Q are constant, it implies that $d \propto V$, therefore separation increases with increase in p.d between the plates

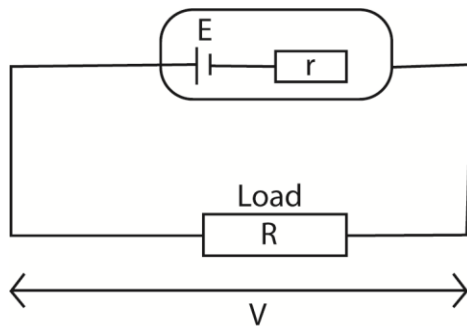
- (e) Explain what happens if a conductor instead of dielectric is placed between the plates of charged capacitor. (02marks)

Charge or p.d or capacitance reduces to zero on the plates. Electrons move from the negative to the positive plate in order to neutralize the charge.

24. (a)(i) Define electromotive force of a battery. (01mark)

Electromotive force of a battery is the energy supplied by the battery to transfer 1C of charge across a complete circuit in which the battery is connected.

- (ii) A cell of e.m.f, E and internal resistance r , drives current through a resistor of resistance, R connected in series with it. Derive an expression for efficiency of the circuit. (04marks)



Power delivered to the load, $P_{out} = IV$

Power supplied by battery, $P_{in} = IE$

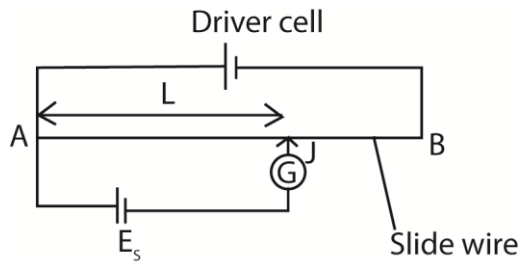
Efficiency, $\eta = \frac{P_{out}}{P_{input}} \times 100\%$

$$= \frac{IV}{IE} \times 100\%$$

But $V = IR$ and $E = I(R + r)$

$$\therefore \eta = \frac{R}{R+r} \times 100\%$$

- (b) Describe with the aid of a diagram how you would standardize a slide wire potentiometer. (03marks)



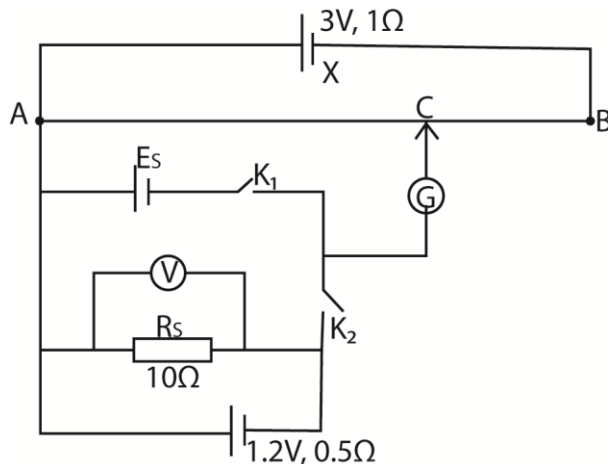
The slide contact is moved along the uniform wire AB until a point where the galvanometer shows no deflection. Distance L is noted

At the balance length, p.d across AJ = e.m.f of E_s

$$E_s = kL$$

$$\therefore k = \frac{E_s}{L}, \text{ where } k = \text{calibration constant.}$$

(c) In the figure below, AB is a uniform resistance wire of length 1m and resistance 4Ω . X is a driver cell of e.m.f 3V and internal resistance 1Ω and E_s is a standard resistor of resistance 10Ω which is connected in series with cell Y of e.m.f 1.22 V and internal resistance 0.5Ω



With switch K_1 closed and K_2 open, the balance length, AC is 60cm while the voltmeter reading is 1.14V. with K_1 open and K_2 closed, the balance length is 80cm. Calculate the

(i) E.m.f E_s , of standard cell. (03marks)

$$\text{Driver current, } I_d = \frac{E_x}{R} = \frac{3}{1+4} = \frac{3}{5} = 0.6A$$

$$\text{Resistance per cm of the wire} = \frac{4}{100} = 0.04\Omega$$

$$E_s = k \times 60 \text{ where } k = \text{p.d per cm}$$

$$= 0.04 \times 0.6 \times 60$$

$$= 1.44V$$

(ii) Percentage error in the voltmeter reading (03marks)

When K_1 is open and K_2 is closed,

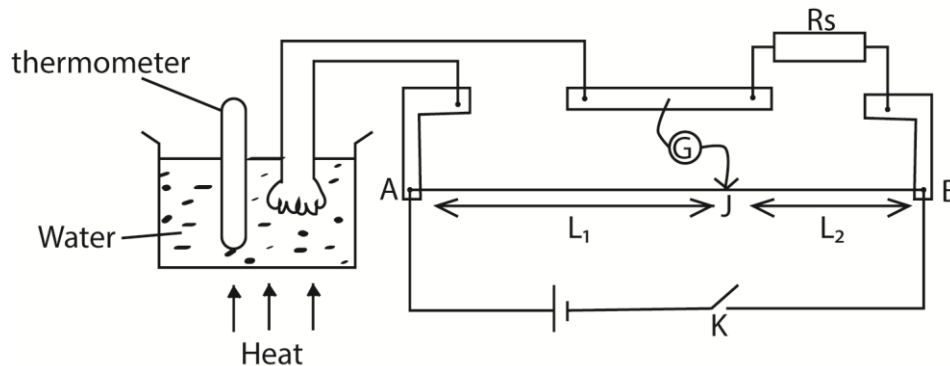
$$(I_s \times R_s) = k \times 80 = 0.04 \times 0.6 \times 80 = 1.92V$$

$$VR = 1.14$$

$$\text{Error} = 1.92 - 1.14 = 0.78V$$

$$\% \text{ error} = \frac{0.78}{1.92} \times 100 = 40.6\%$$

(d) Describe with the aid of a circuit diagram how you would measure the temperature coefficient of resistance of a material in form of a wire. (06marks)

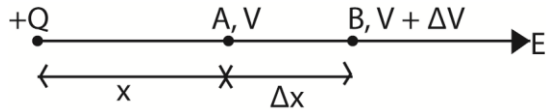


- The apparatus are set up as above
- The specimen wire is made into a coil and immersed in water bath.
- The ends of the coil are connected to the left gap of the Meter Bridge and standard resistor, R_s in the right hand gap.
- The water bath is heated to a suitable temperature, θ , and after through stirring and K is closed. The jockey is tapped to a point on the slide wire AB where the galvanometer shows no deflection
- The balance lengths L_1 and L_2 are noted and recorded.
- The procedure is repeated for different values of θ and the results are tabulated including values of $R_\theta = R_s \times \frac{L_1}{L_2}$.
- A graph of R_θ against θ is plotted and its slope S and intercept R_0 on the R_θ axis are obtained.
- Mean temperature coefficient, $\alpha = \frac{S}{R_0}$

25. (a) State coulomb's law of electrostatics. (01marks)

The force between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance of the separation of charges.

(b) Derive the relation between electric field intensity, E , and electric potential, V , due to a charge at a point. (04marks)



If the potential at A is V and that at B is $V + \Delta V$, then the potential difference between A and B,

$$\begin{aligned} V_{AB} &= V_A - V_B \\ &= V - (V + \Delta V) \\ &= -\Delta V \end{aligned}$$

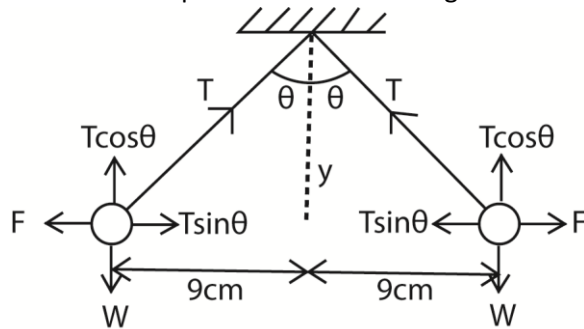
The work done in moving 1C of charge from B to A = $E(\Delta x) = V_{AB}$

$$\begin{aligned} E\Delta x &= -\Delta V \\ E &= -\frac{\Delta V}{\Delta x} \end{aligned}$$

In limits, as $\Delta x \rightarrow 0$, E becomes the electric field strength at a point

$$\therefore E = -\frac{dV}{dx}$$

(c) Two pith ball P and Q each of mass 0.1g are separately suspended from the same point by threads 30cm long. When the balls are given equal charges, they repel each other and come to rest 18cm apart. Calculate the magnitude of charge on each ball. (06marks)



$$y^2 = 30^2 - 9^2$$

$$y = 28.62$$

Horizontal component, $F = T \sin \theta$ (i)

Vertical component, $mg = T \cos \theta$ (ii)

From (i) and (ii)

$$\frac{F}{mg} = \tan \theta$$

$$F = mg \tan \theta = 0.1 \times 10^{-3} \times 9.81 \times \frac{9}{28.62} = 0.309 \times 10^{-3}$$

$$\text{But } F = \frac{kQ^2}{r^2} = \frac{9 \times 10^9 \times Q^2}{(18 \times 10^{-2})^2} = 0.309 \times 10^{-3}$$

$$Q = 3.33 \times 10^{-8} \text{C}$$

(d) Describe how you would investigate the distribution of charge on pear shaped conductor. (04marks)

(04marks)

- A proof plane is placed on a part of a charged conductor transferred into a hollow metallic can placed on the cap of neutral electroscope and the deflection of the electroscope noted.
- The procedure is repeated for the different parts of the charged conductor.

- It is observed that the greatest deflection is got for a proof plane placed at the sharpest point of the charged conductor. This implies that charges are most concentrated where the curvature is greatest.

(e) Explain how a charged body attracts uncharged conductor. (03marks)

- When a charged body is brought near uncharged conductor, the electrons in the conductor are displaced.
- The end nearest the charges body acquire a charge opposite to that of charged body while the end remote acquires a charge similar to that of charged body.
- Consequently, the end nearest to the charge body is attracted.

(f) Describe how an electroscope can be used to distinguish a conductor from an insulator. (01mark)

- An electroscope is given a charge and the divergence is noted.
- The material is brought into contact with the cap of electroscope.
- When there is no change in divergence, the material is an insulator
- When the divergence reduces, the material is a conductor.

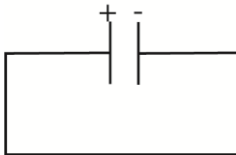
26. (a) Define dielectric strength. (01mark)

Dielectric strength is the maximum electric field intensity an insulator can withstand without conducting.

Or

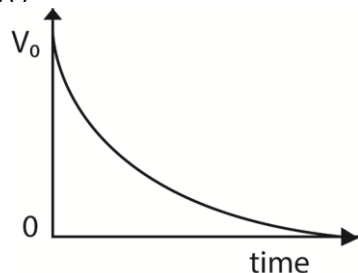
The maximum potential gradient an insulator can withstand without conducting

(b) (i) Explain briefly how a capacitor in which the potential difference, V_0 across the plates, can be fully discharged. (02marks)



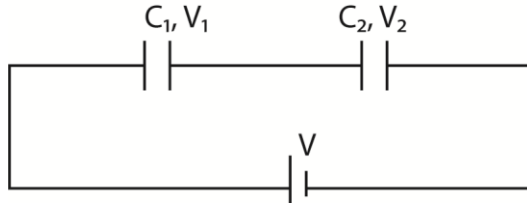
The wire is connected from the positive plate to the negative plate. Electrons flow from the negative plate to the positive plate neutralizing the positive charges. The follow of electrons continues until all the capacitor is fully neutralized.

(ii) Sketch a graph showing a variation of potential difference with time for the process in (b)(i) above



- (c) (i) Two capacitors of capacitance C_1 and C_2 are connected in series. Show that the effective capacitance, C , is given by

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



In series, the charge on each capacitor, Q , is the same, let C be the effective charge

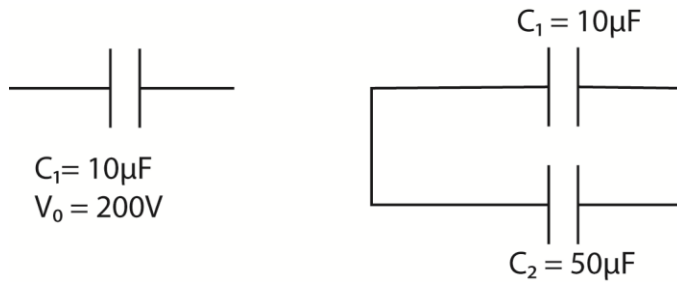
$$V = V_1 + V_2$$

$$\text{Also, } V = \frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

$$\text{Or } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

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

- (ii) A $10.0\mu\text{F}$ capacitor charged to 200V is connected across uncharged $50\mu\text{F}$ capacitor. Calculate the total energy stored in both capacitors before and after connection (04marks)

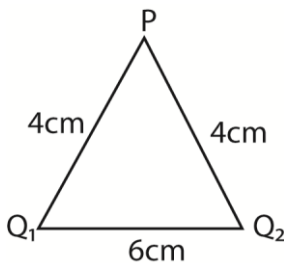


$$\text{Total energy stored before} = \frac{1}{2} C V^2 = \frac{1}{2} \times 10 \times 10^{-6} \times 200^2 = 0.2\text{J}$$

$$\text{Effective capacitance in series after connection} = \frac{10 \times 50}{10 + 50} = 8.33\mu\text{F}$$

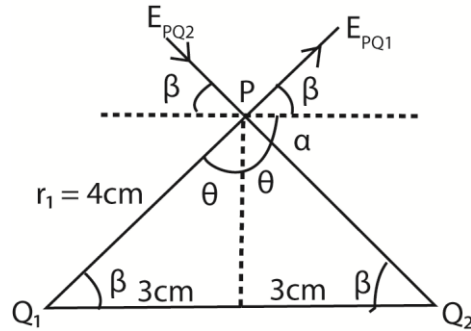
$$\text{Total energy stored after connection} = \frac{1}{2} \times 8.33 \times 10^{-6} \times 200^2 = 0.17\text{J}$$

- (iii) Account for the difference in the energies calculated in (c)(ii) above. (01mark)
The stored energy after connection is less due to energy loss in the connecting wire.
- (d) In the figure below, Q_1 and Q_2 are point charges of magnitude $+5.0\mu\text{C}$ and $-5.0\mu\text{C}$ respectively



Calculate the

- (i) Electric field intensity at P



From electric field intensity, $E = \frac{Q}{4\pi\epsilon_0 r^2}$

$$E_{PQ1} = \frac{Q}{4\pi\epsilon_0 r_1^2} = \frac{(9 \times 10^9) \times 5 \times 10^{-5}}{(4 \times 10^{-2})^2} = 2.8 \times 10^7 \text{NC}^{-1}$$

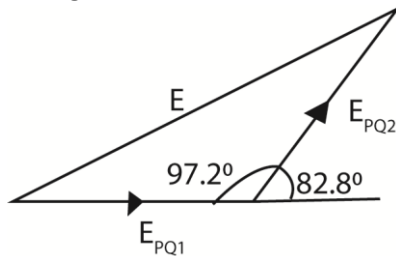
$$E_{PQ2} = \frac{-Q}{4\pi\epsilon_0 r_1^2} = \frac{-(9 \times 10^9) \times 5 \times 10^{-5}}{(4 \times 10^{-2})^2} = -2.8 \times 10^7 \text{NC}^{-1}$$

Using cosine rule, $6^2 = 4^2 + 4^2 - 2 \times 4 \times 4 \cos\theta$

$$\theta = \cos^{-1}\left(\frac{36-32}{32}\right) = 97.2^\circ$$

$$\alpha = 180 - 97.20 = 82.8^\circ$$

Triangle of intensities



$$E^2 = E_{PQ1}^2 + E_{PQ2}^2 - 2 \times E_{PQ1} \times E_{PQ2} \cos 97.2^\circ$$

$$E = 4.2 \times 10^7 \text{NC}^{-1}$$

Since E_{PQ1} and E_{PQ2} have equal magnitude, then the result bisects the angle between them. So it acts horizontally to right

(ii) Potential energy of appoint charge Q_3 of $0.8\mu\text{F}$ placed at P

$$\begin{aligned} \text{From } V &= \sum \frac{Q}{4\pi\epsilon_0 r} \\ &= \frac{Q_1}{4\pi\epsilon_0 r_1} + \frac{Q_2}{4\pi\epsilon_0 r_2} \\ &= 9 \times 10^9 \left[\frac{5 \times 10^{-6}}{4 \times 10^{-2}} - \frac{5 \times 10^{-6}}{4 \times 10^{-2}} \right] = 0 \end{aligned}$$

But potential energy = $QV = 0$

27. (a) (i) Define electrical resistivity and state its units (02marks)

Electrical resistivity is the resistance across opposite faces of a 1m cube of material. Unit of electrical resistivity is ohmmeter (Ωm)

(ii) What is meant by e.m.f and internal resistance of a battery (02marks)

E.m.f of a battery is the energy required to convey 1C of charge round a complete circuit including the cell

Internal resistance of a battery is the resistance in series with external circuit which accounts for energy losses inside a battery when the battery is supplying current.

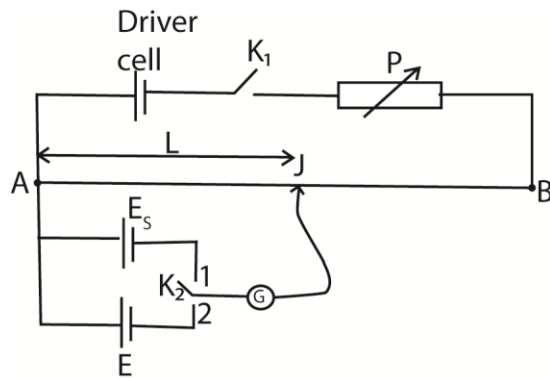
Or

The opposition to the flow of current inside the battery due to its chemical composition.

(b) Explain why resistance of a metal increases when temperature of the metal is increased. (02marks)

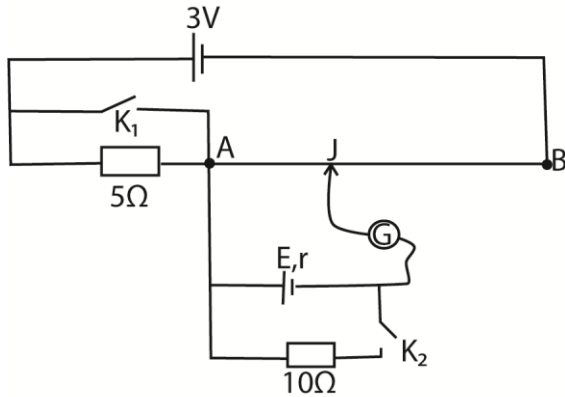
When the temperature of a metal increases, the amplitude of vibration of its atoms increases. This reduces the mean free path for conduction of electrons. Thus fewer electrons flow per second through the metal; the current flowing reduces and thus resistance increases.

(c) Describe with the aid of labelled diagram, how a slide wire potentiometer may be used to determine the e.m.f of a battery. (06marks)



- The circuit is connected as above.
- Switch K₁ is closed
- Switch K₂ is connected to 1 and contact J is moved along AB to a point where the galvanometer shows no deflection and the balance length L₀ is measured.
- Switch K₂ is connected to 2 and contact J is moved along AB to a point where the galvanometer shows no deflection and the balance length L is measured.
- If the e.m.f of the test cell is E, then $E = E_s \frac{L}{L_0}$
-

(d)



The circuit in the figure above shows a uniform slide wire AB of length 100cm and resistance 10Ω. The wire is connected in series with a resistor of resistance 5Ω across 3.0V battery of negligible internal resistance. A cell of resistance, E and internal resistance, r, is connected as shown. With switches K_1 and K_2 open, the galvanometer, G shows no deflection when AJ is 75.0cm. With K_1 and K_2 closed, the galvanometer shows no deflection when AJ is 65.0cm. Find the

(i) Value of e.m.f, E.

At balance with K_1, K_2 open, e.m.f.,

$E = \text{p.d across AD}$

$= I \times R$

$$= 3 \times \frac{15}{(15+5)} \times \frac{75}{100} = 1.69\text{V}$$

(ii) Internal resistance, r

When K_1 's open and K_2 closed

$$\text{P.d across } 10\Omega \text{ resistor, } V = 3 \times \frac{15}{20} \times \frac{65}{100} = 1.46\text{V}$$

$$\text{But } \frac{E}{V} = \frac{R+r}{R}$$

$$\frac{1.69}{1.46} = 1 + \frac{r}{10}$$

$$r = 1.6\Omega$$

(iii) Balance length when K_1 is closed, and K_2 is open

K_1 closed and K_2 open

$$\text{p.d per cm of AB} = \frac{3}{100} \text{Vcm}^{-1}$$

$$\text{If the balance length is } L', \text{ then } \frac{3}{100} L' = 1.69$$

$$L' = 56.3\text{cm}$$

28. (a) (i) Define electric potential (01mark)

Electric potential at a point is the work done in moving a positive charge of one coulomb from infinity to that point in an electric field against electrostatic force.

(ii) Derive an expression for electric potential at a point which is a distance, r, from a point charge Q (04marks)

Force on 1C of a charge, $F = \frac{Q}{4\pi\epsilon x^2}$

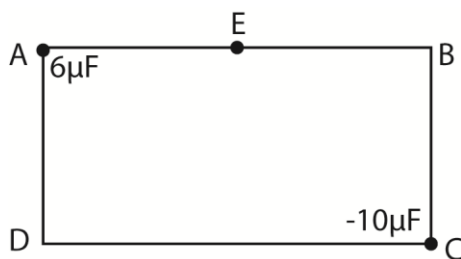
Work done to move the charge through distance Δx against the field

$$\Delta w = -F\Delta x$$

Total work done to bring the charge from infinity to a point, a distance r from a charge Q'

$$\begin{aligned} w &= \int_{\infty}^r -F dx = \int_{\infty}^r = \frac{-Q}{4\pi\epsilon x^2} dx \\ &= -\frac{Q}{4\pi\epsilon} \left[\frac{1}{x} \right]_{\infty}^r \\ &= \frac{Q}{4\pi\epsilon r} \end{aligned}$$

(b) Two charges of magnitude $6\mu\text{F}$ and $-10\mu\text{F}$ are placed at the corners of a rectangle ABCD as shown in the figure below



AB = 6cm and BC = 4cm. Point E is the mid-point of AB. Find the work done in taking a point charge of $1.6 \times 10^{-10}\text{C}$ from D to E. (05marks)

Electric potential, $V = \frac{Q}{4\pi\epsilon_0 r}$

$$V_D = 9 \times 10^9 \left[\frac{6 \times 10^{-6}}{4 \times 10^{-2}} - \frac{10 \times 10^{-6}}{6 \times 10^{-2}} \right] = -1.5 \times 10^5 \text{V}$$

CE = ED

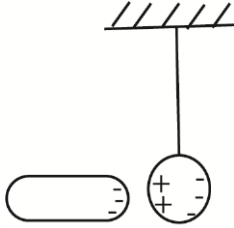
$$CE = \sqrt{3^2 + 4^2} = 5$$

$$V_E = 9 \times 10^9 \left[\frac{6 \times 10^{-6}}{3 \times 10^{-2}} - \frac{10 \times 10^{-6}}{5 \times 10^{-2}} \right] = 0 \text{V}$$

$$V_{ED} = 0 - (-1.5 \times 10^5) = 1.5 \times 10^5 \text{V}$$

$$w = QV = 1.6 \times 10^{-10} \times 1.5 \times 10^5 = 2.4 \times 10^{-5} \text{J}$$

(c) A negatively charged ebonite rod is brought up to an uncharged pith ball suspended by a silk thread. The pith-ball first moves to the rod, touches it and then moves away. Explain these observations (04marks)



The charged ebonite rod induces positive charge on the side of the ball near it and thus attract it.

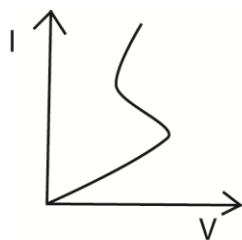
After contact, the ball acquires a negative charge and thus the two bodies repel each other.

29. (a) (i) State Ohm's law. (01mark)

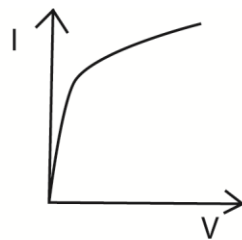
Ohm's law states that the current flowing through a given conductor is directly proportional to the potential difference between its ends provided the physical conditions remain constant.

(ii) Give two examples of non-Ohmic conductors and sketch their current-voltage characteristic. (03marks)

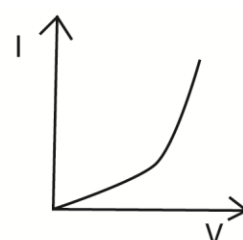
Non-Ohmic conductor include thermistor, filament lamp, junction diode, thermionic diode, gas discharge tube, dilute sulphuric acid electrolyte with platinum electrodes.



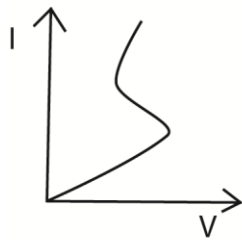
Thermistor



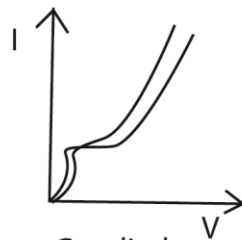
Filament lamp



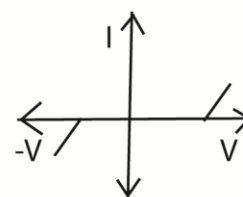
Junction diode



thermionic valve

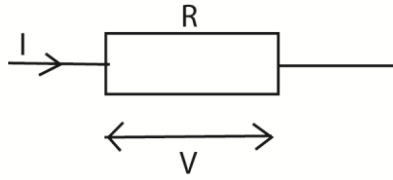


Gas discharge tube



Gas discharge tube

(b) (i) Derive an expression for electrical energy dissipated in a resistor of resistance, R ohms carrying current I ampere for t seconds. (03marks)



When current I flows through the resistor for a time T ,

Total charge conveyed is $Q = IT$

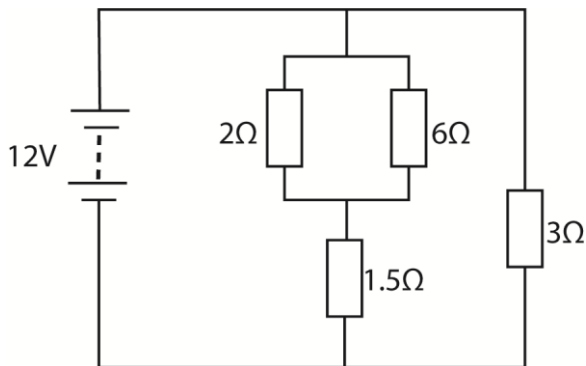
With a p.d V across R , the work done to transfer charge Q through R is

$$W = QV$$

But $V = IR$

$$W = It \times IR = I^2R$$

(ii) A network of resistors of 2Ω , 6Ω , 1.5Ω and 3Ω are connected to a $12V$ d.c. supply of negligible internal resistance as shown below



Calculate the power dissipated in the 6Ω resistor. (04marks)

$$2\Omega \text{ and } 6\Omega \text{ in parallel, effective resistance, } R_1 = \frac{2 \times 6}{2+6} = 1.5\Omega$$

p.d across the parallel network = $6V$

Hence p.d across 6Ω is $6V$

$$\text{Power } P = \frac{V^2}{R} = \frac{6^2}{6} = 6W$$

(c) (i) Define temperature coefficient of resistance (01mark)

Temperature coefficient of resistance is defined as fractional change in resistance at 00 for every degree Celsius rise in temperature.

- (ii) Explain why semiconductors have negative temperature coefficient of resistance. (02marks)

Semi-conductor have few electrons available for conduction at room temperature. When current is passed through it, the material heats up and more electrons are set free. Thus the current increases and resistance decreases as temperature increases. Hence temperature coefficient of resistance is negative.

- (d) An electric heater consists of 5.0m of nichrome wire of diameter 0.58mm. When connected to a 240V supply, the heater dissipated 2.5kW and the temperature of the heater is found to be 1020°C. If the resistivity of nichrome at 10°C is $10.2 \times 10^{-7} \Omega\text{m}$, calculate

- (i) The resistance of nichrome at 10°C (03marks)

$$R_{10} = \frac{\rho L}{A} = \frac{10.2 \times 10^{-7} \times 5 \times 4}{\pi(5.8 \times 10^{-4})^2} = 19.3 \Omega$$

- (ii) The mean temperature coefficient of resistance of nichrome between 10°C and 100°C. (03marks)

$$\text{At } 1020^\circ, \frac{V^2}{R_{1020}} = 2.5 \times 10^3$$

$$\Rightarrow R_{1020} = \frac{240^2}{2.5 \times 10^3} = 23.04 \Omega$$

$$\frac{R_{1020}}{R_{10}} = \frac{1+1020\alpha}{1+10\alpha} = \frac{23.04}{19.3} = 1.194$$

$$1 + 1020\alpha = 1.194 + 11.94\alpha$$

$$\alpha = 1.92 \times 10^{-4} \text{K}^{-1}$$

30. (a) Define electric potential difference (01mark)

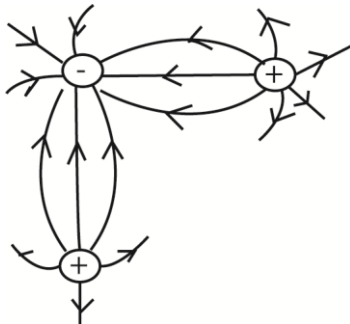
Electric potential difference between two points is the work done to transfer 1C of charge from one point to the other against electrostatic field.

- (b) Explain briefly what happens to the potential energy as two point charges of the same sign are brought closer. (02marks)

Like charges repel. work has to be done against the repulsive forces between them to bring them closer.

- (c) Three point charges of $+5\mu\text{C}$, $-3\mu\text{C}$ and $+2\mu\text{C}$ are placed respectively at three corners of a square of side 6.3cm in a vacuum.

- (i) Sketch the electric field lines due to the charges. (02marks)



- (ii) Calculate the electric field potential at the fourth corner of the square (04marks)

$$\text{Electric potential } V = \frac{kQ}{r}$$

$$\text{Total potential } V = V_1 + V_2 + V_3$$

$$= k \left(\frac{Q_1}{r_1} + \frac{Q_2}{r_2} + \frac{Q_3}{r_3} \right)$$

$$= 9 \times 10^9 \left(\frac{5 \times 10^{-6}}{6.3 \times 10^{-2}} - \frac{3 \times 10^{-6}}{\sqrt{(6.3 \times 10^{-2})^2 + (6.3 \times 10^{-2})^2}} + \frac{2 \times 10^{-6}}{6.3 \times 10^{-2}} \right)$$

$$= 6.97 \times 10^5 \text{V}$$

(iii) Find the electric potential energy, if a charge of $-4\mu\text{C}$ is placed at the fourth corner.
(02marks)

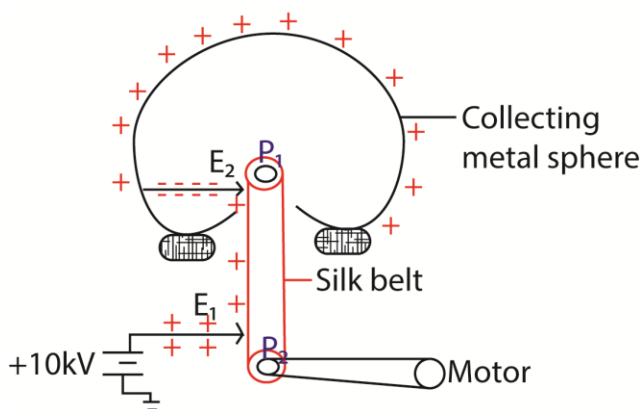
$$\text{Electric potential energy, } W = VQ$$

$$= 6.97 \times 10^5 \times -4 \times 10^{-6}$$

$$= -2.79\text{J}$$

(d) Describe, with the aid of a diagram, how a high voltage can be generated using a Van de Graaff generator. (06marks)

Van der Graff generator



Main features

- It consists of a large hollow metal sphere (collecting sphere) supported on insulating stand.
- A silk belt inside the tube driven by an electric motor possesses the sharply pointed electrode metal E_1 , held at electric potential of about 10kV relative to the earth.
- As the belt moves up, it passes another sharply pointed metal electrode E_2 connected inside the hollow sphere.

Mode of operation

- The metal rod E_1 , is kept at a high positive potential of about 10kV with respect to the earth.
- The high positive charge at the sharp ends ionizes the air around.
- The positive ions are repelled to the silk belt carries then towards the collecting sphere.
- At E_2 , the silk belt induces negative charges on the sharp ends of E_1 and the positive charges on the outer of the sphere. The electric field at point ends E_2 ionizes the air around it.

- (v) The negatively charged ions are repelled to the silk belt which is carrying positively charged ions
- (vi) The positive ions are neutralized before passing over the upper pulley P_1 .
- (vii) The process of silk belt charging up and discharging is repeated many times per second and each time the belt passes, the sphere charges up positively until it has electric it has electric potential of about 10^6V relative to the earth.
- (e) Explain how two insulating bodies rubbed together acquire charge.
 When two dissimilar insulators are rubbed together, heat is generated due to friction. Heat cause a material of lower function to lose electron to the other. The material that loses electrons becomes positively charged while the one that accepts electron becomes negatively charge.

31. (a) (i) Define capacitance of a capacitor. (01mark)

Capacitance of a capacitor is the ratio of the magnitude of charge on one of the plates of of a capacitor to the potential difference between the plates.

(ii) Drive an expression for energy stored in a capacitor of capacitance C charged to a p.d, V . (04marks)

Suppose the p.d between the plates at some instant is V . When a small charge of δq is transferred from the negative plate to the positive plat, the p.d increases by δV .

Work done to transfer the charge; $\delta w = (V + \delta V)\delta q$
 $\approx V\delta q$

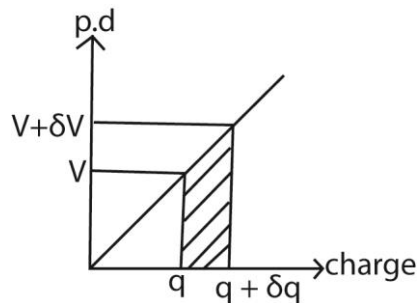
But $V = \frac{q}{C}$

$\therefore \frac{q}{C} \delta q$

Total work done = $\int_0^q \frac{q}{C} \delta q = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} CV^2$

Or

From $q = CV$, V is proportional to q , this gives the graph of V against q below



Shaded area = $\frac{1}{2} (V + V + \delta V) \times dV$

= work done to increase charge on the capacitor by δq

\therefore to charge a capacitor from $q = 0$ to $q = Q$

Work done, w = average voltage \times charge

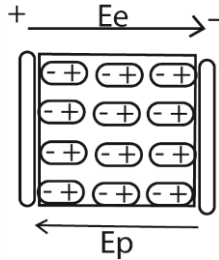
$= \frac{1}{2} (0 + V) \times Q$

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

But $Q = CV$

$$\therefore w = \frac{1}{2} CV^2$$

(b)(i) Explain the effect of placing an insulator between the plates of a charged capacitor.
(05marks)



When a dielectric is placed between the plates of a charged capacitor, the nucleus of the molecules of the dielectric are urged in the direction of the field and the electrons in opposite direction.

The molecules get polarized and the surface of the dielectric near the capacitor develops charges opposite to those on adjacent plates while the charges inside the dielectric cancel out.

Since the charge on the dielectric are not conductible, electric field intensity develops between the surfaces of the dielectric in the direction opposite to the supplied field. The resultant electric field intensity is thus reduced.

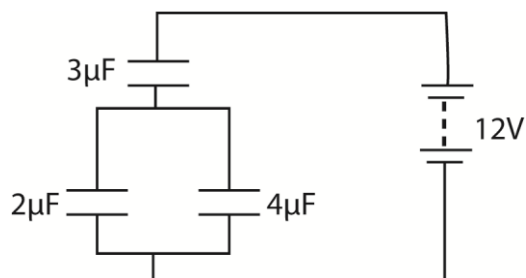
But $E = \frac{V}{d}$ hence the p.d between the plates V is reduced.

From $C = \frac{Q}{V}$; a reduction in V leads to increase in C

(ii) State two physical properties desirable in a material to be used as a dielectric in a capacitor.
(02marks)

- Large dielectric constant
- High dielectric strength

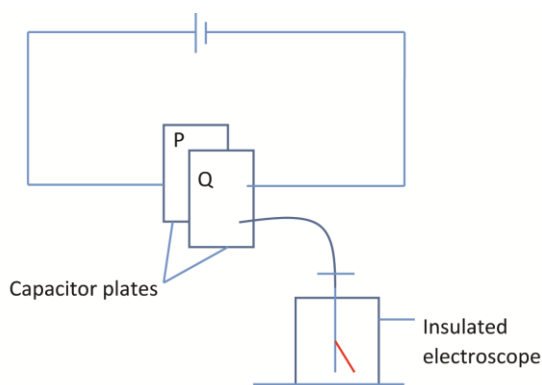
(c)



A battery of e.m.f. 12V is connected across a system of capacitors as shown in the figure above. Find the

- (i) Charge on the $3\mu\text{F}$ capacitor (03marks)
 Effective capacitance in parallel, $C = C_1 + C_2 = (2 + 4)\mu\text{F} = 6\mu\text{F}$
 Effective capacitance in series = $\frac{6 \times 10^{-6} \times 3 \times 10^{-6}}{(6+3) \times 10^{-6}} = 2 \times 10^{-6}\text{C}$
 $Q = CV = 2 \times 10^{-6} \times 12 = 2.4 \times 10^{-5}\text{C}$
 Hence the charge on $3\mu\text{F}$ capacitor = $2.4 \times 10^{-5}\text{C}$
- (ii) Energy stored in the $4\mu\text{F}$ capacitor (03marks)
 p.d across the $6\mu\text{F}$, $V = \frac{Q}{C} = \frac{2.4 \times 10^{-5}}{6 \times 10^{-6}} = 4.0\text{V}$
 p.d across $4\mu\text{F} = 4.0\text{V}$
 energy store by $4\mu\text{F}$ capacitor = $\frac{1}{2}CV^2 = \frac{1}{2} \times 4 \times 10^{-6} \times 4^2 = 3.2 \times 10^{-5}\text{J}$

(d) Describe a simple experiment to show that capacitance of a capacitor increases with surface area of the plates. (02marks)



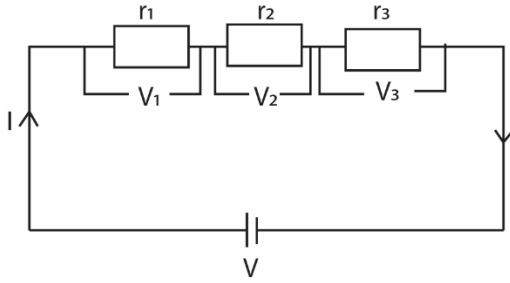
A p.d is set across the capacitor plates P and Q, by connecting a cell across it. One plate Q is connected to the cap of electroscopes. With the p.d constant and the plates in the above position with air in between them, the divergence of the leaf of electroscopes is noted.

Plate P is then slid relative to Q keeping the separation constant, hence reducing the effective area of the plate. The divergence is seen to decrease.

Since divergence is proportional to charge on the plates, which in turn is proportional to the capacitance, C, then, C is reduced.

This shows that $C \propto A$

32. (a) (i) Derive the formula for combined resistance of three resistors in series. (04marks)



For series arrangement, the same current I flows through the resistors but each resistor has its own P.d. across

For r_1 , $V_1 = r_1 I$ (i)

For r_2 , $V_2 = r_2 I$ (ii)

For r_3 , $V_3 = r_3 I$ (iii)

$$V = V_1 + V_2 + V_3$$

$$= r_1 I + r_2 I + r_3 I$$

$$= I(r_1 + r_2 + r_3)$$

Resultant resistance, $R = \frac{V}{I} = (r_1 + r_2 + r_3)$

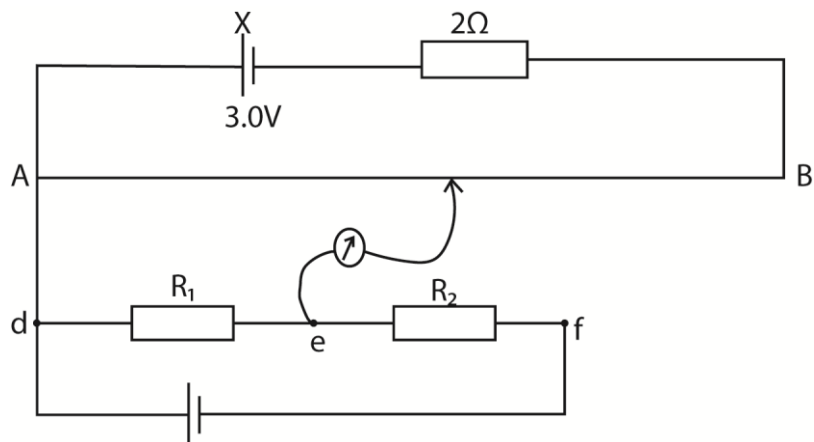
(ii) Explain why a metal wire becomes hot when an electric current flows through it. (04marks)

Electrons are accelerated by the electric field in the conductor. As they drive, they collide with ions in the conductor losing some of their kinetic energy to the ions, this energy increases vibrational energy of the ions, hence temperature increases

(iii) What advantage does the potentiometer have over Wheatstone bridge when used to compare two low resistances? (02marks)

The potentiometer gives accurate balance lengths for low resistance because resistances of conducting wires do not affect the results. For the Wheatstone bridge, the resistance of its end connection becomes significant when used to compare low resistances, which makes it less accurate.

(b)



In the figure above, AB is a slide wire of length 1.0m and resistance 10Ω. X is a driver cell of e.m.f 3.0V and negligible internal resistance. When the center –zero galvanometer is connected in turns to points e and f, the balance lengths obtained are 45.0cm and 80.0cm respectively.

Calculate the

- (i) The current flowing through R_1 . (04marks)
 If the current through the driver circuit and R_1 is I_d and I_1 respectively, it follows that

$$I R_1 = I_d R$$

$$\text{At e, } R = \frac{45}{100} \times 10 = 4.5\Omega$$

$$I_d = \frac{3}{10+2} = 0.25\text{A}$$

$$I_1 R_1 = 0.25 \times 4.5 = 1.125$$

$$I_1 = \frac{1.125}{R_1}$$

- (ii) Resistances of R_1 and R_2 . (02marks)

When at f

$$I_1(R_1 + R_2) = I_d \left(\frac{80}{100} \times 10 \right) = 0.25 \times 8 = 2$$

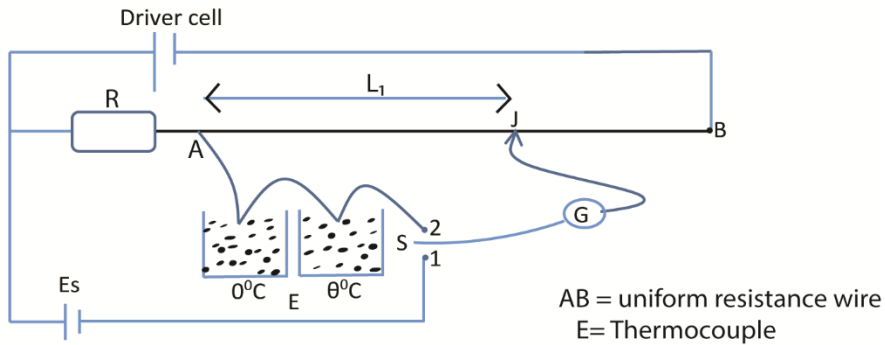
$$\therefore I_1(R_1 + R_2) = 2 \dots\dots\dots (i)$$

$$\text{Also } I_1 R_1 = 1.125 \dots\dots\dots (ii)$$

From Eqn. (i) and (ii)

$$\frac{R_1}{R_1 + R_2} = \frac{1.125}{2} = \frac{9}{16}$$

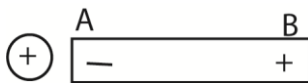
- (c) Describe with aid of a diagram, how a calibrated slide wire potentiometer may be used to measure thermoelectric e.m.f. (04marks)



- With switch S in position 1, J is moved along AB until the galvanometer G shows no deflection. The balancing length L_1 is noted
- With switch S in position 2, J is moved along AB until the galvanometer G shows no deflection. The balancing length L_2 is noted
- The e.m.f of the thermocouple is $E = kL_2$
While $E_S = I(kL_1 + R)$
 $\therefore E = \frac{E_S k L_2}{R + k L_1}$ where k is the resistance per cm of the uniform resistance wire

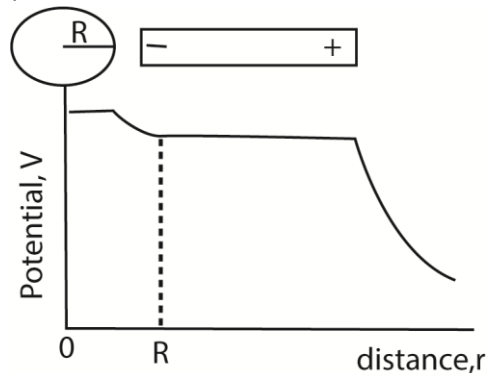
33. (a) Explain why a redistribution of charge occurs on uncharged metal rod when a positively charged metal sphere is brought near one end (03marks)

When a positively charged metal sphere is brought close to an uncharged rod, say AB as shown below; delocalized electrons in metallic lattice of the rod are electrostatically attracted by the sphere and move towards A

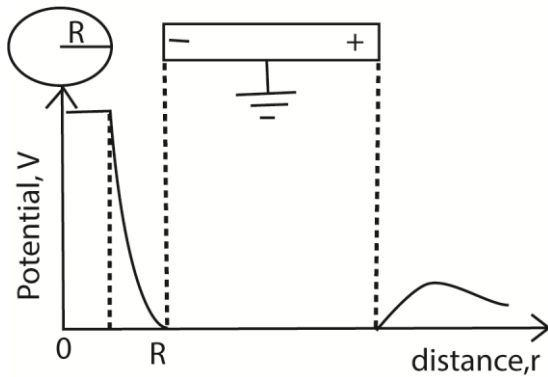


(b) Sketch a graph showing the variation of potential

(i) Relative to the earth along the axis of metal rod in (a) from the center of the charged sphere to the furthest end of the rod. (02marks)



(ii) along the axis of the rod in (a) from the center of the sphere if the rod is earthed. (02marks)



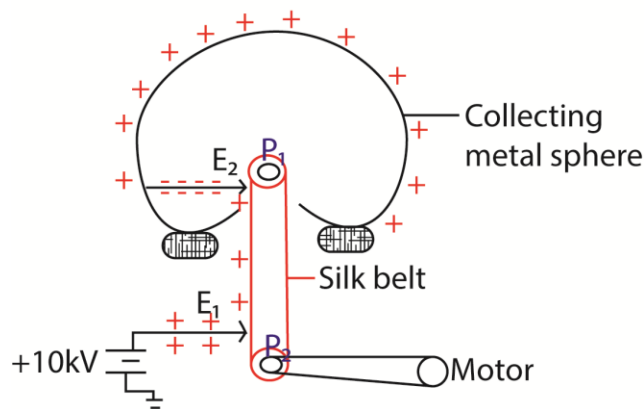
When the rod is earthed, it gets zero potential (potential of the earth)

- (c) Explain why the electric field intensity close to the surface of a charged conductor is always at right angles to the surface of the conductor. (03marks)

The surface of a charged body is an equipotential surface. Therefore when the charge moves on the surface of the conductor, no energy change occurs hence no work is done. This implies that the component of the force due to the electric field along the surface of the conductor is zero. Hence the electric field lines are perpendicular to the surface of the conductor.

- (d) Describe with the aid of a diagram the mode of operation of Van de Graff generator. (006marks)

Van der Graff generator



Main features

- It consists of a large hollow metal sphere (collecting sphere) supported on insulating stand.
- A silk belt inside the tube driven by an electric motor possesses the sharply pointed electrode metal E_1 , held at electric potential of about 10kV relative to the earth.
- As the belt moves up, it passes another sharply pointed metal electrode E_2 connected inside the hollow sphere.

Mode of operation

- The metal rod E_1 , is kept at a high positive potential of about 10kV with respect to the earth.

- (ii) The high positive charge at the sharp ends ionizes the air around.
- (iii) The positive ions are repelled to the silk belt carries then towards the collecting sphere.
- (iv) At E_2 , the silk belt induces negative charges on the sharp ends of E_1 and the positive charges on the outer of the sphere. The electric field at point ends E_2 ionizes the air around it.
- (v) The negatively charged ions are repelled to the silk belt which is carrying positively charged ions
- (vi) The positive ions are neutralized before passing over the upper pulley P_1 .
- (vii) The process of silk belt charging up and discharging is repeated many times per second and each time the belt passes, the sphere charges up positively until it has electric it has electric potential of about 10^6V relative to the earth.

(e) Explain how two insulating bodies rubbed together acquire charge.

When two dissimilar insulators are rubbed together, heat is generated due to friction. Heat cause a material of lower function to lose electron to the other. The material that loses electrons becomes positively charged while the one that accepts electron becomes negatively charge.

(e) A proton is fired from infinity with a speed of $3.7 \times 10^6\text{ms}^{-1}$ towards a stationary charge of $+50e$. Calculate the speed of the proton at a point 10^{-12}m from stationary charge. (Assume mass of proton = $1.6 \times 10^{-27}\text{kg}$) (04marks)

Initial kinetic energy = Electric potential energy gained + Final K.E

$$\frac{1}{2} m_p u_p^2 = \frac{e \times 50e}{4\pi\epsilon_0 r} + \frac{1}{2} m_p v_p^2$$

$$\frac{1}{2} \times 1.67 \times 10^{-27} \times (3.7 \times 10^6)^2 = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2 \times 50}{10^{-12}} + \frac{1}{2} \times 1.67 \times 10^{-27} \times (v_p)^2$$

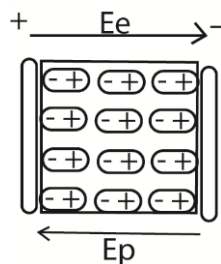
$$V_p^2 = -1.064 \times 10^{11}$$

v_p has no real roots.

34. (a)(i) What is meant by a dielectric material? (01marks)

A dielectric material is an electrical insulator that can be polarized by an applied electric field

(ii) Explain the effect of a dielectric on the capacitance of a capacitor. (05marks)



When a dielectric is placed between the plates of a charged capacitor, the nucleus of the molecules of the dielectric are urged in the direction of the field and the electrons in opposite direction.

The molecules get polarized and the surface of the dielectric near the capacitor develops charges opposite to those on adjacent plates while the charges inside the dielectric cancel out.

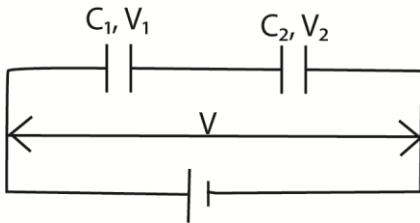
Since the charge on the dielectric are not conductible, electric field intensity develops between the surfaces of the dielectric in the direction opposite to the supplied field. The resultant electric field intensity is thus reduced.

But $E = \frac{V}{d}$ hence the p.d between the plates V is reduced.

From $C = \frac{Q}{V}$; a reduction in V leads to increase in C

(b) Two capacitors of capacitances, C_1 and C_2 , are connected in series with a battery of e.m.f, V . Show that the p.d, V_1 across the capacitor of capacitance, C_1 is given by

$$V_1 = \left(\frac{C_2}{C_1 + C_2} \right) V \quad (04\text{marks})$$



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

$$V = V_1 + V_2$$

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

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

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

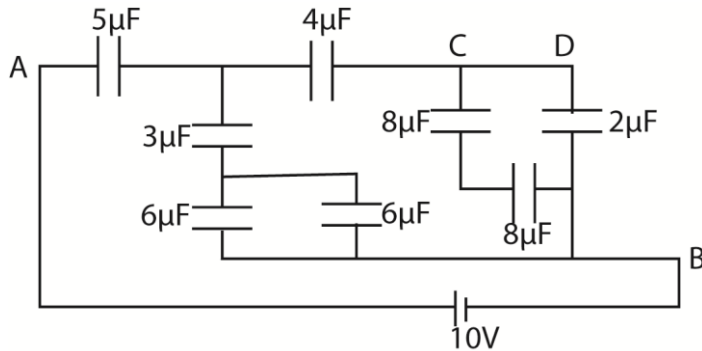
$$Q = \frac{C_1 C_2}{C_1 + C_2} V$$

$$\text{Also, } Q = C_1 V_1$$

$$\text{Then } C_1 V_1 = \frac{C_1 C_2}{C_1 + C_2} V$$

$$V_1 = \left(\frac{C_2}{C_1 + C_2} \right) V$$

(c) The figure below shows a network of capacitors connected to a 10V battery. Calculate the total energy stored in the network. (06marks)



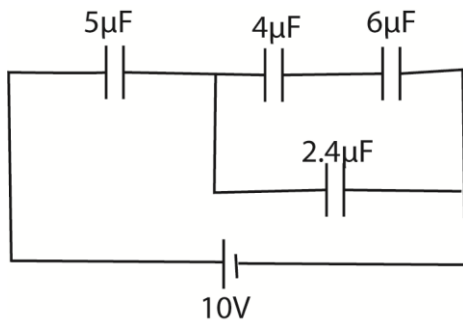
The two $8\mu F$ capacitor are in series, therefore their effective capacitance, $C_1 = \frac{8 \times 8}{8+8} = 4\mu F$

The two $6\mu F$ capacitors are in parallel and their effective capacitance, $C_2 = 6 + 6 = 12\mu F$

C_2 and $3\mu F$ capacitors are in series and their effective capacitance $C_3 = \frac{12 \times 3}{12+3} = 2.4\mu F$

C_1 and $2\mu F$ capacitors are in parallel, their effective capacitance $C_4 = 2 + 6 = 6\mu F$

The diagram can be summarized as follows

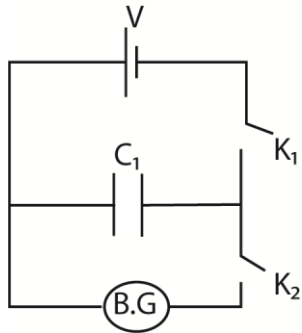


The effective capacitance of $2\mu F$, $4\mu F$ and $6\mu F = \left(\frac{4 \times 6}{4+6} + 2.4 \right) \mu F = 4.8\mu F$

Effective capacitance between $5\mu F$ and $4.8\mu F = \frac{5 \times 4.8}{5+4.8} = 2.45\mu F$

Energy stored in the network, $E = \frac{1}{2} CV^2 = \frac{1}{2} \times 2.45 \times 10^{-6} \times 10^2 = 1.225 \times 10^{-4} J$

(d) Describe how the unknown capacitance of a capacitor can be determined using a ballistic galvanometer



- The circuit is connected as shown with a capacitor of known capacitance C_1 .
- Switch K_1 is closed and K_2 is opened. The capacitor of capacitance C_1 is charged by the battery of e.m.f V .
- K_1 is opened and K_2 is closed to discharge the capacitor through the ballistic galvanometer, B.G. the first deflection of the B.G θ_1 is noted
- The capacitor is then replaced with the capacitor of unknown capacitance C_2 . the experiment is repeated and deflection θ_2 is noted
- Hence $\frac{c_2}{c_1} = \frac{\theta_2}{\theta_1}; c_2 = c_1 \frac{\theta_2}{\theta_1}$

35. (a)(i) State Coulomb's law of electrostatics (01mark)

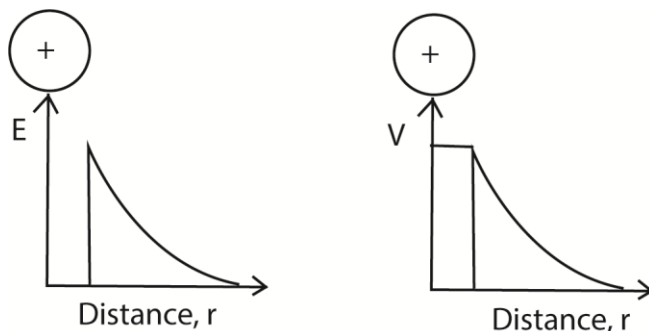
The force between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of their distance apart

(ii) Define the terms electric field intensity and electric potential at a point. (02marks)

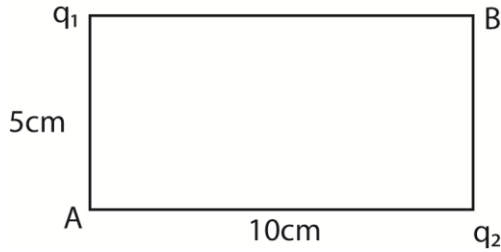
Electric field intensity at a point is the force experienced by 1C of positive charge placed at that point in electric field.

Electric potential at a point is the work done to move 1C of positive charge from infinity to that point against electrostatic repulsion.

(b) Sketch graphs of variation of electric potential and electric field intensity with distance from the center of a charged conducting sphere. (02marks)



(c) Charges q_1 and q_2 of $-5.0\mu F$ and $+2.0\mu F$ respectively are placed at two opposite corners of a rectangle of sides 5cm and 10 cm as shown below.



Calculate the

(i) Electric potential at A (04marks)

$$V_1 = \frac{kq_1}{r_1} = \frac{9 \times 10^9 \times -5 \times 10^{-6}}{0.05} = -9 \times 10^6 \text{V}$$

$$V_{21} = \frac{kq_2}{r_2} = \frac{9 \times 10^9 \times 2 \times 10^{-6}}{0.1} = 1.8 \times 10^5 \text{V}$$

$$V = V_1 + V_2 = -9 \times 10^6 \text{V} + 1.8 \times 10^5 \text{V} = -8.82 \times 10^6 \text{V}$$

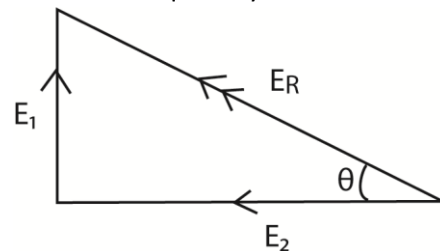
(ii) Electric field intensity at A (05marks)

$$E = \frac{kQ}{r^2}$$

$$E_1 = \frac{9 \times 10^9 \times 5 \times 10^{-6}}{0.05^2} = 1.8 \times 10^7 \text{NC}^{-1}$$

$$E_2 = \frac{9 \times 10^9 \times 2 \times 10^{-6}}{0.1^2} = 1.8 \times 10^6 \text{NC}^{-1}$$

E is a vector quantity so E_1 and E_2 is added to give resultant intensity E_R



$$E_R = \sqrt{E_1^2 + E_2^2} = \sqrt{(1.8 \times 10^7)^2 + (1.8 \times 10^6)^2} = 1.81 \times 10^7 \text{NC}^{-1}$$

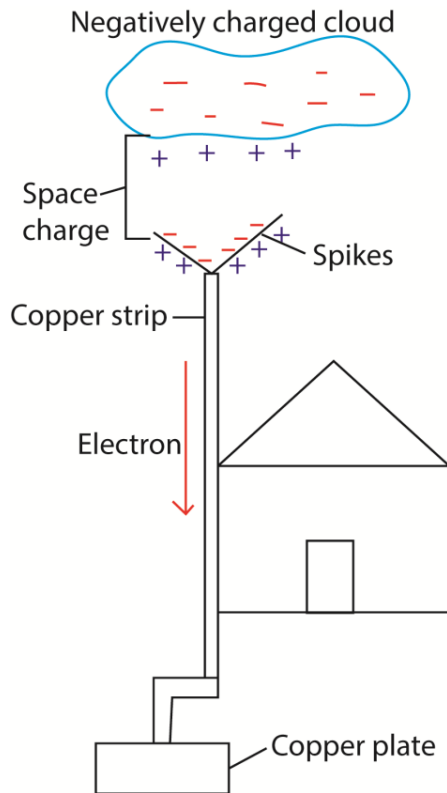
$$\theta = \tan^{-1} \left(\frac{1.8 \times 10^7}{1.8 \times 10^6} \right) = 84.289^\circ$$

Therefore the resultant electric field intensity at A is $1.81 \times 10^7 \text{NC}^{-1}$ at an angle of 84.289°

(d) (i) What is meant by corona discharge? (02marks)

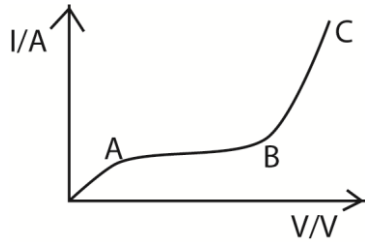
The high electric field intensity at the sharp points of charged conductor ionizes air around it. The ions of opposite charge are attracted to the sharp point partially neutralizes the charges at the pointed end of the conductor. The apparent loss of charges from the sharp end of the conductor in this way is called corona discharge.

(ii) Explain how the lightning conductor works (04marks)



Action

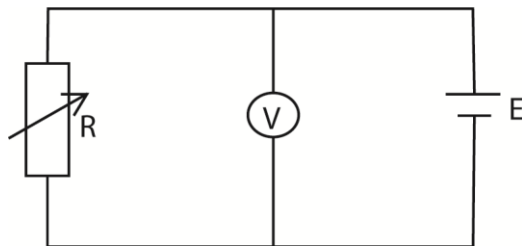
- (i) When a negatively charged cloud passes over lightning conductor, it induces positive charges on the spikes by repelling electrons to the grounds through copper conductor.
 - (ii) A high electric field concentration of positive ions on the spikes ionizes air around it causing positively charged 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.
36. (a) Define current density and the ohm and state their units. (03marks)
- Current density is the amount of current flowing through a conductor of cross section area 1m^2
 - The Ohm is the resistance of a conductor if the current of 1A flows through it when the potential difference across it is 1V. Unit is Ω .
- (b) (i) sketch the current versus voltage characteristic for a gas discharge tube (01mark)



(ii) Explain the main features of the graph in (b)(i) above. (03marks)

- OA – very little current detected due to photoelectric effect on the cathode releasing electrons
- AB – current increases slowly because anode begins to attract electrons
- BC - current increases exponentially because anode accelerates electrons that collide with and cause ionization of gas atoms thereby producing a large volume of conducting electrons.

(c)



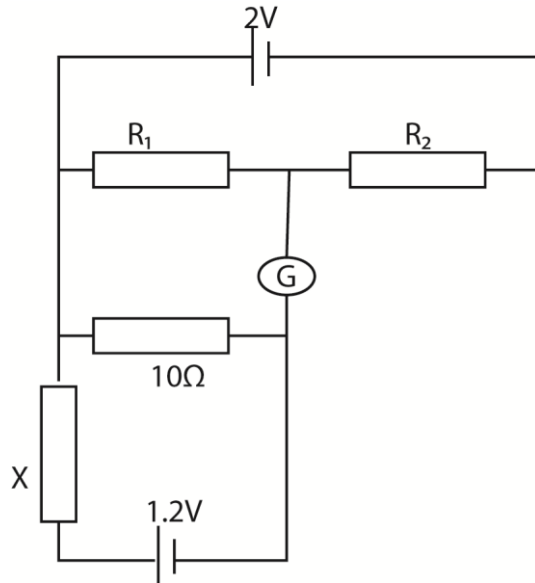
The figure above shows a cell of e.m.f, E and internal resistance, r, connected to a voltmeter, V, and variable resistor R.

Explain how the value of V varies with R. (04marks)

From $V_{AB} = IR$

When R increases, v increases and when R decreases also V decreases

(d)



In the figure above, R_1 and R_2 are resistors of 10Ω and 90Ω respectively. If the cells have negligible internal resistances, find the value of X for which G shows no deflection. (04marks)

Current flowing in the driver circuit

$$I_d = \frac{2}{10+90} = \frac{2}{100} = 0.02A$$

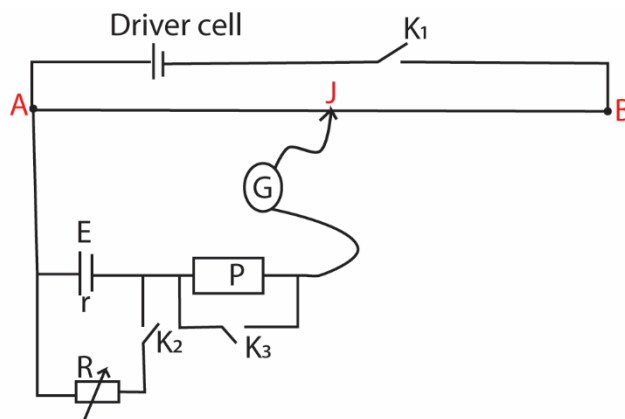
$$\text{Current flowing in the test circuit, } I_1 = \frac{1.2}{x+10}$$

$$\text{p.d across the } 10\Omega \text{ resistor} = \frac{1.2}{x+10} \times 10 = 0.2$$

$$x = 50\Omega$$

- (e) Describe how the internal resistance of a cell can be measured using a slide wire potentiometer. (05marks)

Experiment to determine internal resistance of a cell



P = protective resistor

R = variable resistor

G = center zero galvanometer

E = dry cell whose internal resistance is required

J = jockey

Procedure

(a) The dry cell is first balanced against the slide wire as follows:

K_1 is closed while K_2 and K_3 are left open, the jockey is placed in different places on the slide wire until the galvanometer shows no deflection. K_3 is then closed and the actual balance length L_0 is noted.

At balance

$$E = kL_0 \dots\dots\dots(i) \text{ where } k \text{ is the p.d per cm}$$

(b) The variable resistor is adjusted to a suitable value and the p.d across it is balanced against the slide wire as follows

With K_1 and K_2 closed, K_3 open, an approximate balance length is obtained. K_3 is then closed and actual balance length, L is obtained.

At balance

$$IR = kL \dots\dots\dots(ii) \text{ where } I \text{ is current flowing through the resistor}$$

The experiment is repeated for different values of R and corresponding lengths, L are recorded.

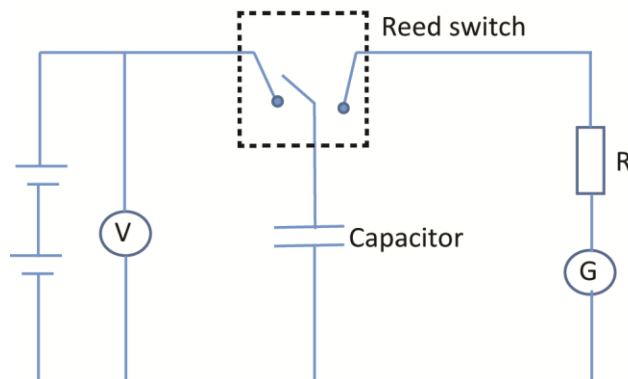
The results tabulated including values of $\frac{1}{R}$ and $\frac{1}{L}$

A plot of $\frac{1}{R}$ against $\frac{1}{L}$ give a straight line with intercept = $\frac{-1}{r}$ or $r = \frac{\text{intercept}}{\text{slope}}$

37. (a) (i) Define capacitance and state its units (02marks)

Capacitance of a capacitor is the ratio of the magnitude of charge on either plate of the capacitor to the potential difference between the plates.

(ii) With the aid of a labelled diagram, describe an experiment to measure capacitance of a capacitor. (05marks)



- The setup is shown above
- The switch is closed and the reading of current I and voltage V are noted at known frequency, f of the reed switch.
- The capacitance of a capacitor, $C = \frac{I}{fV}$

(b) A capacitor is charged by a 30V d.c supply. When the capacitor is fully charged, it is found to carry charge of $5.0\mu\text{C}$. Calculate the:

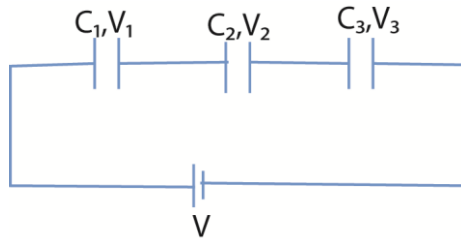
(i) capacitance of the capacitor. (02marks)

$$C = \frac{Q}{V} = \frac{5 \times 10^{-6}}{30} = 1.67 \times 10^{-7} \text{F}$$

(ii) energy stored in the capacitor (03marks)

$$\text{Energy} = \frac{1}{2} CV^2 = \frac{1}{2} \times 1.67 \times 10^{-7} \times 30^2 = 7.5 \times 10^{-5} \text{J}$$

(c) Derive the expression for effective capacitance of three capacitors C_1 , C_2 and C_3 respectively connected in series. (04marks)



The charge on each of the capacitor is the same equal to Q

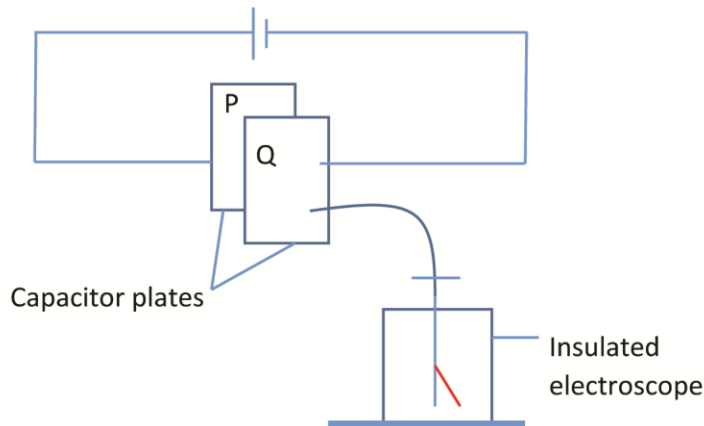
Total voltage $V = V_1 + V_2 + V_3$

$$= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = Q \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right)$$

But $\frac{V}{Q} = \frac{1}{C}$ where C is the resultant capacitance.

$$\therefore \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

(d) Describe briefly an experiment to show the effect of varying the distance of separation of the plates of a capacitor on capacitance. (04marks)



The plate P is then slid back and separation between the plates is increased by moving P away from Q. The divergence of the leaf is observed to decrease. Since divergence of the leaf is proportional to charge on the plates, which in turn is proportional to capacitance C , then C is reduced. This shows that $C \propto 1/d$.

38. (a) Define the terms electrical resistivity and temperature coefficient of resistance (02marks)
 Electrical resistivity is the electrical resistance across opposite faces of a cube of a material of 1m length.
 Temperature coefficient of resistivity is fractional change in resistance at 00C per degree rise in temperature.

- (b) (i) Explain why the temperature coefficient of resistance is positive for metals. (03marks)

In metals, free electrons are charge carrier. As temperature increases, the amplitude of vibration of lattice ions increases and this increase the obstruction to electron drift leading to increase in resistance.

- (ii) what is a super conductor (01marks)

Super conductors are materials whose resistance vanishes when they are cooled to temperatures near -273°C

- (c) The temperature coefficient of resistance of two wires A and B of diameters 1.20mm and 0.80mm are 0.0004K^{-1} and 0.0003K^{-1} respectively. If the ratio of their resistances at 0°C is 1.5, calculate

- (i) the ratio of resistances at 100°C

$$\text{From } R_{\theta} = R_0(1 + \alpha\theta)$$

$$\Rightarrow R_{100A} = R_{0A} (1 + 100\alpha_A) \dots\dots\dots (i)$$

$$R_{100B} = R_{0B} (1 + 100\alpha_B) \dots\dots\dots (ii)$$

From (i) and (i)

$$\frac{R_{100A}}{R_{100B}} = \frac{R_{0A}}{R_{0B}} \times \frac{(1+100\alpha_A)}{(1+100\alpha_B)} = 1.5 \times \frac{1+100 \times 0.0004}{1+100 \times 0.0003} = 1.51$$

(ii) their electrical resistance at 100°C

From $R = \rho \frac{L}{A}$

$$R_A = \rho_A \frac{L}{\pi(0.6 \times 10^{-3})^2} \dots\dots\dots (i)$$

$$R_B = \rho_B \frac{L}{\pi(0.4 \times 10^{-3})^2} \dots\dots\dots (ii)$$

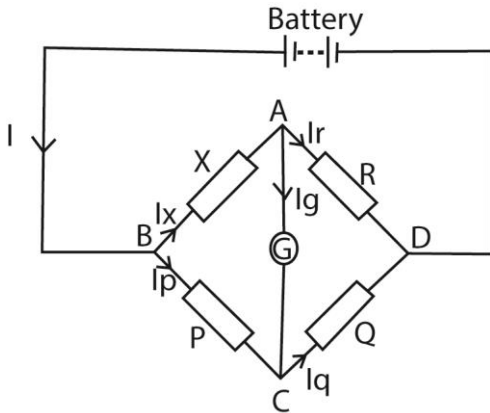
From (i) and (ii)

$$\frac{R_{100A}}{R_{100B}} = \frac{\rho_A}{\rho_B} \times \frac{(0.4 \times 10^{-3})^2}{(0.6 \times 10^{-3})^2} = \frac{\rho_A}{\rho_B} \times \frac{2^2}{3^2}$$

$$\frac{R_{100A}}{R_{100B}} = 1.51$$

$$\therefore \frac{\rho_A}{\rho_B} = 1.51 \times \frac{3^2}{2^2} = 3.3975$$

(c) (i) Derive the balance condition for Wheatstone bridge. (04marks)



When resistances P, Q, R and X are such that no current flows through the galvanometer, the bridge is said to be balanced, i.e., $I_g = 0$

⇒ Potential at A = potential at C

$$V_{AB} = V_{BC} \text{ and } V_{AD} = V_{DC}$$

$$I_x X = I_p P \text{ and } I_r R = I_q Q$$

$$\frac{I_x X}{I_r R} = \frac{I_p P}{I_q Q}$$

Since $I_g = 0$, then $I_x = I_r$ and $I_p = I_q$

$$\text{Hence } \frac{X}{R} = \frac{P}{Q}$$

(ii) Explain why the Wheatstone bridge is not suitable for measuring very low or very high resistances. (04marks)

- Cannot measure low resistances because the resistance of the connecting wires become significant.
- It cannot measure very high resistances because the instrument become insensitive

39. (a)(i) Define electric potential and electric field intensity. (02marks)

Electric potential is a point in electric field is work done to transfer 1C charge from infinity to that point.

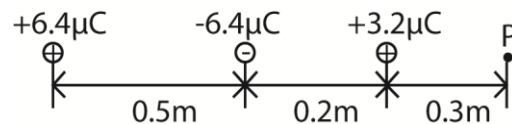
Electric field intensity at a point is the force experienced by 1C of positive charge placed at that point in electric field.

(ii) What is the relationship between electric potential and electric field intensity? (01mark)

Electric field intensity at a point is equal to the negative of potential gradient at that point,

$$\text{i.e, } E = -\frac{dV}{dx}$$

(b)



Three point charges of $+6.4\mu\text{C}$, $-6.4\mu\text{C}$ and $3.2\mu\text{C}$ are arranged in line as shown in the figure above. Find the field intensity at P. (06marks)

$$\text{From } E = \frac{kQ}{r^2} \text{ (k = } 9 \times 10^9 \text{F}^{-1}\text{m)}$$

Let intensity due to $+6.4\mu\text{C}$, $-6.4\mu\text{C}$ and $+3.2\mu\text{C}$ be E_1 , E_2 and E_3 respectively

$$E_1 = \frac{6.4 \times 10^{-6} \times 9 \times 10^9}{1^2} = 5.76 \times 10^4 \text{NC}^{-1}$$

$$E_2 = -\frac{6.4 \times 10^{-6} \times 9 \times 10^9}{0.5^2} = -23.04 \times 10^4 \text{NC}^{-1}$$

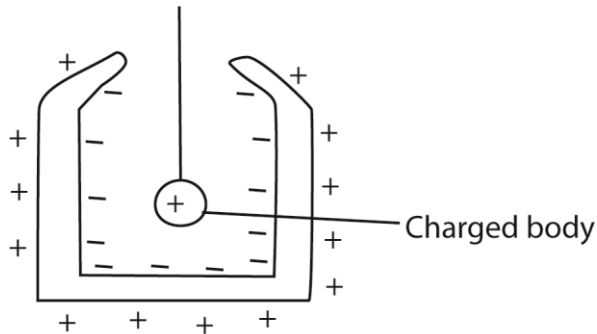
$$E_3 = \frac{3.2 \times 10^{-6} \times 9 \times 10^9}{0.3^2} = 32 \times 10^4 \text{NC}^{-1}$$

Since E is a vector quantity, E at P is the sum of E_1 , E_2 and E_3 ;

$$E = (5.76 - 23.04 + 32) \times 10^4 \text{NC}^{-1} = 14.72 \times 10^4 \text{NC}^{-1}$$

- (c) (i) Explain with the aid of a diagram, how a charged body can be screened against external electric fields (03marks)

Place the charged body in a hollow conductor (Faraday cage). This is equal but opposite charges to be induced on the inside wall of hollow conductor. An equal and similar charge is induced on one outside wall.



Any external field does not affect the outside wall only; i.e., the charged body is shielded electrostatically.

- (ii) Describe briefly how the sign of a charge on a given body can be detected using a gold leaf electroscope (04marks)

- A gold leaf of known charge is used
- The test charge is brought near the cap of the electroscope.
- If divergence of the leaf increases, the body has the same charge as the gold leaf electroscope.

- (ii) What is meant by action points in electrostatics? (04marks)

Point action is the apparent loss of charge at the sharp point of a charged body. The high electrostatic intensity at the sharp point of a charged body causes ionization of air molecules around. Ions with similar charge as that on the sharp point are repelled while those with opposite charges are attracted and partially neutralize the charges on the sharp point.

40. (a) Define the farad (01mark)

A farad is the capacitance of a capacitor if the p.d across its plate is 1V and the charge on the capacitor is 1C.

- (b) Describe briefly the energy transformations that take place when charging a capacitor using a dry cell. (03marks)

Energy changes from chemical energy in the battery to electrical energy in the connecting wire to electrical potential energy in capacitor plus heat energy dissipated in connecting wire.

- (c) The capacitance of a variable radio capacitor can be charged continuously from 10pF to 900pF by turning the dial from 0° to 140° . With the dial set at 140° , the capacitor is

connected to a 9V battery. After charging, the capacitor is disconnected from the battery and the dial turned to 0° . Calculate the

(i) charge on capacitor. (03marks)

$$\text{Charge on a capacitor } Q = CV = 900 \times 10^{-12} \times 9 = 8.1 \times 10^{-9} \text{C}$$

(ii) energy stored in the capacitor with the dial at 140° . (03marks)

$$\text{Energy} = \frac{1}{2} CV^2 = \frac{1}{2} \times 900 \times 10^{-12} \times 9^2 = 3.65 \times 10^{-8} \text{J}$$

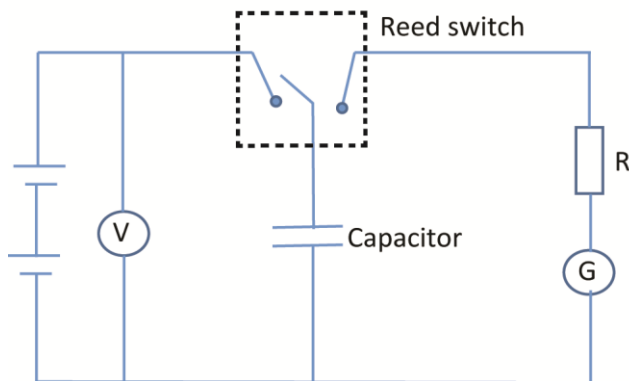
(iii) work required to turn the dial from 140° to 0° if the friction is neglected. (03marks)

Energy for $C = 10\text{pF}$;

$$\text{Energy} = \frac{1}{2} CV^2 = \frac{1}{2} \times 10 \times 10^{-12} \times 9^2 = 4.05 \times 10^{-10} \text{J}$$

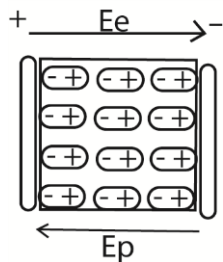
$$\text{Work done} = 3.65 \times 10^{-8} \text{J} - 4.05 \times 10^{-10} \text{J} = 3.61 \times 10^{-8} \text{J}$$

(d) Describe an experiment to determine the effect of area of overlap on capacitance of a parallel plate capacitor (04marks)



- The reed switch repeatedly charges and discharges a pair of parallel plates through a sensitive galvanometer.
- The charge Q on the capacitor is proportional to current I
- With the p.d V and plate separation, d , kept constant, the current I is observed for different area overlap.
- The results I and A are tabulated and a plot of I against A gives a straight line showing that I is proportional to A and hence $C \propto A$

(e) Explain why the capacitance of a capacitor changes when a dielectric is placed between its plates. (04marks)



When a dielectric is placed between the plates of an insulated charged capacitor, it gets polarized with the sides near each plate bearing opposite charge to that on the plate.

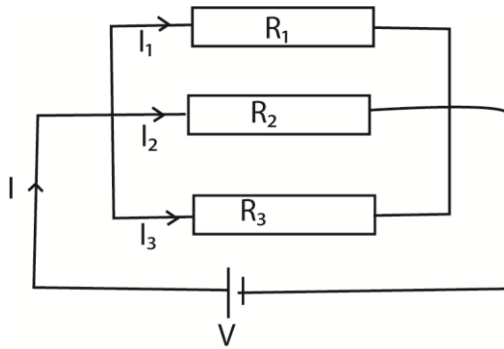
These are bound charges which are not neutralized thus develop an electric field that oppose the applied electric field.

They lower electric field and voltage between the plates which increases capacitance of the capacitor.

41. (a) (i) Define a volt. (01mark)

A volt is the potential difference between two points if work done to transfer 1C of charge from one of the point to the other is 1J

(ii) Derive the formula for the combined resistance of three resistors in parallel. (04marks)



The p.d across each resistor is the same and equal to V

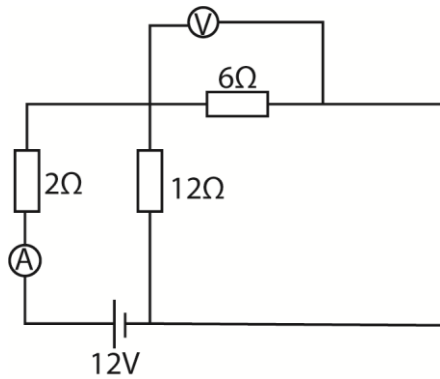
By conservation of current at the junction, $I = I_1 + I_2 + I_3$

From Ohm's law: $\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$ where R is the equivalent resistance in the circuit

Dividing throughout by V

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

(iii)



In the circuit above, has negligible internal resistance. Find the ammeter and voltmeter readings (04marks)

$$\text{Effective resistance } R = 2 + \frac{6 \times 12}{6 + 12} = 6\Omega$$

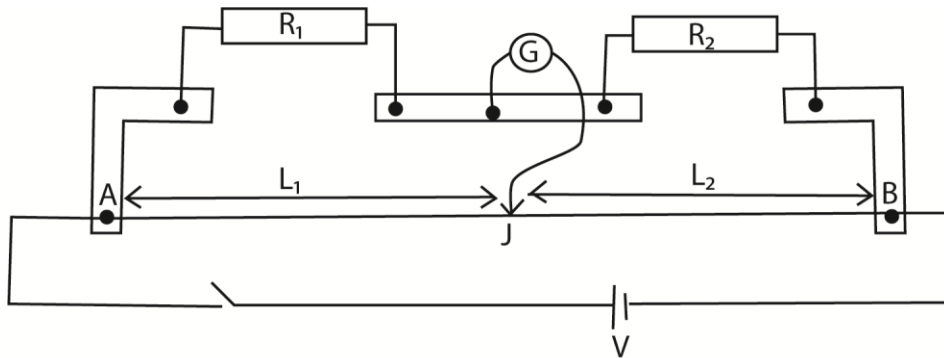
$$\text{Current through } 2\Omega \text{ resistor} = \frac{V}{R} = \frac{12}{6} = 2A$$

Hence ammeter reading = 2A

$$\text{Effective resistance of } 6\Omega \text{ and } 12\Omega = \frac{6 \times 12}{6 + 12} = 4\Omega$$

$$V = IR = 2 \times 4 = 8V$$

(b) (i) Draw a labelled diagram of a meter bridge and derive the relation for balance. (05marks)



- At balance, current passing through G is zero
- This implies that p.d across $R_1 =$ p.d across AJ
- Let I_1 and I_2 be current through R_1 and AJ respectively, and k the resistance per unit length of wire AB
- The $I_1 R_1 = I_1 k L_1$ (i)
- Also $I_g = 0$, I_1 passes through R_2 and I_2 passes through JB and p.d across $R_2 =$ p.d across JB
- Then $I_1 R_2 = I_2 k L_2$(ii)
- Dividing (i) by (ii)

$$\frac{R_1}{R_2} = \frac{L_1}{L_2}$$

(ii) Explain why the balance point should be close to the middle of the wire (02marks)

- When the length measured is big, percentage error is negligible
- When the balance point is close to the middle the end errors are minimized

(c) A coil of a wire has resistance of 30Ω at 200°C and 34.5Ω at 600°C . Calculate its temperature coefficient of resistance. (04marks)

From $R_\theta = R_0(1 + \alpha\theta)$

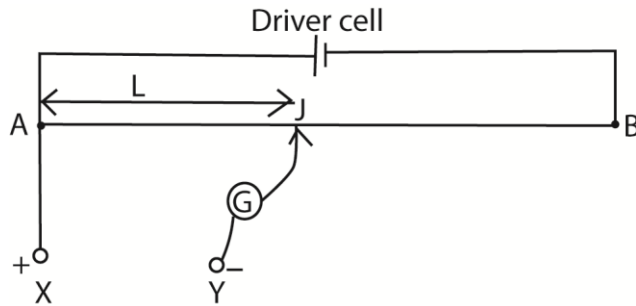
$30.0 = R_0(1 + 20\alpha)$ (i)

$34.5 = R_0(1 + 60\alpha)$ (ii)

From (i) and (ii)

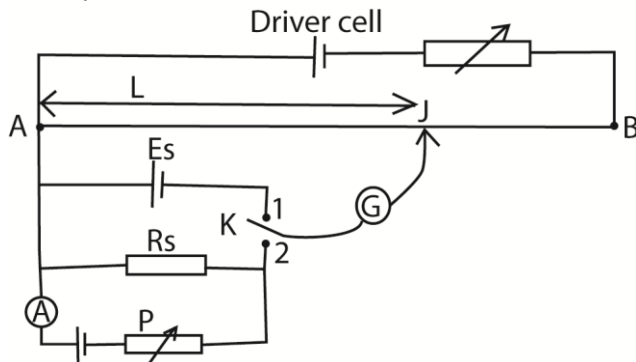
$\alpha = 4.05 \times 10^{-3} \text{K}^{-1}$

42. (a) Explain the principle of a slide wire potentiometer. (03marks)



- The driver cell maintains a steady current through a uniform resistance wire AB.
- The p.d per unit length of the wire is therefore constant.
- At balance, when G shows no deflection, the p.d across length AJ = test p.d
i.e. $V = kL$

(b)(i) Using a labelled diagram, describe how an ammeter is calibrated using a slide wire potentiometer. (06marks)



- E_s and R_s are standard e.m.f and standard resistance
- Switch K is connected to position 1 and jockey tapped at different positions along wire AB until the galvanometer shows no deflection.
- The balance length L_s is measured.
- Switch K is connected to position 2 and the resistance P adjusted to obtain a suitable reading I_r on the ammeter A.
- The balance length L and ammeter reading I_r are recorded.
- The procedure is repeated for the different setting of P, and corresponding values of L and I_r tabulate including values of $I_a = \frac{E_s}{L_s} \times \frac{L}{R_s}$
- A graph of I_a against I_r constitutes the calibration curve of the ammeter.

(ii) What is the advantage of the potentiometer over an ordinary voltmeter in measurement of voltages? (02marks)

- It does not draw any current from the p.d thus gives accurate results.
- It can measure a wide range of p.d since the length of the slide wire can be adjusted

(c) Two cells A and B connected in series, give a balance length of 758mm along a potentiometer wire. When cell B is reversed, the balance length falls to 123mm. If the e.m.f of cell A is 1.5V, calculate the e.m.f of cell B. (04marks)

$V \propto L \Rightarrow V = kL$ where k is constant

$$E_A + E_B = 0.758k \dots\dots\dots (i)$$

$$E_A = 0.123k \dots\dots\dots (ii)$$

$$\text{But } E_A = 1.5 \Rightarrow k = \frac{1.5}{0.123}$$

Substituting into eqn. (i)

$$E_B = \left(0.758 \times \frac{1.5}{0.123}\right) - 1.5 = 7.74V$$

(d) The resistance of a nichrome element of an electric fire is 50.9Ω at 20.0°C . When operating on a 240V supply, the current flowing through it is 4.17A. Calculate the steady temperature reached by the electric fire if the temperature coefficient of resistance of nichrome is $1.7 \times 10^{-4}\text{K}^{-1}$

$$\text{From } R = \frac{V}{I} \Rightarrow R = \frac{240}{4.17} = 57.55\Omega$$

$$\text{But } R_\theta = R_0(1 + \alpha\theta),$$

$$50.9 = R_0 (1 + 1.7 \times 10^{-4} \times 20)$$

$$R_0 = 50.72\Omega$$

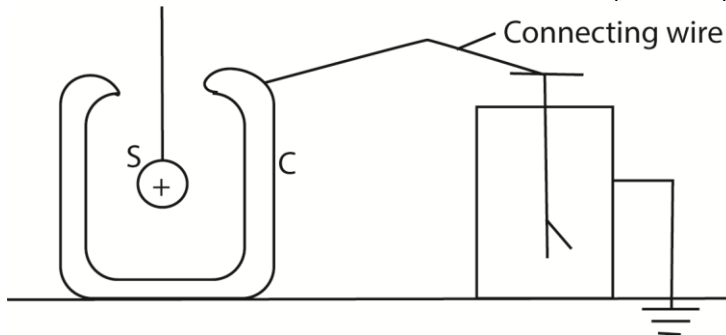
$$57.55 = 50.72 (1 + 1.7 \times 10^{-4}\theta)$$

$$\theta = 792.1^\circ$$

43. (a) Explain the meaning of an equipotential surface as applied to electric field. (02marks)

An equipotential surface is one on which electric potential is the same at all points. The electric field lines are perpendicular to the surface and therefore work done to move 1C charge along the surface is equal to zero.

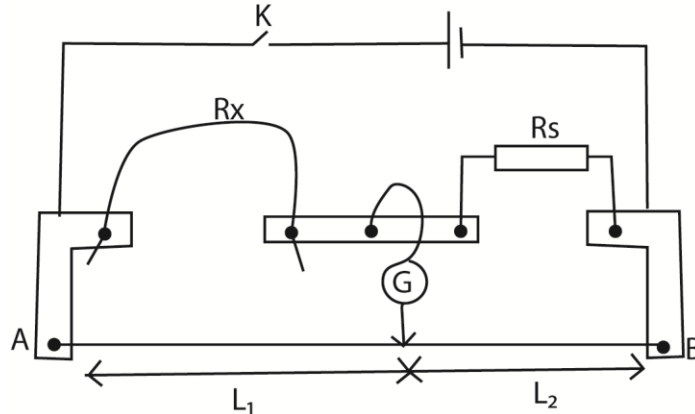
(b) With the aid of a diagram, describe an experiment to show that excess charge resides only on the outside surface of a hollow conductor. (05marks)



- A positive charge metal sphere S is lowered into a metal can using an insulating thread.
- The leaf of the electroscope diverges.
- The sphere S is withdrawn from C, and the leaf of electroscope collapses.

Electrical resistivity of a material is the resistance between opposite faces of 1m cube of the material. It is measured in Ohms (Ω)

- (ii) Describe with the aid of circuit diagram, an experiment to determine the electrical resistivity of a given wire using a meter bridge. (07marks)



A length L_x of the wire under test is connected in the left hand gap of the Meter Bridge and standard of resistance R_s 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 L_x and the results tabulated including the values of $R_x = \frac{L_1}{L_2} R_s$

A graph of R_x against L_x is plotted and slope S is determined.

The average diameter, D , of the wire is measure from different points of the wire.

$$\text{Resistivity, } \rho = S \left(\frac{\pi D^2}{4} \right)$$

- (iii) The resistivity of mild steel is $15 \times 10^{-8} \Omega\text{m}$ at 20°C and its temperature coefficient is $50 \times 10^{-4} \text{K}^{-1}$. Calculate the resistivity at 60°C . (05marks)

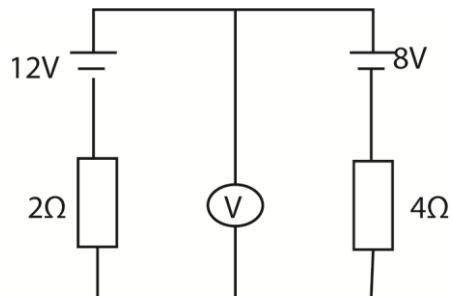
$$\rho_\theta = \rho_0(1 + \alpha\theta)$$

$$15 \times 10^{-8} = \rho_0(1 + 20 \times 50 \times 10^{-4})$$

$$\rho_0 = \frac{15 \times 10^{-8}}{(1 + 20 \times 50 \times 10^{-4})} = 1.364 \times 10^{-7}$$

$$\rho_{60} = \frac{15 \times 10^{-8}}{(1 + 20 \times 50 \times 10^{-4})} (1 + 60 \times 50 \times 10^{-4}) = 1.77 \times 10^{-7}$$

(b)



Resistors of 2Ω and 4Ω are connected in series with power supplies of $12V$ and $8V$ as shown in the figure above. Calculate

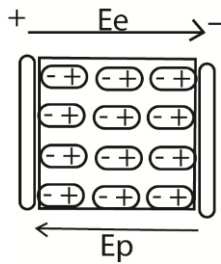
- (i) The reading of voltmeter (04marks)
 Net e.m.f = $12-8=4V$
 Total resistance = $2 + 4 = 6\Omega$
 $I = \frac{E}{R} = \frac{4}{6} = \frac{2}{3}A$
 Reading of the voltmeter = $12-IR$ ($R = 2$)
 $= 12 - \frac{2}{3} \times 2$
 $= 10.7V$

- (ii) The power dissipated in the 4Ω resistor (02marks)
 $P = I^2R = \left(\frac{2}{3}\right)^2 \times 4 = 1.78W$

45. (a) Define the following

- (i) Capacitance of capacitor (01mark)
 Capacitance of a capacitor is the ratio of the magnitude of charge on one of the plates of the capacitor, to the potential difference between the plates.
- (ii) Dielectric constant (01mark)
 Dielectric constant of a material is the ratio of the capacitance of a capacitor when the space between its plates is filled with the material, to the capacitance of the same capacitor when the space between its plates is a vacuum.

(b) Explain the effect of dielectric on the capacitance of a capacitor. (04marks)



When a dielectric is placed between the plates of an insulated charged capacitor, it gets polarized with the sides near each plate bearing opposite charge to that on the plate.

These are bound charges which are not neutralized thus develop an electric field that oppose the applied electric field.

They lower electric field and voltage between the plates which increases capacitance of the capacitor.

(c) Derive an expression for energy stored in a capacitor of capacitance, c , charged to a voltage, V . (05marks)

Suppose the p.d between the plates at some instant is V . When a small charge of δq is transferred from the negative plate to the positive plate, the p.d increases by δV .

$$\text{Work done to transfer the charge; } \delta w = (V + \delta V)\delta q \approx V\delta q$$

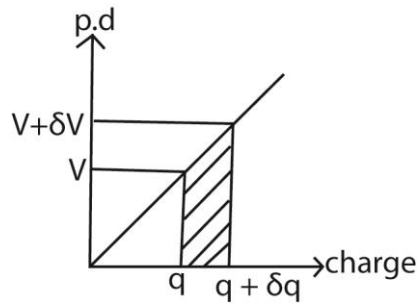
$$\text{But } V = \frac{q}{C}$$

$$\therefore \frac{q}{C} \delta q$$

$$\text{Total work done} = \int_0^Q \frac{q}{C} \delta q = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} CV^2$$

Or

From $q = CV$, V is proportional to q , this gives the graph of V against q below



$$\text{Shaded area} = \frac{1}{2}(V + V + \delta V) \times \delta q$$

= work done to increase charge on the capacitor by δq

\therefore to charge a capacitor from $q = 0$ to $q = Q$

Work done, w = average voltage \times charge

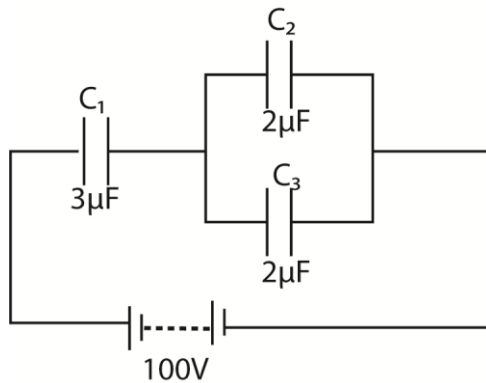
$$= \frac{1}{2}(0 + V) \times Q$$

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

But $Q = CV$

$$\therefore w = \frac{1}{2} CV^2$$

(d)



In the figure above, C_1 , C_2 , and C_3 are capacitors of capacitances $3\mu\text{F}$, $2\mu\text{F}$ and $2\mu\text{F}$ respectively, connected to a battery of e.m.f 100V.

- (i) Calculate the energy stored in the system of capacitors if the space between the plates of C_1 is filled with an insulator of dielectric constant 3, and the capacitors are fully charged. (06marks)

Net capacitance of C_2 and C_3 in parallel is $C_4 = C_2 + C_3 = 2 + 2 = 4\mu\text{F}$

After inserting dielectric, C_1 become $C_5 = 3C_1 = 3 \times 3 = 9\mu\text{F}$

Net capacitance C of C_4 and $C_5 = \frac{9 \times 4}{9+4} = 2.77\mu\text{F}$

Energy stored $= \frac{1}{2} CV^2 = \frac{1}{2} \times 2.77 \times 10^{-6} \times 100^2 = 0.01385\text{J}$

- (ii) Account for the change in energy stored by an isolated parallel plate capacitor when the plate separation is doubled. (03marks)

$$E = \frac{1}{2} CV^2 = \frac{Q^2}{2C} = \frac{Q^2 d}{2\epsilon_0 A}$$

⇒ When the separation is doubled, the energy stored is doubled.

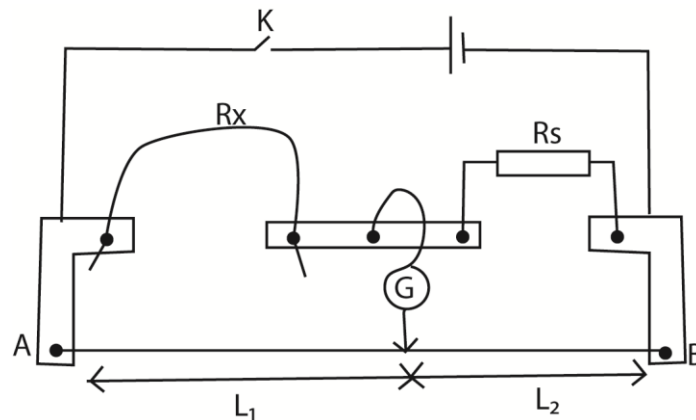
⇒ To increase the separation, work is done in pulling the plates apart. This work done (energy) is stored as electrical energy between plates of the capacitor.

46. (a) (i) Define electrical resistivity and the ohm. (02marks)

Electrical resistivity is the electrical resistance across opposite faces of a cube of a material of length 1m

An Ohm is the resistance of a conductor through which 1 ampere flows when the potential difference across it is 1 volt.

- (ii) Describe an expression to determine the electrical resistivity of a material in form of a wire using a meter bridge. (07marks)



A length L_x of the wire under test is connected in the left hand gap of the Meter Bridge and standard of resistance R_s 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.

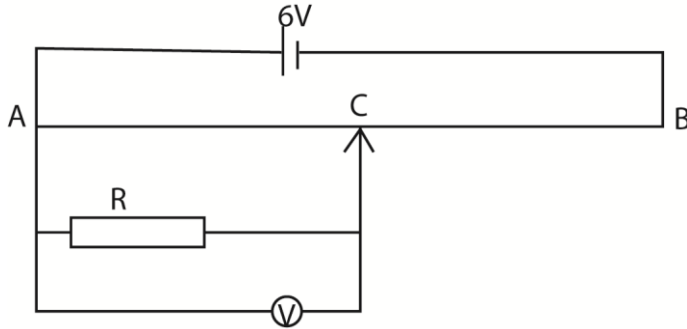
The procedure is repeated for different length of L_x and the results tabulated including the values of $R_x = \frac{L_1}{L_2} R_s$

A graph of R_x against L_x is plotted and slope S is determined.

The average diameter, D , of the wire is measure from different points of the wire.

$$\text{Resistivity, } \rho = S \left(\frac{\pi D^2}{4} \right)$$

(b)



In the figure above wire AB of length 1.00m has a resistance of 10Ω . If point C is the midpoint of AB, and the voltmeter reading is 2.0V, find the value of R. (06marks)

$$\text{Resistance } R_{AC} \text{ of } AC = \frac{10}{2} = 5\Omega$$

$$\text{Resistance } R_{BC} \text{ of } BC = \frac{10}{2} = 5\Omega$$

AC is in parallel with R, thus p.d across AC = p.d across R = 2V

p.d. across CB = $6 - 2 = 4V$

$$\text{current in } CB = I_{CB} = \frac{V}{R} = \frac{4}{5} A$$

$$\text{current in } AC = I_{AC} = \frac{V}{R} = \frac{2}{5} A$$

$$\text{Current in } R, I_R = \frac{V}{R} = \frac{2}{R}$$

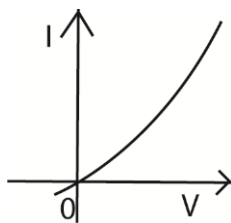
From Kirchoff's law, $I_{AC} + I_R = I_{CB}$

$$\frac{2}{5} + \frac{2}{R} = \frac{4}{5}$$

$$R = 5\Omega$$

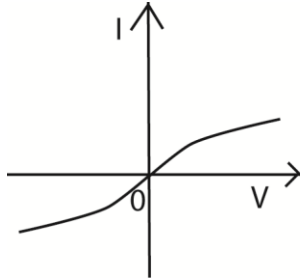
(c) Describe the current versus voltage characteristics of a

(i) semi-conductor diode (02marks)



Current flows when p.d is applied in one direction but the current is almost zero when the p.d is applied in the opposite direction.

(ii) filament lamp (02marks)



For low voltage, current, I , varies linearly with V . But for high values of V , a given value of V causes a small change in current. So the curve bends.

Hence the resistance dV/dI of the filament increases with temperature.

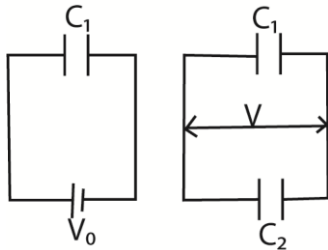
(d) Why does Ohm's law hold at constant temperature only? (01mark)

Because change in temperature alters resistance of a material

47. (a) Define the terms dielectric constant and capacitance (02marks)

Dielectric constant of a medium is the ratio of capacitance of a capacitor with the space between its plates filled with the medium to the capacitance of the same capacitor when the space between its plates is a vacuum.

(b) An air capacitor of capacitance $400\mu\text{F}$ is charged to 180V and then connected across an uncharged capacitor of capacitance $500\mu\text{F}$.



(i) find the energy stored in the $500\mu\text{F}$ capacitor. (04marks)

Total charge before connection of $500\mu\text{F}$ = total charge after connection of $500\mu\text{F}$

$$Q_0 = Q_1 + Q_2$$

$$Q_0 V_0 = Q_1 V + C_2 V$$

$$Q_0 V_0 = V(C_1 + C_2)$$

$$V = \frac{C_1 V_0}{C_1 + C_2}$$

$$V = \frac{400 \times 10^{-6} \times 180}{(500 + 400) \times 10^{-6}} = 80\text{V}$$

$$\text{Energy stored} = \frac{1}{2} C V^2 = \frac{1}{2} \times 500 \times 10^{-6} \times 80^2 = 1.6\text{J}$$

(ii) With the capacitor still connected a dielectric of dielectric constant 1.5 is inserted between plates of the 400 μ F capacitor.

If the separation between the plates remains the same find the new p.d across the two capacitors. (03marks)

After insertion of a dielectric, 400 μ F capacitance become = 1.5 x 400 = 600 μ F

$$Q_0 V_0 = Q_1 V + C_2 V$$

$$Q_0 V_0 = V(\epsilon_r C_1 + C_2 V)$$

$$V = \frac{C_1 V_0}{\epsilon_r C_1 + C_2}$$

$$V = \frac{400 \times 10^{-6} \times 180}{(600+500)10^{-6}} = 65.45V$$

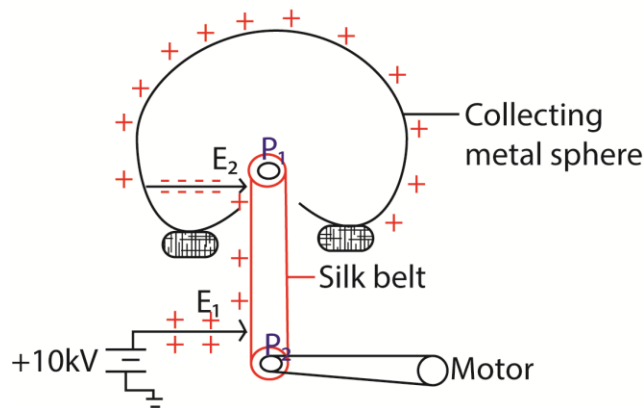
(c) (i) state the characteristics of an equipotential surface. (02marks)

- Along any direction line n the surface, there is no electric field
- Equipotential surfaces are always perpendicular to the lines of force
- Work done to move a charge from one point to another on equipotential surface is zero

(ii) Describe how a conductor can be charged at zero potential (03marks)

(d) Describe with the aid of a diagram how a high voltage can be generated using a Van de Graaff generator. (06marks)

Van der Graff generator



Main features

- a. It consists of a large hollow metal sphere (collecting sphere) supported on insulating stand.
- b. A silk belt inside the tube driven by an electric motor possesses the sharply pointed electrode metal E_1 , held at electric potential of about 10kV relative to the earth.
- c. As the belt moves up, it passes another sharply pointed metal electrode E_2 connected inside the hollow sphere.

Mode of operation

- (i) The metal rod E_1 , is kept at a high positive potential of about 10kV with respect to the earth.
- (ii) The high positive charge at the sharp ends ionizes the air around.
- (iii) The positive ions are repelled to the silk belt carries then towards the collecting sphere.

- (iv) At E_2 , the silk belt induces negative charges on the sharp ends of E_1 and the positive charges on the outer of the sphere. The electric field at point ends E_2 ionizes the air around it.
- (v) The negatively charged ions are repelled to the silk belt which is carrying positively charged ions
- (vi) The positive ions are neutralized before passing over the upper pulley P_1 .
- (vii) The process of silk belt charging up and discharging is repeated many times per second and each time the belt passes, the sphere charges up positively until it has electric it has electric potential of about 10^6V relative to the earth.

48. (a) (i) State coulomb's law (01marks)

The force between two point charges is directly proportional to the product of the magnitude of the charges and inversely proportional to the square of the distance of separation of the charges.

(ii) Show that the electric flux through a spherical surface enclosing a charge in vacuum is

$$Q/\epsilon_0$$

$$c \text{ and } A = 4\pi r^2$$

If an electric flux ϕ is due to an electric field E , charge Q enclosed by a sphere of radius r , then

$$\phi = E.A$$

$$= \frac{Q}{4\pi\epsilon_0 r^2} \times 4\pi r^2$$

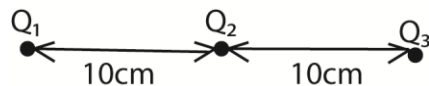
$$= \frac{Q}{\epsilon_0}$$

(b) Define the term electric field intensity and electric potential (02marks)

Electric intensity is the force exerted on a positive charge of 1C placed in an electric field

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

(c)



Three point charges Q_1 , Q_2 , and Q_3 of magnitude $+5\mu F$, $+6\mu F$ and $-20\mu F$ respectively are situated along a straight line as shown in figure above. Calculate the electric field

(i) Intensity midway between Q_1 and Q_2 (03marks)

$$E = \frac{Q}{4\pi\epsilon_0 r^2}$$

$$E_x = E_{Q1} + E_{Q2} + E_{Q3}$$

$$E_1 = \frac{Q}{4\pi\epsilon_0 r_1^2} = \frac{5 \times 10^{-6} \times 9 \times 10^9}{(5 \times 10^{-2})^2} = 1.8 \times 10^7 \text{NC}^{-1}$$

$$E_2 = \frac{Q}{4\pi\epsilon_0 r_2^2} = \frac{6 \times 10^{-6} \times 9 \times 10^9}{(5 \times 10^{-2})^2} = 2.16 \times 10^7 \text{NC}^{-1}$$

$$E_3 = \frac{Q}{4\pi\epsilon_0 r_3^2} = \frac{20 \times 10^{-6} \times 9 \times 10^9}{(15 \times 10^{-2})^2} = 0.8 \times 10^7 \text{NC}^{-1}$$

$$E_x = (1.8 - 2.16 + 0.8) \times 10^7 \text{NC}^{-1}$$

$$= 4.44 \times 10^6 \text{NC}^{-1}$$

(ii) Potential midway between Q_1 and Q_2 (03marks)

$$V = \frac{Q}{4\pi\epsilon_0 r}$$

$$V_x = V_{Q1} + V_{Q2} + V_{Q3}$$

$$E_1 = \frac{Q}{4\pi\epsilon_0 r_1} = \frac{5 \times 10^{-6} \times 9 \times 10^9}{5 \times 10^{-2}} = 9 \times 10^5 \text{V}$$

$$E_2 = \frac{Q}{4\pi\epsilon_0 r_2^2} = \frac{6 \times 10^{-6} \times 9 \times 10^9}{5 \times 10^{-2}} = 10.8 \times 10^5 \text{V}$$

$$E_3 = \frac{Q}{4\pi\epsilon_0 r_3^2} = \frac{-20 \times 10^{-6} \times 9 \times 10^9}{15 \times 10^{-2}} = -12.0 \times 10^5 \text{V}$$

$$E_x = (9 - 10.8 - 12.0) \times 10^5 \text{V}$$

$$= 7.8 \times 10^5 \text{V}$$

(d) (i) Explain why two insulating bodies rubbed together acquire equal and opposite charges. (03marks)

For two insulators A and B, B with a lower work function loses electrons more easily than A. When A and B are rubbed together, heat is produced and B loses electrons while A gains electrons; B becomes positively charged while A becomes negatively charged.

(ii) Describe how a gold leaf electroscope can be used to verify the observation in (d)(i) above (06marks)

A neutral metallic can is placed on the cap of neutral gold leaf electroscope and one of the bodies is lowered into the cap without touching it. The divergence θ_1 of the leaf is noted.

The process is repeated with B and divergence θ_2 is noted.

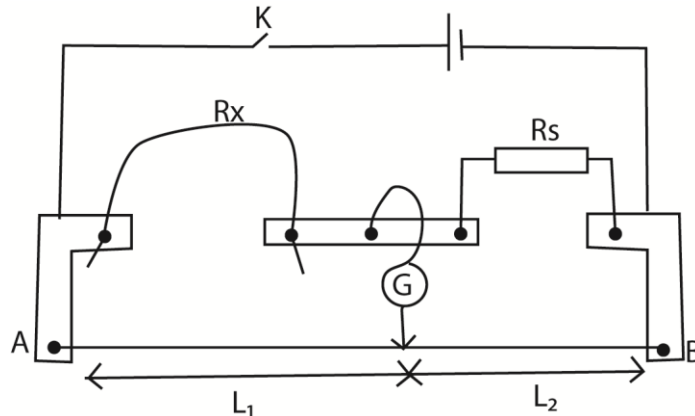
It is observed that $\theta_1 = \theta_2$; this implies that the magnitudes of the two charges are equal.

A and B are now put into contact, and the composite body is lowered into the can without touching it. No divergence is observed implying that the charges are equal and opposite.

49. (a) State Ohm's law (01mark)

Ohm's law states that the current flowing through a given conductor is directly proportional to the potential 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 \$L_x\$ of the wire under test is connected in the left hand gap of the Meter Bridge and standard of resistance \$R_s\$ 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 \$L_x\$ and the results tabulated including the values of $R_x = \frac{L_1}{L_2} R_s$

A graph of \$R_x\$ against \$L_x\$ 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 \$15\Omega\$ 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 \$3.0\Omega\$ is connected a resistor of resistance \$8\Omega\$. Calculate the:

- (i) Power generated (02marks)

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

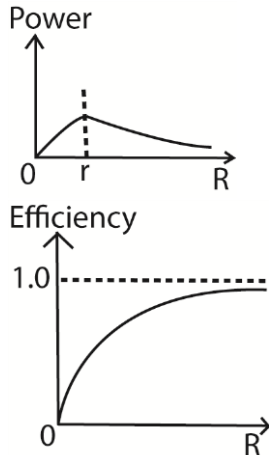
$$= \frac{18 \times 18}{8+3}$$

$$= 29.45W$$

(ii) efficiency. (02marks)

$$\begin{aligned} \eta &= \frac{P_{out}}{P_{in}} = \frac{IV}{IE} = \frac{V}{E} \\ &= \frac{IR}{I(R+r)} = \frac{R}{R+r} \\ &= \frac{8}{8+3} \\ &= 0.727 \text{ or } 72.7\% \end{aligned}$$

(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)



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

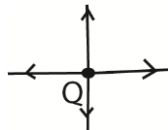
When a p.d is applied across a wire, the conduction electron gain kinetic energy from the applied field. As the electrons drift along the wire, in a direction opposite to the applied field, they collide with the ions and lose their kinetic energy to the ions.

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

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

Electric potential is the work done in 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)



$$\delta w = f \delta r$$

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

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

$$\delta w = \frac{-Q}{4\pi\epsilon_0 r^2} \delta r$$

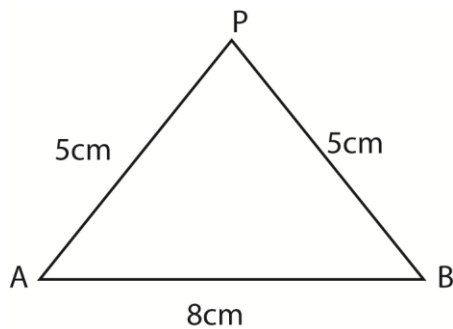
work done to move a positive charge of 1C from infinity to a point a distance r from Q

$$w = \int_{\infty}^r \frac{-Q}{4\pi\epsilon_0 r^2} \delta r$$

$$= \frac{Q}{4\pi\epsilon_0} \left[\frac{1}{r} \right]_{\infty}^r$$

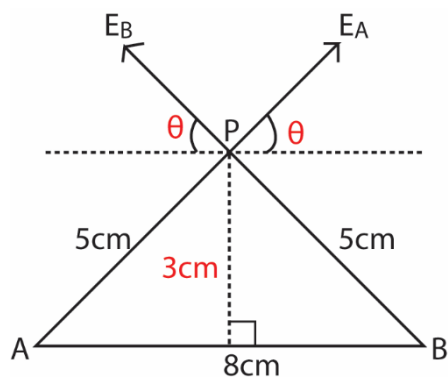
$$= \frac{Q}{4\pi\epsilon r}$$

(c)



Two point charges A and B of charges $+0.10\mu\text{C}$ and $+0.05\mu\text{C}$ 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



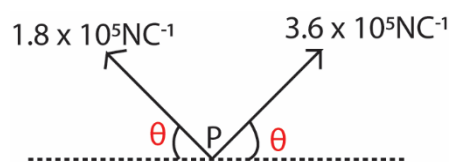
$$\sin \theta = \frac{3}{5} = 0.6; \quad \cos \theta = \frac{4}{5} = 0.8$$

E at P due to charge at A

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

E at A due to charge at B

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

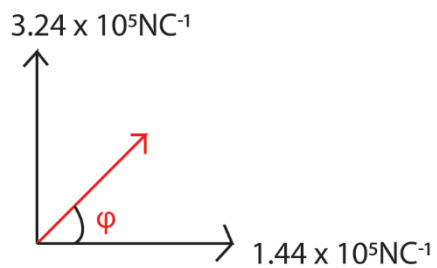


Resolving vertically

$$\begin{aligned} E_y &= 3.6 \times 10^5 \sin \theta + 1.8 \times 10^5 \sin \theta \\ &= 5.4 \times 10^5 \sin \theta \\ &= 5.4 \times 0.6 = 3.24 \times 10^5 \text{ NC}^{-1} \end{aligned}$$

Resolving horizontally

$$\begin{aligned} E_x &= 3.6 \times 10^5 \cos \theta - 1.8 \times 10^5 \cos \theta \\ &= 1.8 \times 10^5 \times 0.8 \\ &= 1.44 \times 10^5 \text{ NC}^{-1} \end{aligned}$$



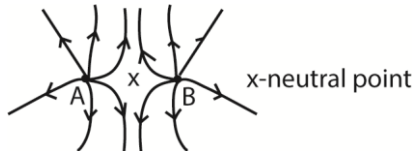
$$R^2 = (1.44 \times 10^5)^2 + (3.24 \times 10^5)^2$$

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

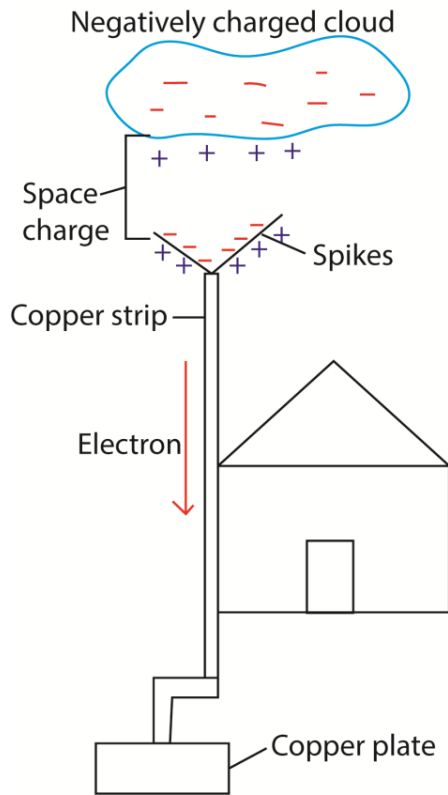
$$\tan \theta = \frac{3.24 \times 10^6}{1.44 \times 10^6}$$

$$\theta = 66^\circ$$

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



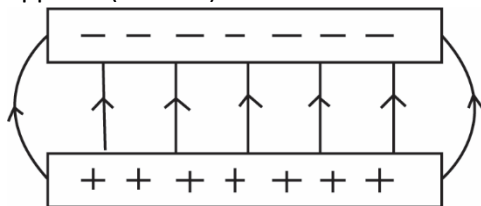
(e) Explain how a lightning conductor works. (04marks)



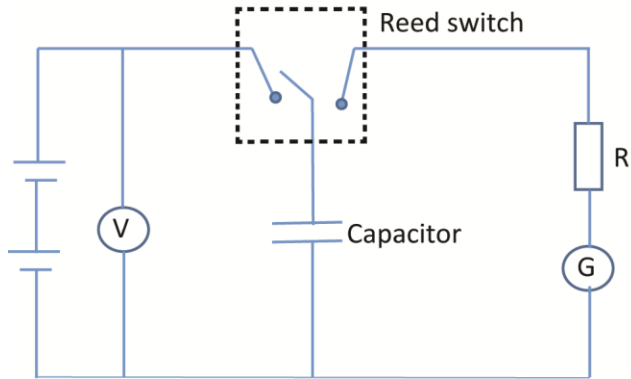
Action

- (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.

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

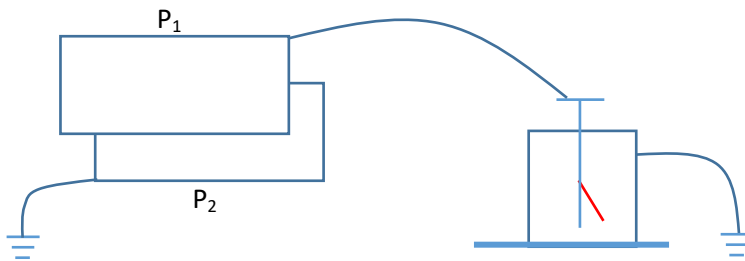


(b) (i) Describe, with aid of a diagram, how you would investigate the factors which affect the capacitance of a parallel plate capacitor. (07marks)



- 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.d.s, 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 $C \propto \epsilon$.

Alternative experiments



P_1 and P_2 are capacitor plates initially with air between them. 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 $C \propto A$

Plate P_2 is displaced sideways relative to P_1 to reduce the effective area A of the plates. The divergence of the leaf increases. 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 $C \propto A$.

(a) To show that $C \propto 1/d$

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 $C \propto 1/d$

(b) To show that $C \propto \epsilon$

The position of P_2 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 $C \propto \epsilon$.

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

$$C = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 0.1 \times 0.1}{5 \times 10^{-3}} = 1.77 \times 10^{-11} F$$

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

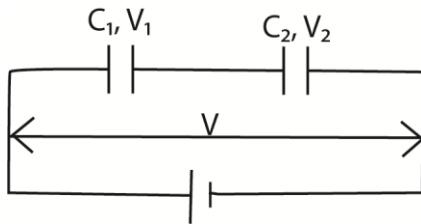
$$V = \frac{Q}{4\pi\epsilon R}$$

$$\epsilon = \frac{Q}{4\pi R V} = \frac{6.9 \times 10^{-10}}{4\pi \times 0.107 \times 10} = 1.026 \times 10^{-11} Fm^{-1}$$

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

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

Solution



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

$$V = V_1 + V_2$$

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

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

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

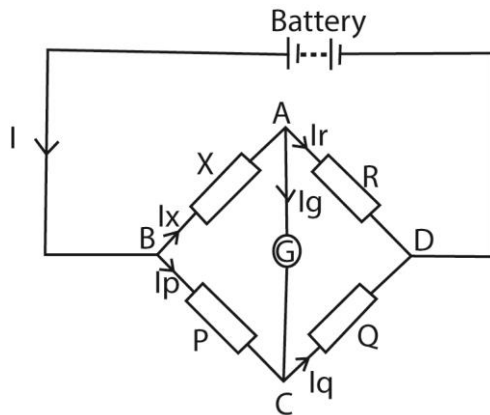
$$Q = \frac{C_1 C_2}{C_1 + C_2} V$$

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

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

- (ii) A $20\mu\text{F}$ capacitor is charged to 40V and then connected across uncharged $60\mu\text{F}$ capacitor. Calculate the potential difference across the $60\mu\text{F}$ capacitor.
 Charge on the capacitor before connection = charge on a capacitor after connection
 $20 \times 10^{-6} \times 40 = (20 \times 10^{-6} + 60 \times 10^{-6})V$
 $V = 10.0\text{V}$

52. (a) Derive the condition for a Wheatstone bridge to be balanced. (04marks)



When resistances P, Q, R and X are such that no current flows through the galvanometer, the bridge is said to be balanced, i.e., $I_g = 0$

⇒ Potential at A = potential at C

$$V_{AB} = V_{BC} \text{ and } V_{AD} = V_{DC}$$

$$I_x X = I_p P \text{ and } I_r R = I_q Q$$

$$\frac{I_x X}{I_r R} = \frac{I_p P}{I_q Q}$$

Since $I_g = 0$, then $I_x = I_r$ and $I_p = I_q$

$$\text{Hence } \frac{X}{R} = \frac{P}{Q}$$

(b) (i) Define temperature coefficient of resistance. (01mark)

Temperature coefficient of resistance is the fractional change in resistance at 00C per degree Celsius rise in temperature.

- (ii) When a coil X connected across the left hand gap of a meter bridge is heated to a temperature of 30°C , the balance point is found to be 51.5cm from the left-hand end of the slide wire. When the temperature is raised to 100°C , the balance point is 54.6cm from the left end. Find the temperature coefficient of resistance of X. (06marks)

Solution

Resistance at 30°C is given by

$$R_{30} = R_s \frac{51.5}{48.5} = 1.062R_s$$

Resistance at 100°C is given by

$$R_{30} = R_s \frac{54.6}{45.4} = 1.203R_s$$

$$\text{From } R_\theta = R_0(1 + \alpha\theta)$$

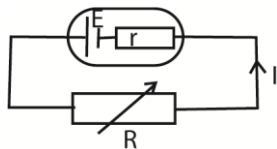
$$1.062R_s = R_0(1 + 30\alpha) \dots\dots\dots (i)$$

$$1.203R_s = R_0(1 + 100\alpha) \dots\dots\dots (ii)$$

$$\text{From (i) and (ii) } \alpha = 2 \times 10^{-3} \text{K}^{-1}$$

- (c) (i) A battery of e.m.f E and internal resistance, r , is connected to a resistor of variable resistance, R . Obtain the expression for maximum power dissipated in a resistor.

Circuit diagram



$$E = I(R + r)$$

$$EI = I^2(R + r)$$

$$\text{Power dissipated in a resistor} = I^2R$$

$$\text{For maximum power, } \frac{dP}{dR} = 0$$

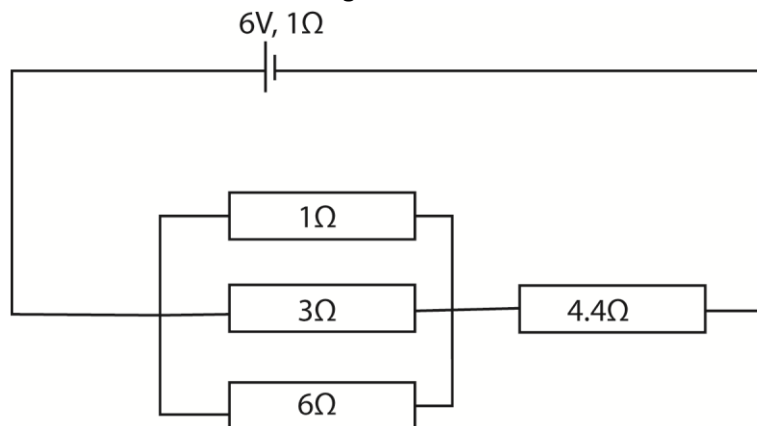
$$\frac{dP}{dR} = E \frac{dI}{dR} - 2Ir \frac{dI}{dR} = 0$$

$$> E = 2Ir$$

substituting for E in $E = IR + Ir$ and simplifying

$$R = r, \text{ hence } P_{\max} = I^2R = \frac{E^2}{4r}. \text{ Since } I = \frac{E}{2r}$$

- (iii) A battery of e.m.f 6V and internal resistance 1Ω is connected across a network of resistor as shown in the diagram below



Find the current supplied by the battery. (04marks)

Effective resistance R_1 for resistors in parallel

$$\frac{1}{R_1} = \frac{1}{1} + \frac{1}{3} + \frac{1}{6} = \frac{6+2+1}{6} = \frac{9}{6}$$

$$R_1 = \frac{6}{9}$$

$$\text{Effective resistance, } R \text{ of } R_1, 1\Omega \text{ and } 4.4\Omega \text{ resistor in series} = 4.4 + \frac{6}{9} + 1 = 6.07\Omega$$

$$\text{Current} = \frac{V}{R} = \frac{6}{6.07} = 0.99A$$

53. (a) State coulomb's law of electrostatics (01marks)

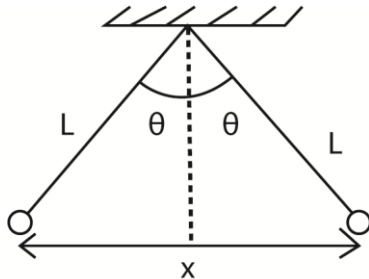
The force between two point charges is directly proportional to the product of the magnitude of the charges and inversely proportional to the square of the distance of separation of the charges.

(b) (i) Define electric field intensity and electric potential. (02marks)

Electric potential is a point in electric field is work done to transfer 1C charge from infinity to that point.

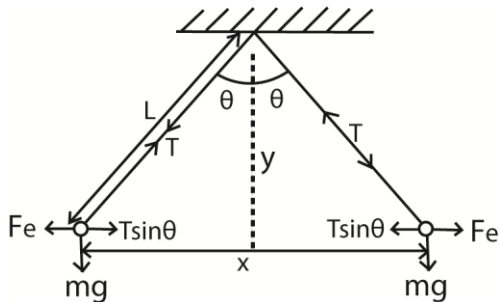
Electric field intensity at a point is the force experienced by 1C of positive charge placed at that point in electric field.

(ii) Two identical conducting balls of mass, m , are each suspended in air from a silk thread of length L . when the two balls are each given identical charge, q , they move apart as shown in the figure below



If at equilibrium each thread makes a small angle θ with the vertical, show that the separation, x , is given by

$$x = \left[\frac{q^2 L}{2\pi\epsilon m g} \right]^{\frac{1}{3}} ; \text{ where } \epsilon \text{ is permittivity of air}$$



Horizontally, $F_e = T \sin \theta$ (i)

Vertically $mg = T \cos \theta$ (ii)

Dividing Eqn. (i) by Eqn (ii)

$$\frac{F_e}{mg} = \tan \theta, \text{ but } F_e = \frac{q^2}{4\pi\epsilon_0 x^2}$$

$$\text{Hence } \tan \theta = \frac{q^2}{4\pi\epsilon_0 x^2 mg} \text{ and } \sin \theta = \frac{x}{2L}$$

For small angles, $\tan \theta \approx \sin \theta \approx \theta$

$$\Rightarrow \frac{q^2}{4\pi\epsilon_0 x^2 mg} = \frac{x}{2L}$$

$$x = \frac{q^2 L}{4\pi\epsilon_0 mg}$$

(c) (i) Define the term capacitance of a capacitor. (01mark)

Capacitance of a capacitor is the ratio of the magnitude of charge on one of the plates of the capacitor, to the potential difference between the plates.

(ii) State the factors that affect capacitance of a capacitor (03marks)

- Plate separation
- Area of overlap
- Permittivity of the material between the plates

(iii) Show that the energy stored in a capacitor of capacitance, C charged to a p.d V is equal to $\frac{1}{2} CV^2$. (03marks)

Suppose the p.d between the plates at some instant is V. When a small charge of δq is transferred from the negative plate to the positive plate, the p.d increases by δV .

$$\text{Work done to transfer the charge; } \delta w = (V + \delta V)\delta q \approx V\delta q$$

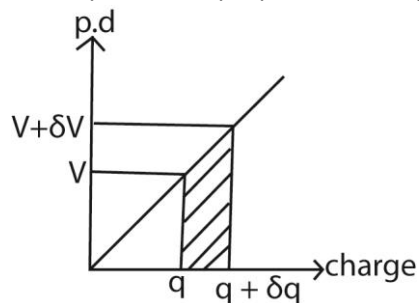
$$\text{But } V = \frac{q}{C}$$

$$\therefore \frac{q}{C} \delta q$$

$$\text{Total work done} = \int_0^q \frac{q}{C} \delta q = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} CV^2$$

Or

From $q = CV$, V is proportional to q, this gives the graph of V against q below



$$\text{Shaded area} = \frac{1}{2} (V + V + \delta V) \times \delta q$$

= work done to increase charge on the capacitor by δq

\therefore to charge a capacitor from $q = 0$ to $q = Q$

Work done, w = average voltage x charge

$$= \frac{1}{2} (0 + V) \times Q$$

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

But $Q = CV$

$$\therefore w = \frac{1}{2} CV^2$$

- (d) The plates of parallel plate capacitor each of area 2.0cm^2 are 5mm apart. The plates are in vacuum and potential difference of $10,000\text{V}$ is applied across the capacitor.

Find the magnitude of the charge on the capacitor (04marks)

$$Q = \frac{\epsilon_0 A}{d} V = \frac{8.85 \times 10^{-12} \times 2.0 \times 10^{-4} \times 10000}{5 \times 10^{-3}} = 3.54\text{NC}$$

54. (a) Define temperature efficiency of resistance and electrical resistivity. (02marks)

Temperature coefficient of resistance is the fractional change in resistance at 00C per degree Celsius rise in temperature.

- (b) A nichrome wire of length 1.0m and diameter 0.72mm at 25°C , is made into a coil. The coil is immersed in 200cm^3 of water at the same temperature and current of 5.0A is passed through the coil for 8minutes until when the water starts to boil at 100°C .

Find

- (i) The resistance of the coil at 25°C . (02marks)

$$R = \frac{\rho L}{A} \text{ but } A = \frac{\pi d^2}{4}$$

$$\therefore R = \frac{4\rho L}{\pi d^2} = \frac{4 \times 1.2 \times 10^{-6} \times 1}{4\pi \times (0.72 \times 10^{-3})^2} = 2.95\Omega$$

- (ii) The electrical energy expended assuming all of it goes into heating the water (02marks)

$$W = mc\Delta\theta = 200 \times 10^{-6} \times 10^3 \times 4.2 \times 10^3 \times (100 - 25) = 6.3 \times 10^4\text{J}$$

- (iii) The mean temperature coefficient of resistance of nichrome wire between 0°C and 100°C . (06marks)

$$\text{Electrical energy dissipated, } = I^2 R_{\text{mean}} t$$

$$\Rightarrow 6.3 \times 10^4 = 5^2 \times R_{\text{mean}} \times 8 \times 60$$

$$R_{\text{mean}} = 5.25\Omega$$

$$R_{\text{mean}} = \frac{R_{25} + R_{100}}{2}$$

From $R =$

$$R_{100} = 2R_{\text{mean}} - R_{25}$$

$$= 2 \times 5.25 - 2.95$$

$$= 7.55\Omega$$

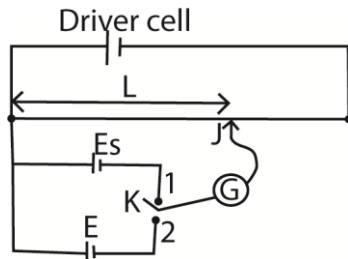
From $R\theta = R_0(1 + \alpha\theta)$

$$2.95 = R_0(1 + 25\alpha) \dots\dots\dots (i)$$

$$7.55 = R_0(1 + 100\alpha) \dots\dots\dots (ii)$$

$$\text{From (i) and (ii) } \alpha = 4.3 \times 10^{-2}\text{K}^{-1}$$

- (c) Describe, with the aid of circuit diagram how a slide wire potentiometer can be used to measure e.m.f of a cell. (04marks)



Es is the cell with known e.m.f and
 E is the cell whose e.m.f is to be determined
 AB = 1m

Switch K in position 1. Balance length L_s where the galvanometer shows no deflection is determined

If k is the calibration constant, $E_s = kL_s$ (i)

Switch K in position 2. Balance length L where the galvanometer shows no deflection is determined

If k is the calibration constant, $E = kL$ (ii)

From eqn. (i) and (ii)

$$E = \frac{LE_s}{L_s}$$

- (d) An accumulator of e.m.f 2.0V is connected across a uniform wire of length 1.0m and resistance 8.0Ω. A cell of e.m.f 1.50V is connected in series with a galvanometer and connected across a length L of slide wire. The galvanometer shows no deflection when L is 90.0cm. Find the internal resistance of an accumulator. (04marks)

$$\text{Resistance of AC} = \frac{8 \times 90}{100} = 7.2\Omega$$

$$\text{Current supplied by the driver cell} = \frac{2}{8+r} = \frac{V}{R}$$

$$\Rightarrow \frac{2}{8+r} = \frac{1.5}{7.2}$$

$$r = 1.5\Omega$$

55. (a) Distinguish between e.m.f and terminal p.d of a battery. (02marks)

Electromotive force of a battery is the energy supplied by the battery to transfer 1C of charge across a complete circuit in which the battery is connected while terminal p.d is the p.d across external resistor in a circuit.

- (b)(i) define electrical resistivity (01mark)

Electrical resistivity is the resistance across opposite faces of a 1m^3 cube

- (ii) Explain any two factors on which the resistance of a conductor depends. (05marks)
- Temperature: an increase in temperature increases resistance of a conductor because increase in temperature increases the amplitude of vibration of the atoms in the conductor. This increases the rate of collision between drifting electrons and the atom which reduced the drift speed of electrons. Hence increases resistance.

- Cross section area: A big cross section area increases the number of electrons that pass through in a unit time leading to higher current and low resistance
- Length: increase in length of a conductor leads to a longer path for electrons. This increases the number of collision, lower the drift velocity and thus increases resistance.

(c) Two wires A and B have length which are in ratio 4:5, diameter which are in ratio 2:1, and resistances in ratio of 3:2. If the wires are arranged in parallel and a current of 1.0A flows through the combination, find the

(i) Ratio of resistance of wire A to that of wire B (04marks)

$$\frac{l_A}{l_B} = \frac{4}{5} \text{ and } \frac{d_A}{d_B} = \frac{2}{1}$$

$$\Rightarrow \frac{A_A}{A_B} = \left(\frac{r_A}{r_B}\right)^2; \frac{R_A}{R_B} = \frac{3}{2}$$

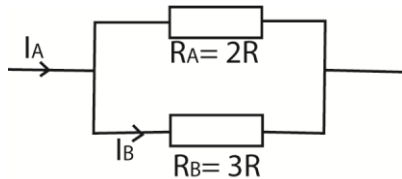
$$R_A = \frac{\rho_A \cdot L_A}{A_A} \text{ and } R_B = \frac{\rho_B \cdot L_B}{A_B}$$

$$\frac{R_A}{R_B} = \frac{\rho_A}{\rho_B} \cdot \frac{L_A}{L_B} \cdot \frac{A_B}{A_A}$$

$$\frac{3}{2} = \frac{\rho_A}{\rho_B} \cdot \frac{4}{5} \cdot \left(\frac{2}{1}\right)^2$$

$$\frac{\rho_A}{\rho_B} = 0.47$$

(ii) Current through wire A (03marks)



Total resistance across the parallel combination

$$\frac{1}{R'} = \frac{1}{3R} + \frac{1}{2R} = \frac{5}{6R}$$

$$R' = \frac{6R}{5}$$

$$V = I \times R = \frac{I \times 6R}{5}$$

$$I = \frac{V}{R_A} = \frac{6R}{5} \cdot \frac{1}{3R} = 0.4A$$

(d) Explain why a wire becomes hot when current flows through it. (05marks)

The p.d applied across the wire increases the kinetic energy of the electrons; these electrons collide with the ions and lose their kinetic energy partially converted to heat.

56. (a)(i) State Ohm's law (01marks)

States that the current flowing through a conductor is directly proportional to the P.d. across it provided that there is no change in physical conditions such as temperature of the conductor.

(ii) State the factors which affect the resistance of a conductor. (02marks)

- Length of a conductor
- Cross-section area of the conductor

- temperature
- (iii) A conductor of length L and cross section area A has free electrons per unit volume each of charge e . find the drift velocity, v , of these electrons if a current, I , flows through the conductor. (04marks)

In 1s electrons move through a distance v from Q, where v is the drift velocity.

Therefore charge crossing through cross-section area per second = $(ne)vA$

Current, $I = nevA$

$$v = \frac{I}{neA}$$

Alternatively

Volume of conductor = AL

Number of free electrons = nAL

Total charge drifting through the conductor = $neAL$

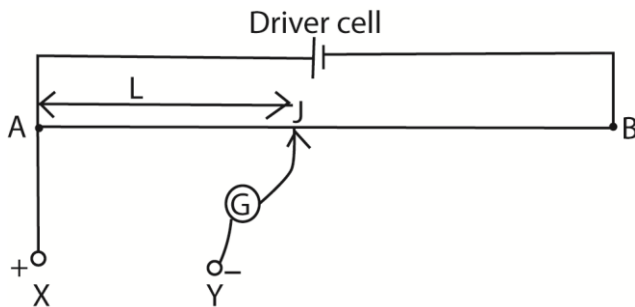
In a given time, t ; $I = \frac{neAL}{t}$

$$= neAv \text{ (since } v = \frac{L}{t} \text{)}$$

$$v = \frac{I}{neA}$$

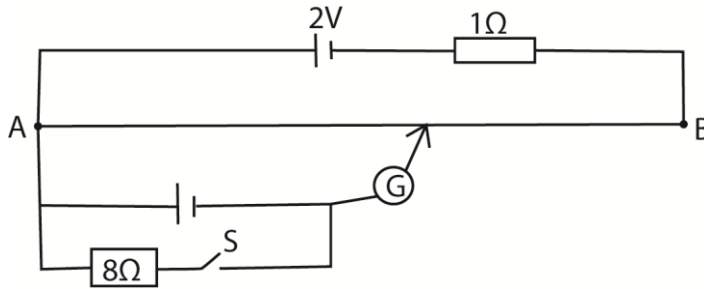
- (b) Outline the principle of a slide wire potentiometer. (04marks)

A potentiometer consists of a uniform wire AB about 1m, and a driver cell, X that maintains a steady current I in the wire AB .



- The driver cell maintains a steady current through a uniform resistance wire AB .
- The p.d per unit length of the wire is therefore constant.
- At balance, when G shows no deflection, the p.d across length AJ = test p.d
i.e. $V = kL$

- (c)



In the figure above the slide wire AB is 1m long and has resistance 4Ω. When switch S is:

- (i) Open the balance length Ac is 88.8cm. find the value of the e.m.f of the cell (03mark)

$$\text{p.d across AB} = 2 \times \frac{4}{5} = 1.6\text{V}$$

$$\text{p.d per cm} = \frac{1.6}{100} \text{Vcm}^{-1}$$

$$\text{e.m.f of the cell} = \frac{1.6}{100} \times 88.8 = 1.42\text{V}$$

- (ii) Closed, the balance length is found to be 82.5cm.

Calculate the internal resistance of a cell. (04marks)

$$\frac{E}{V} = \frac{R+r}{R} = \frac{L_0}{L}$$

$$\frac{8+r}{8} = \frac{88.8}{82.5}$$

$$r = 0.61\Omega$$

- (e) State two advantages of using a potentiometer for measuring voltage (02marks)

- It does not draw current from the p.d it measuring
- Can be used to compare small resistance

57. (a) What is a dielectric material

A dielectric is a material which does not possess conductible or free charges. It can withstand a high electric field before it conducts.

- (b) A capacitor filled with a dielectric is charge and then discharged through a milliammeter. The dielectric is then withdrawn half way and the capacitor charged to the same voltage, and discharged through the milliammeter again, show that the relative permittivity, E_r of the dielectric is given by

$$E_r = \frac{I}{2I' - I} \text{ where } I \text{ and } I' \text{ are the readings of the milliammeter respectively. (06marks)}$$

Solution

- Initially, $C = \frac{\epsilon_0 \epsilon_r A}{d}$, where A is area of the plates and d is the separation of the plates
- When the dielectric is withdrawn half way, the resultant capacitance is due to two capacitors connected in parallel, each with plate area that is half the original.
- Eventually, $C = C_1 + C_2$

$$= \frac{\epsilon_0 \epsilon_r \frac{A}{2}}{d} + \frac{\epsilon_0 \frac{A}{2}}{d}$$

$$= \frac{\epsilon_0 A}{2d} (\epsilon_r + 1)$$

Initial charge on the plates is $Q = CV$

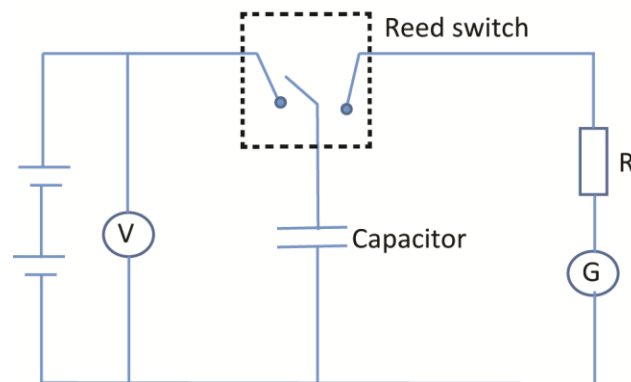
Final on the plates is $Q_1 = C_1 V$

$$\frac{I}{I_1} = \frac{Q}{Q_1} = \frac{CV}{C_1 V} = \frac{C}{C_1}$$

$$= \frac{\epsilon_0 \epsilon_r A}{d} \div \frac{\epsilon_0 A}{2d} (\epsilon_r + 1)$$

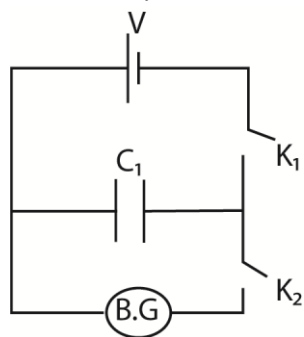
$$= \frac{2\epsilon_r}{\epsilon_r + 1}$$

(c) Describe with the aid of a diagram how you would determine the capacitance of a capacitor. (05marks)



- The setup is shown above
- The switch is closed and the reading of current I and voltage V are noted at known frequency, f of the reed switch.
- The capacitance of a capacitor, $C = \frac{I}{fV}$

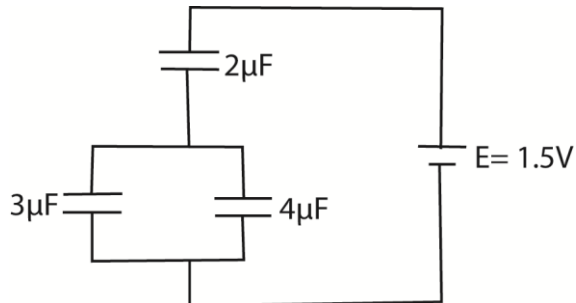
Alternatively



- The circuit is connected as shown with a capacitor of known capacitance C_1 .
- Switch K_1 is closed and K_2 is opened. The capacitor of capacitance C_1 is charged by the battery of e.m.f. V .

- K_1 is opened and K_2 is closed to discharge the capacitor through the ballistic galvanometer, B.G. the first deflection of the B.G θ_1 is noted
- The capacitor is then replaced with the capacitor of unknown capacitance C_2 . the experiment is repeated and deflection θ_2 is noted
- Hence $\frac{c_2}{c_1} = \frac{\theta_2}{\theta_1}; c_2 = c_1 \frac{\theta_2}{\theta_1}$

(d)



A battery of e.m.f 15V is connected across a system of capacitors as shown above, find the

- (i) Charge on the $4\mu F$ capacitor (04marks)
- Effective capacitance, C of $3\mu F$ and $4\mu F$ that are parallel = $3 + 4 = 7\mu F$
- Effective capacitance, C_1 of $7\mu F$ and $2\mu F$ in series = $\frac{7 \times 2}{7+2} = \frac{14}{9}\mu F$
- $Q = CV = \frac{14}{9} \times 10^{-6} \times 1.5 = 2.33 \times 10^{-6} C$
- The charge on $2\mu F$ capacitor = $2.33 \times 10^{-6} C$
- P.d across $2\mu F$ capacitor = $\frac{2.33 \times 10^{-6}}{2 \times 10^{-6}} = 1.165V$
- p.d on either $3\mu F$ or $4\mu F$ = $1.5 - 1.165 = 0.335V$
- Charge on $4\mu F$ capacitor = $CV = 4 \times 10^{-6} \times 0.335 = 1.34 \times 10^{-6} C$
- (ii) Energy stored in the $3\mu F$ capacitor. (04marks)
- $E = \frac{1}{2} CV^2 = \frac{1}{2} \times 3 \times 10^{-6} \times 0.335^2 = 1.68 \times 10^{-7} J$