UNIT - III Current Electricity

Meter bridge - Construction & Working - Potentiometer - Calibration of ammeter - Calibration of low range Voltmeter - Carey foster's bridge - Theory - Determination of Specific resistance of the material of the unknown coil - Thermoelectricity - Peltier And Thomson Coefficient - Application of thermodynamics to a thermocouple - Thermoelectric diagram - Determination of Peltier and Thomson coefficient.

ELECTRICITY AND MAGNETISM

UNIT - 3 CURRENT ELECTRICITY

Definitions:

Potential Difference.

The potential difference between two points is the amount of work done in moving a unit +ve charge from the point at a lower potential to the point at higher potential.

Volt:

It is the practical unit for measuring potential difference. The potential difference between two points is 1 volt if 1 joule of work is done in moving 1 coulomb of charge from one point to the other.

Electric Current:

Electric current through a conductor is the rate of flow of charge i.e., the amount of charge that flows per unit time.

Ampere:

The Practical unit in which current is measured is amperes. The current flowing through a conductor is one ampere if the rate of flow of charge is 1 Coulomb per second.

Resistance:

The current that flows through a conductor depends on the potential difference applied.

According to ohm's law the steady current I flowing through a conductor at constant temperature, is directly proportional to the potential difference V across its ends.

$$V \propto I$$

$$V = RI.$$

Ohm:

It is the practical unit for measuring resistance. A conductor has a resistance of 1 ohm if a current of 1 ampere flows through it under a potential difference of 1 Volt.

Metre Bridge:

The metre bridge or slide wire bridge is one form of Wheatstone's bridge.

⇒ It consist of a wire AC of low temp. coefficient and length 100 cm (1 metre).

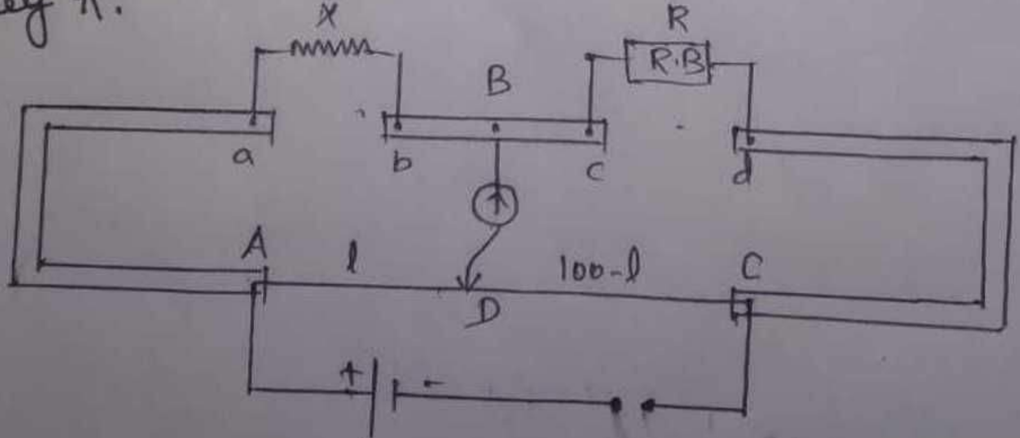
⇒ The wire is stretched on a wooden board and the ends of the wire are joined to thick copper strips.

⇒ ab and cd are two gaps in which the unknown resistance X and a resistance box RB are connected respectively.

⇒ One terminal of the galvanometer is connected to the point B and the other terminal is connected to a jockey which slides along the wire AC.

⇒ A metre scale is fixed along the wire AC so as to measure the balancing length.

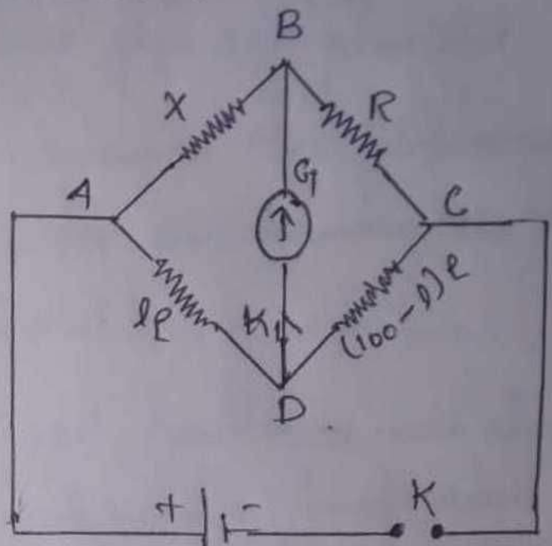
⇒ The cell is connected between the points A and C through a key K.



⇒ Neglecting the resistances of the connecting wires and the copper strips the circuit is equivalent to that of a Wheatstone's bridge.

⇒ If ρ is the resistance per cm length of the bridge wire AC then the resistances of the branches AD and DC will be $l\rho$ and $(100-l)\rho$ respectively.

⇒ Let D be the balance point when the resistance introduced in the resistance box (RB) is R.



For zero deflection of the galvanometer

$$\frac{X}{l\rho} = \frac{R}{(100-l)\rho}$$

$$X = R\frac{l\rho}{(100-l)\rho} = R\left[\frac{l}{100-l}\right]$$

The value of X is calculated for different values of R and the mean value gives the unknown resistance.

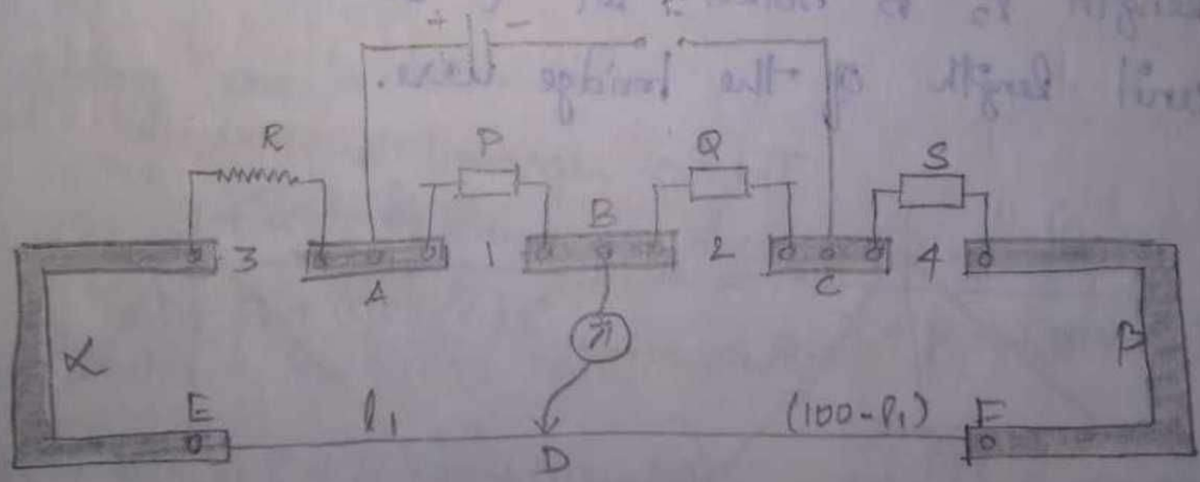
For increased accuracy in measurement, two more gaps similar to ab and cd are provided and extra resistances whose values are 10 or 20 times more than the resistance of the bridge wire AC are connected to the gaps so that the effective length of the ratio arms is increased.

CAREY FOSTER BRIDGE :

A Carey Foster Bridge is principally the same as a metre bridge except that two gaps are provided.

This bridge is used to measure the difference between two nearly equal resistances and knowing the value of one, the other can be calculated.

In this bridge, the end resistances are eliminated in calculations, which is an advantage and hence it can conveniently be used to measure a given low resistance.



P and Q are two resistance boxes connected in the inner gaps 1 and 2, R is the unknown low resistance and S is a fractional resistance box.

Let the length of the bridge wire be 100 cm and α and β the end resistances on the sides of

R and S respectively.

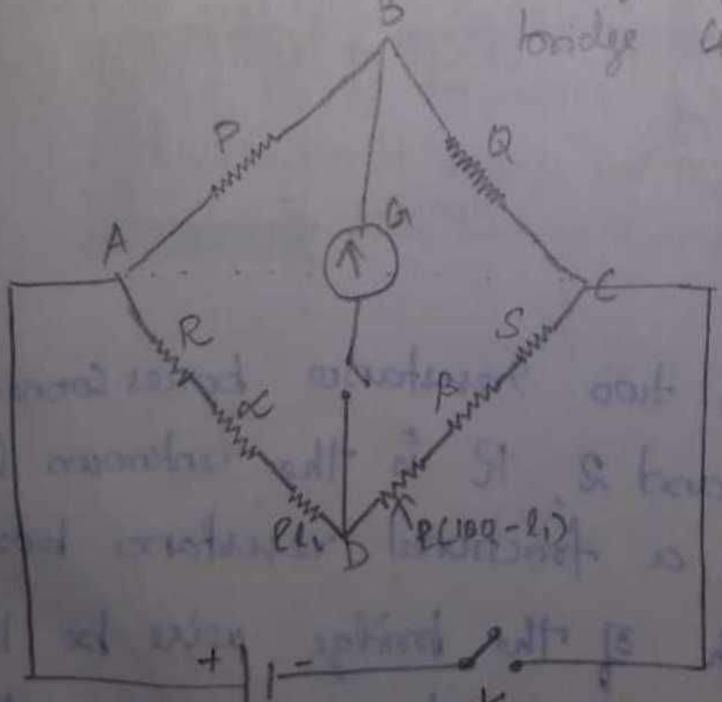
The Galvanometer G is connected between the point B and D.

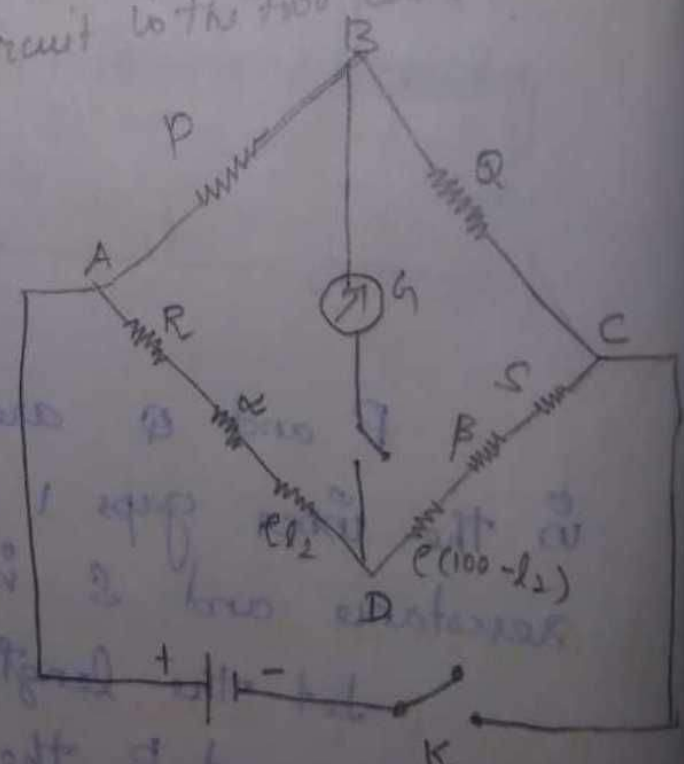
The cell is connected through a Key between the point A and C.

Keeping suitable values of P and Q, the resistance R is placed in the left gap and S is the right gap and the balance length l_1 is measured from the point E.

R and S are interchanged and the balancing length l_2 is noted. Let ρ be the resistance per unit length of the bridge wire.

The Fig represent the equivalent Wheatstone bridge circuit in the two cases





For zero deflection of the galvanometer, in the first case

$$\frac{P}{Q} = \frac{R + \alpha + l_1 \rho}{S + \beta + (100 - l_1)\rho} \quad — ①$$

IInd case

$$\frac{P}{Q} = \frac{S + \alpha + l_2 \rho}{R + \beta + (100 - l_2)\rho} \quad — ②$$

Equating equ ① & ②

$$\frac{R + \alpha + l_1 \rho}{S + \beta + (100 - l_1)\rho} = \frac{S + \alpha + l_2 \rho}{R + \beta + (100 - l_2)\rho}$$

Adding one to both sides.

$$\frac{R + \alpha + l_1 \rho}{S + \beta + (100 - l_1)\rho} + 1 = \frac{S + \alpha + l_2 \rho}{R + \beta + (100 - l_2)\rho} + 1$$

$$\frac{R + \alpha + l_1 \rho + S + \beta + (100 - l_1)\rho}{S + \beta + (100 - l_2)\rho} = \frac{S + \alpha + l_2 \rho + R + \beta + (100 - l_2)\rho}{R + \beta + (100 - l_2)\rho}$$

$$\frac{R + \alpha + \cancel{l_1 \rho} + S + \beta + 100\rho - \cancel{l_1 \rho}}{S + \beta + (100 - l_1)\rho} = \frac{S + \alpha + \cancel{l_2 \rho} + R + \beta + 100\rho - \cancel{l_2 \rho}}{R + \beta + (100 - l_2)\rho}$$

$$\frac{R + S + \alpha + \beta + 100\rho}{S + \beta + (100 - l_1)\rho} = \frac{R + S + \alpha + \beta + 100\rho}{R + \beta + (100 - l_1)\rho} \quad — ③$$

The numerators of equ (3) are equal. ∴ The denomenators are equal.

$$S + \beta + 100\rho - l_1\rho = R + \beta + 100\rho - l_2\rho$$

$$S - l_1\rho = R - l_2\rho$$

$$R - S = \rho(l_2 - l_1) \quad \text{—} (4)$$

$$R = S + \rho(l_2 - l_1) \quad \text{—} (5)$$

Thus, knowing the values of l_1 and l_2 the difference $R-S$ can be calculated, provided ρ the resistance per unit length of the bridge wire is known (equ. iv).

Further, if the value of S is known, R can be calculated (equ v).

(ii) Determination of ρ.

To determine the resistance per unit length of the bridge wire, the resistance R is replaced by a thick copper strip (i.e., $R=0$) and the balancing length l_1' is determined.

Now keeping S in the left gap and the copper strip in the right gap the balancing length l_2' is determined with the same values of P and Q.

from equ ⑤

$$0 = S + \rho(l_2' - l_1')$$

$$-\rho(l_2' - l_1') = S$$

$$\rho = \frac{S}{(l_1' - l_2')} \quad \text{— ⑥}$$

The experiment is repeated with different values of S and the mean value of ρ is taken.

Calibration of the bridge wire:

In equ ⑤, $\rho(l_2 - l_1)$ measures the resistance of the bridge wire between the two balance points.

Thus R-S = Resistance of the bridge wire between the two balance point.

Initially, using known Values of R and S, the resistance of various portions of the bridge wire is determined.

The balance ~~length~~ points can be shifted to various positions of the wire by suitably altering the values of P and Q.

A graph drawn b/w the length of the wire along the X-axis and the resistance of the wire along Y-axis. This calibration is necessary when the bridge wire is not uniform.

Determination of the temperature co-efficient of resistance:

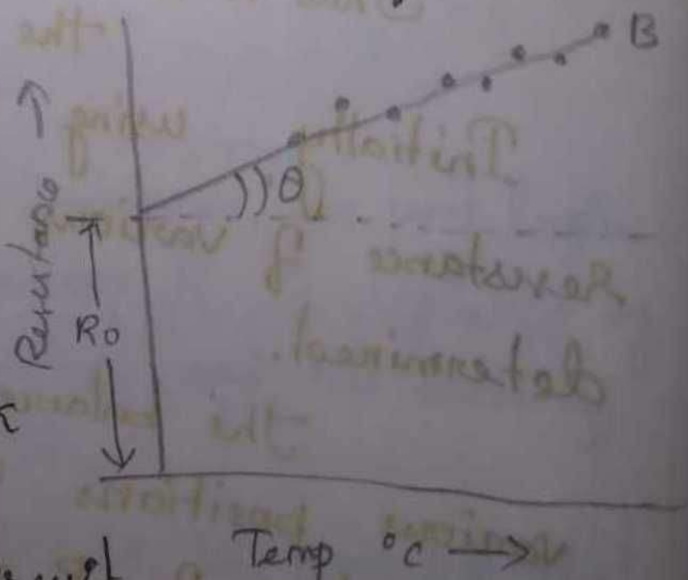
If R_0 and R_t are the resistances of a wire at temp. $0^\circ C$ and $t^\circ C$ respectively, then

$$R_t = R_0[1 + \alpha t]$$

where α is the temp. coefficient of resistance of the material.

It is defined as the increase in resistance per unit resistance per degree centrigrade rise of temp.

To determine the value of α the given wire is wound noninductively in the form of a double spiral on a glass tube.



This tube is immersed in a water bath.

The two ends of the wire are connected with thick copper leads in the gap 3 of the Carey Foster bridge circuit.

The resistance of the wire is determined at different temps. of the bath starting from 0°C.

A graph is drawn with temp along the X-axis and resistance along the Y-axis.

For small temp ranges the graph is a straight line.

$$R_t = R_0(1+\alpha t)$$

$$\frac{R_t - R_0}{R_0} = \alpha t$$

$$\alpha = \frac{R_t - R_0}{R_0 t}$$

Expressing in terms of calculus

$$\alpha = \frac{1}{R_0} \cdot \frac{dR}{dt}$$

In the graph, the slope of the line $= \tan\theta = \frac{dR}{dt}$ and the Y intercept $= R_0$.

Using these values from the graph, α can be calculated.

The value of α can also be calculated from two values of resistance R_1 and R_2 at temp t_1° and $t_2^\circ C$ respectively.

$$R_1 = R_0[1+\alpha t_1], \quad R_2 = R_0[1+\alpha t_2]$$

$$\frac{R_1}{R_2} = \frac{1+\alpha t_1}{1+\alpha t_2}, \quad R_1 + R_1\alpha t_2 = R_2 + R_2\alpha t_2$$

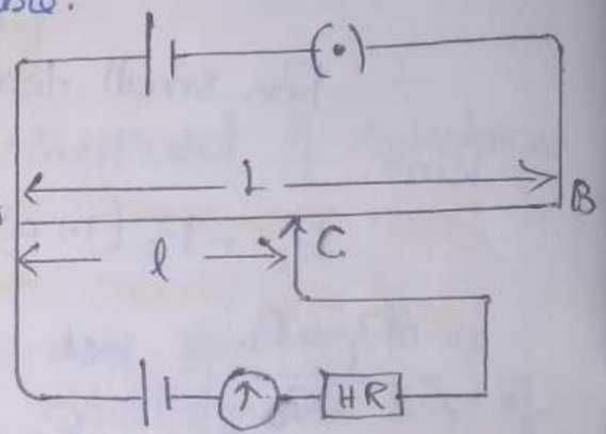
$$\alpha[R_1 t_2 - R_2 t_1] = R_2 - R_1$$

$$\boxed{\alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1}}$$

Potentiometer:

Principle:

A potentiometer is a device for measuring or comparing potential differences. A potentiometer can be used to measure any electrical quantity which can be converted into a proportionate D.C potential difference.



It consist of a uniform wire AB of length 10 m stretched on a wooden board. A steady current is passed through the wire AB with the help of a cell of EMF E.

Let ρ = resistance per unit length of potentiometer wire and,

I = Steady current passing through the wire.

Let C be a variable point.

Let $AB = L$ and $AC = l$.

PD across AB $= L \rho I$ and

PD across AC $= l \rho I$

$$\frac{\text{PD across AB}}{\text{PD across AC}} = \frac{L \rho I}{l \rho I} = \frac{L}{l}$$

$$\therefore \text{PD across AC} = \frac{l}{L} \times \text{PD across AB}.$$

i.e. for a steady current passing through the potentiometer wire AB, PD across any length is proportional to the length of the wire.

If a D.C voltmeter is connected between A and the variable point C, it will be noted that the voltmeter register greater values of PDs as the point C slides from A to B.

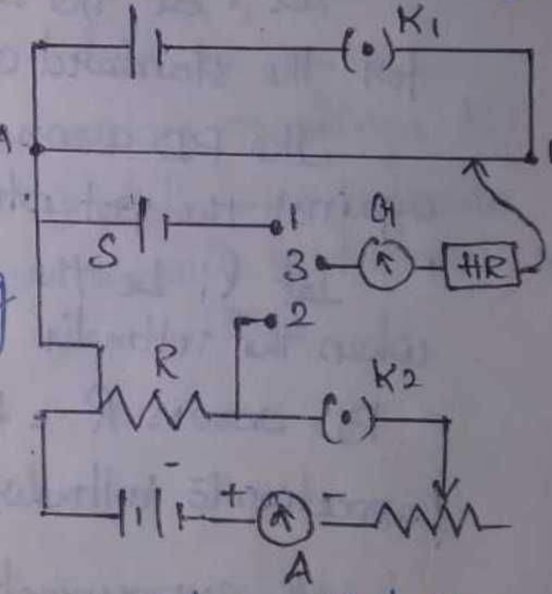
Calibration of Ammeter:

Connect the ends of the potentiometer wire to the terminals of a storage cell through a key K_1.

S is a standard cell. Connect the ammeter (A) to be calibrated in series with a battery, key K_2, a rheostat and a resistance R. ~~the~~

When a current I passes through the standard resistance R, the PD across R is IR.

This potential drop is measured with the help of potentiometer.



Connect 1 and 3 and balance the EMF of the standard cell against the potentiometer. Find the balancing length from A.

The P.D per cm of the Potentiometer $\Big\} = \frac{E}{l}$

Connect 2 and 3. Adjust the rheostat so that the ammeter reads a value A_1.

Balance the PD across R against the potentiometer and find the balancing length l_1.

P.D across $R = \frac{El_1}{l}$

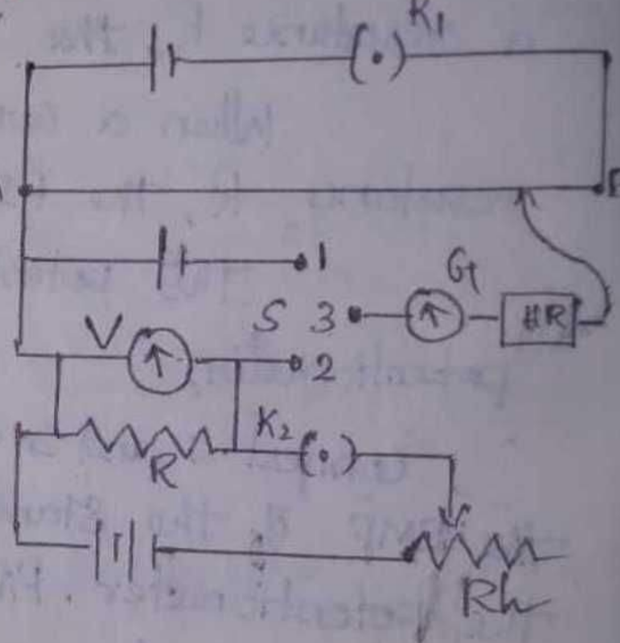
current through $R = \frac{El_1}{lR}$

correction to ammeter reading $= \left(\frac{El_1}{lR}\right) - A_1$

I_1, the corrections for other ammeter readings are determined. A calibration curve is plotted for ammeter, taking ammeter readings on X-axis and correction on Y-axis.

Calibration of Voltmeter (Low range)

The connections are made as shown in Fig. The voltmeter is connected parallel to R.



Let l be the balancing length for the standard cell.

The PD across R is balanced against the potentiometer.

Let l_1 be the balancing length when the voltmeter reads V_1.

PD across R $= El_1 / l$

Correction to voltmeter $= \left(\frac{El_1}{l}\right) - V_1$

The experiment is repeated for various readings of the voltmeter and a calibration graph is drawn.

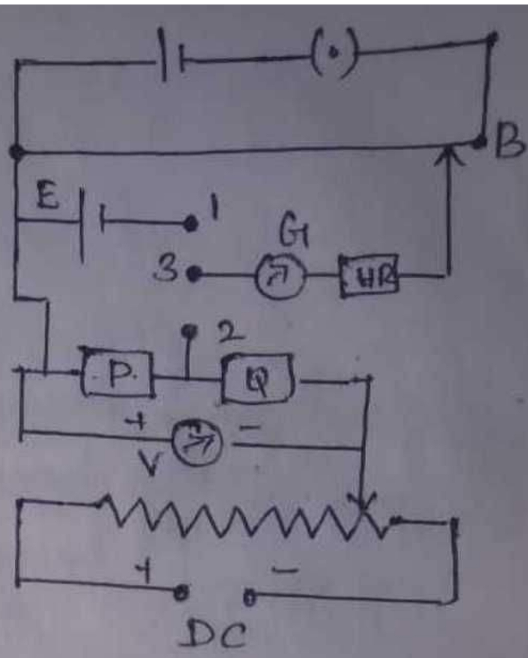
Calibration of voltmeter (High Range)

Connections are made as shown in Fig.

Take suitable high resistances in P and Q such that the PD across P does not exceed the PD across the potentiometer.

The balancing length l for the standard cell is determined first.

Then the PD across P is balanced against the potentiometer and the balancing length l_1 is determined



$$\text{PD across } P = \frac{El_1}{l}$$

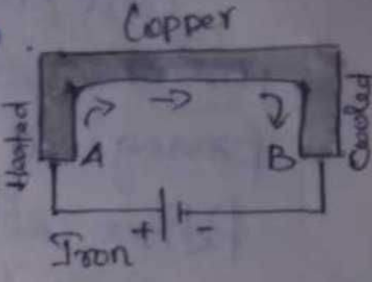
$$\text{PD across } P+Q = \left[\frac{P+Q}{P}\right]\left[\frac{El_1}{l}\right]$$

$$\text{Correction to Voltmeter} = \left[\frac{P+Q}{P}\right]\left[\frac{El_1}{l}\right] - V_1 .$$

The experiment is repeated for various readings of the voltmeter. A calibration curve is plotted for voltmeter, ~~taking~~ voltmeter, ~~taking~~ reading on X-axis and corrections on Y-axis.

Thermoelectricity

Peltier Effect:



Consider a copper-iron thermocouple. When a current is allowed to pass through the thermocouple in the direction of arrows (from A to B), heat is absorbed at the junction A.

This absorption or evolution of heat at a junction when a current is sent through a thermocouple is called Peltier effect.

The Peltier effect is a reversible phenomenon. If the direction of the current is reversed, then there will be cooling at the junction A and heating at the junction B.

When an electric current is passed through a closed circuit made up of two different metals, one junction is heated and the other junction is cooled. This is known as Peltier effect.

The amount of heat H absorbed or evolved at a junction is proportional to the charge q passing through the junction. i.e.,

$$H \propto q \quad \text{or} \quad H \propto It$$

$$H = \pi I t$$

Where π is a constant called Peltier coefficient

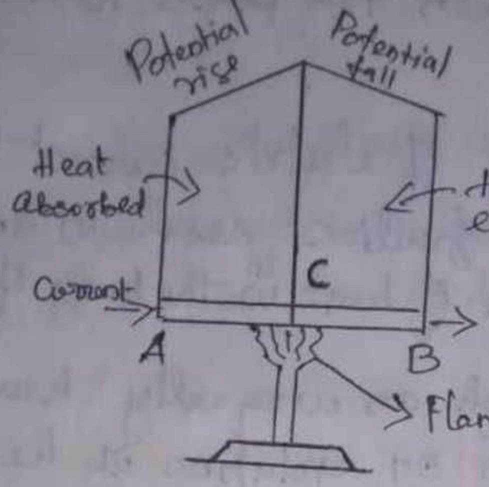
When $I = 1A$ and $t = 1s$, then $H = \pi$.

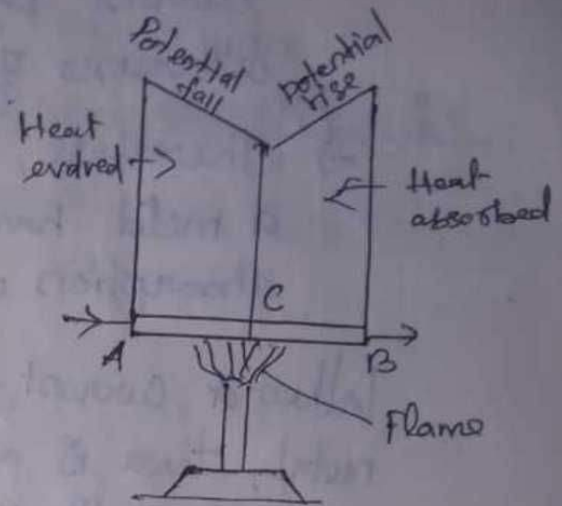
The energy that is liberated or absorbed at a junction between two dissimilar metals due to the passage of unit quantity of electricity is called Peltier coefficient.

It is expressed in joule / coulomb i.e., volt.

Peltier Effect	Joule Effect
1. It is a reversible effect	It is an irreversible effect.
2. It takes place at the junction only.	It is observed throughout the cond
3. It may be a heating or a cooling effect	It is always a heating effect.
4. Peltier effect is directly proportional to I ($H = \pm \pi I t$)	Amount of heat evolved is directly proportional to the current.
5. It depends upon the direction of the current	It is independent of the direction of the current.

Thomson Effect:





⇒ Consider a copper bar AB heated in the middle at the point C.

⇒ A current is passed from A to B.

⇒ It is observed that heat is absorbed in the part AC and evolved in the part CB.

⇒ This is known as Positive Thomson effect.

⇒ Similar effect is observed in metals like Ag, Zn, Sb and Cd.

⇒ An iron bar AB, heat is evolved in the part AC and absorbed in the part CB.

⇒ This is known as Negative Thomson effect.

⇒ Similar effect is observed in metals like Pt, Ni, Co and Bi.

⇒ For lead, the Thomson effect is zero.

⇒ The Thomson effect is reversible.

⇒ In the case of copper, the hotter parts are at a higher potential than the colder ones.

=) It is opposite in the case of iron.

=) Heat is either absorbed or evolved when current passes between two points having a difference of potential.

=) Therefore, the passage of electric current through a metal having temp. gradient results in an absorption or evolution of heat in the body of the metal.

When a current flows through an unequally heated metal, there is an absorption or evolution of heat throughout in the body of the metal. This is known as 'Thomson effect'.

Thomson Coefficient:

The Thomson Coefficient σ of a metal is defined as the amount of heat energy absorbed or evolved when a charge of 1 coulomb flows in the metal between two points which differ in temp. by 1°C.

Thus, if a charge of q coulomb flows in a metal between two points having a temp. difference of 1°C,

heat energy absorbed or evolved $= \sigma q$ joule.

But if E volt be the Thomson emf developed between these points then this energy must be equal to Eq joule.

$$\sigma q = Eq$$

$$\sigma = E.$$

Thus the Thomson coefficient of a metal, expressed in joule per coulomb per °C, is numerically equal to the emf in volt, developed between two points differing in temp by 1°C.

Hence it may also be expressed in volt per °C.

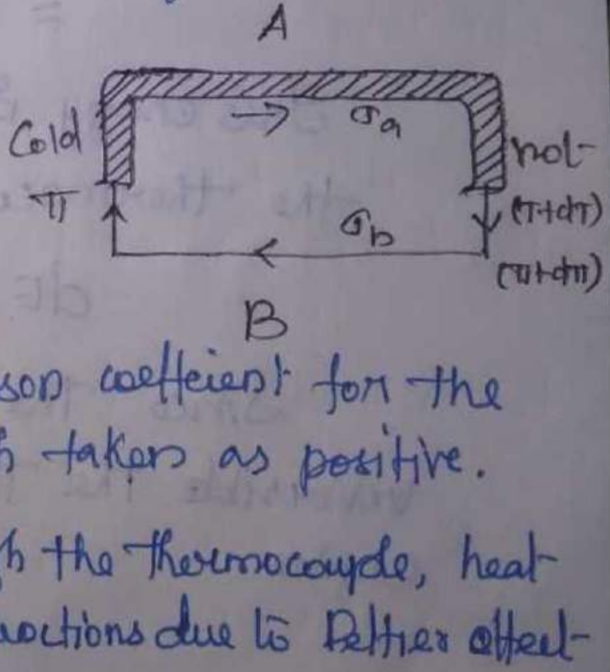
=> σ is not a constant for a given metal.

=> It is a function of temperature.

Thermodynamics of Thermocouple:

=> Consider a thermocouple consisting of two metals A and B.

=> Let T and T+dT be the temps of the cold and hot junctions respectively.



=> Let Π and $\Pi + d\Pi$ be the peltier coefficients for the pair at the cold and hot junctions.

=> Let σ_a and σ_b be the Thomson coefficient for the metals A and B respectively, both taken as positive.

=> When a charge flows through the thermocouple, heat will be absorbed and evolved at the junctions due to Peltier effect and all along the metal due to Thomson effect.

Let 1 Coulomb of charge flow through the thermocouple in the direction from A to B at the hot junction.

Heat energy absorbed due to Peltier effect at the hot junction $= (\pi + d\pi)$ joules

Heat energy evolved due to Peltier effect at the cold junction $= \pi$ joules.

Heat energy absorbed in the metal A due to Thomson effect $= \sigma_a \, dT$ joules

Heat energy evolved in the metal B due to Thomson effect $= \sigma_b \, dT$ joules.

$\therefore$ Net heat energy absorbed in the thermocouple

$$= (\pi + d\pi - \pi) + (\sigma_a \, dT - \sigma_b \, dT)$$

$$= d\pi + (\sigma_a - \sigma_b) \, dT$$

This energy is used in establishing a P.D dE in the thermocouple

$$dE = d\pi + (\sigma_a - \sigma_b) \, dT \quad \text{—} \quad (1)$$

Since the Peltier and Thomson effects are reversible the thermocouple acts as a reversible heat-engine.

Thermo-Electric Diagrams:

A thermocouple is formed from two metals A and B. The difference of temp. of the junctions is TK.

The thermo emf E is given by the equ.

$$E = aT + bT^2$$

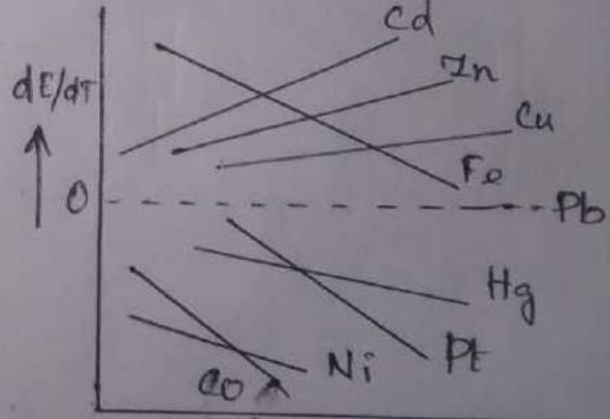
A graph between E and T is a parabola.

$$\frac{dE}{dT} = a + 2bT.$$

$\frac{dE}{dT}$ is called thermoelectric power.

A graph between thermoelectric power (dE/dT) and difference of temperature T is a straight line.

This graph is called the thermo-electric power line or the thermo-electric diagram.



Thomson coefficient of lead is zero. So generally thermo-electric lines are drawn with lead as one metal of the thermo couple.

The thermoelectric line of a Cu-Pb couple has a positive slope while that of Fe-Pb couple has a negative slope.

The Fig. shows the power lines for a no. of metals.