UNIT 2

CURRENT ELECTRICITY

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Charges

- **Charges at rest**
- **Charges at random motion**
- **Charges moving in a particular direction (drifting of charges)**

2.1 ELECTRIC CURRENT

2.1.1 Conventional Current

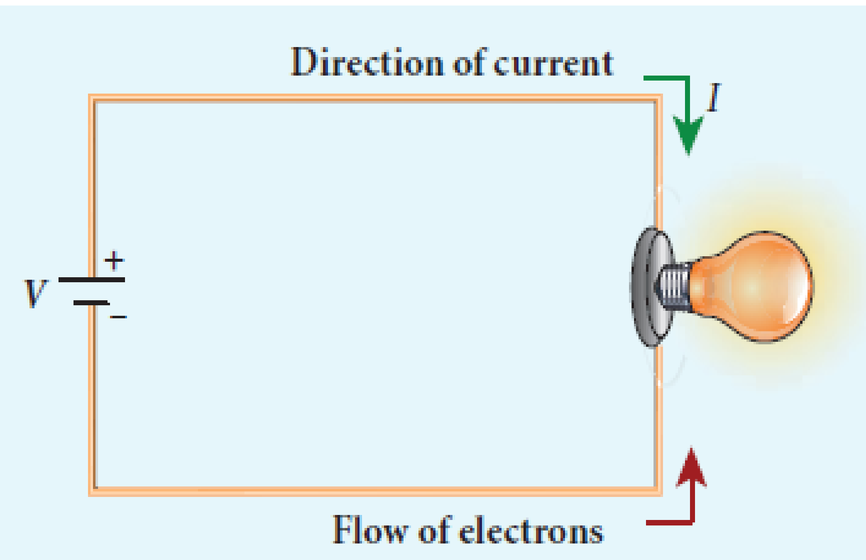


Figure 2.3 Direction of conventional current and electron flow

If a net charge Q passes through any cross section of a conductor in time t, then the current is defined as $I = \frac{Q}{t}$. But charge flow is not always constant. Hence current can more generally be defined as

$$I_{avg} = \frac{\Delta Q}{\Delta t} \tag{2.1}$$

Where ΔQ is the amount of charge that passes through the conductor at any cross section during the time interval Δt. If the rate at which charge flows changes in time, the current also changes. The instantaneous current I is defined as the limit of the average current, as $\Delta t \rightarrow 0$

$$I = \lim_{\Delta t \rightarrow 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt} \tag{2.2}$$

Current

1. **If a net charge Q passes through any cross section of a conductor in time t, then the current is defined as** $I = \frac{Q}{t}$

2. <u>Charge flow is not always constant</u>.

current (more general) $I_{avg} = \frac{\Delta Q}{\Delta t}$

3. If the rate at which charge flows changes in time, the current also changes.

The instantaneous current I is defined as the limit of the average current, as

$$I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

2.1.2 Drift velocity

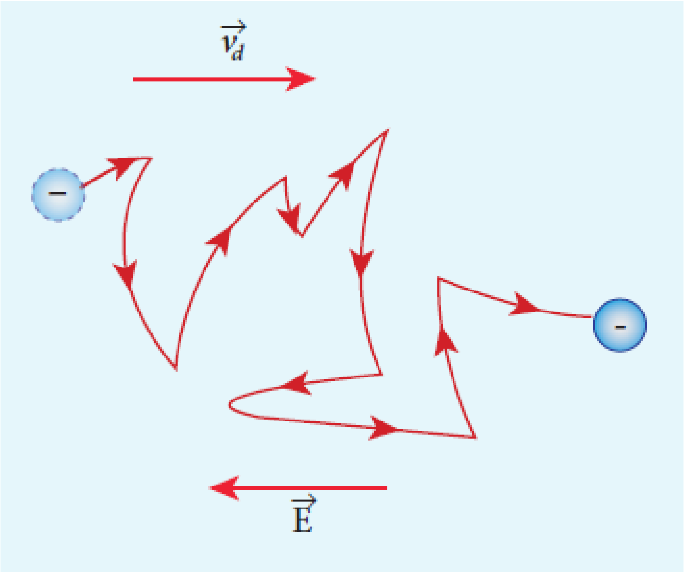


Figure 2.4 Electric current

$$\vec{a} = \frac{-e\vec{E}}{m} \qquad \left(\text{since}\,\vec{F} = -e\vec{E}\right) \qquad (2.3)$$

The drift velocity $\vec{v}_d$ is given by

$$\vec{v}_d = \vec{a}\ \tau$$

$$\vec{v}_d = -\frac{e\tau}{m}\vec{E} \qquad (2.4)$$

$$\vec{v}_d = -\mu\vec{E} \qquad (2.5)$$

Here $\mu = \frac{e\tau}{m}$ is the mobility of the electron and it is defined as the magnitude of the drift velocity per unit electric field.

$$\mu = \frac{\left|\vec{v}_d\right|}{\left|\vec{E}\right|} \qquad (2.6)$$

2.1.3 Microscopic model of current

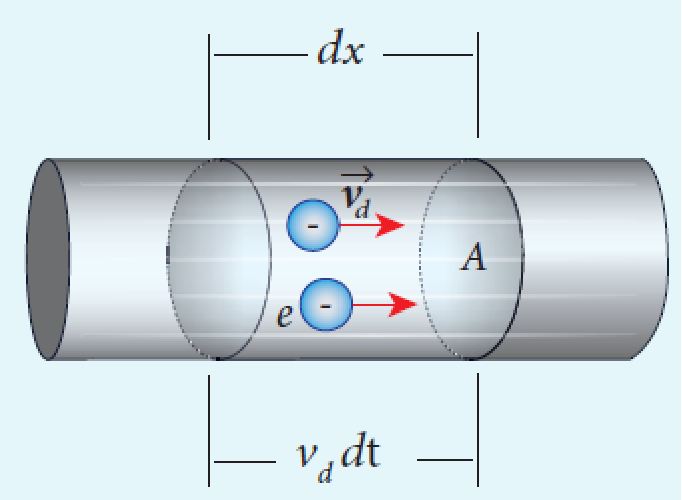


Figure 2.5 Microscopic model of current

Step 1: The electrons available in the volume element

$$= (A\, v_d\, dt\,)\, n$$

Step 2 : Total charge in volume element

$$dQ = (e)(Av_d dt)n$$

Step 3: Current:

$$\text{current } I = \frac{dQ}{dt} = \frac{neAv_d dt}{dt}$$

$$I = ne\,Av_d.$$

Step 4: Current density J

$$J = \frac{I}{A}$$

Substituting ….

$$\vec{J} = -\frac{n \cdot e^2 \tau}{m}\vec{E}$$

$$\vec{J} = -\sigma\vec{E}$$

Terms to infer - microscopic

Current Density

$$\boxed{\vec{J} = \sigma \vec{E}}$$

Conductivity

$$\sigma = \frac{ne^2\tau}{m}$$

Resistivity

$$\rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau}$$

2.2 OHM'S LAW

Microscopic to macroscopic

$$J = \sigma E = \sigma \frac{V}{l}$$

$$\frac{I}{A} = \sigma \frac{V}{l}.$$

$$V = I\left(\frac{l}{\sigma A}\right)$$

R

$$R = \frac{V}{I}$$

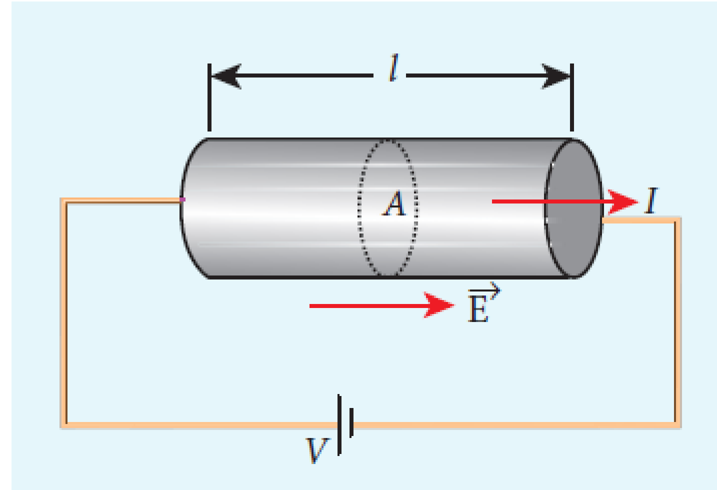
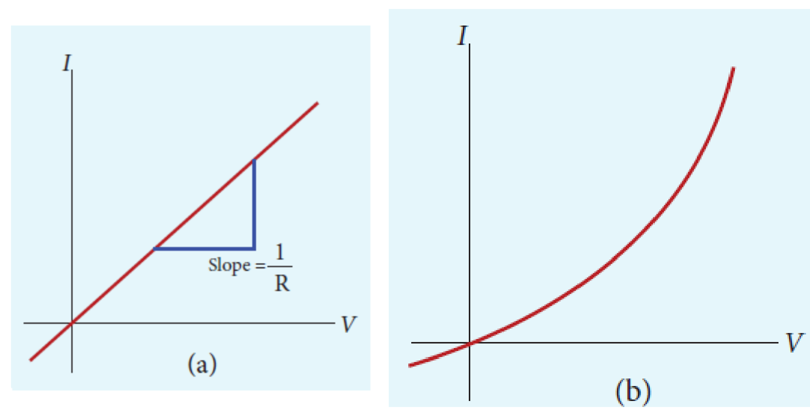


Figure 2.7 Current through the conductor



(a) Ohmic (b) Non Ohmic device

2.2.1 Resistivity

$$R = \frac{l}{\sigma A}$$

$$\rho = \frac{1}{\sigma}$$

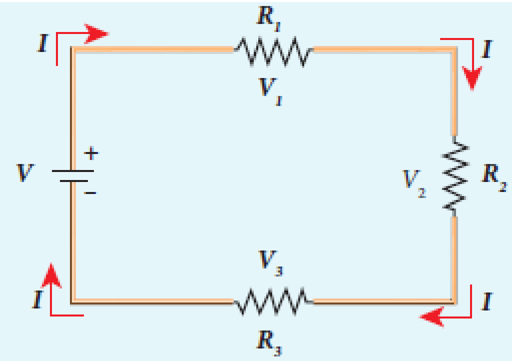
$$R = \rho \frac{l}{A}$$

The resistance is the ratio of potential difference across the given conductor to the current passing through the conductor.

2.2.2 Resistors in series and parallel

Resistors in series

- When two or more resistors are connected end to end, they are said to be in series.



(a) Three resistors in series

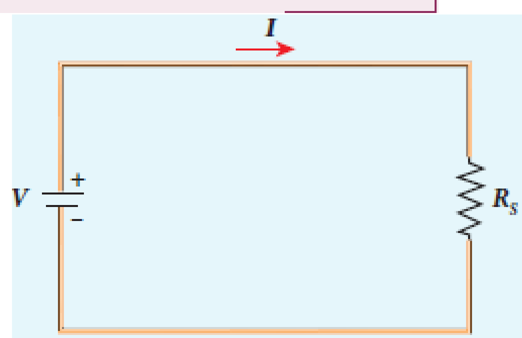
The current I passing through all the three resistors are the same.

- Resistors could be simple resistors or bulbs or heating elements or other devices.

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \quad (2.21)$$

$$V = I\,(R_1 + R_2 + R_3)$$

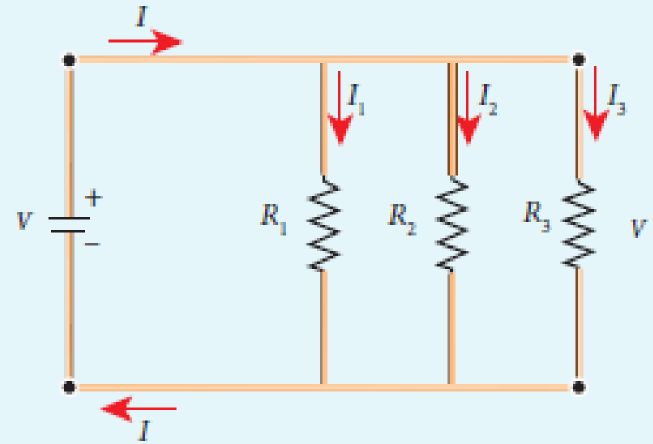
$$V = I.R_S \quad (2.22)$$



(b) Equivalent resistance (R_S) has the same current

Note: The value of equivalent resistance in series connection will be greater than each individual resistance.

Resistors in parallel



(a) Three resistors in parallel

$$I = I_1 + I_2 + I_3$$

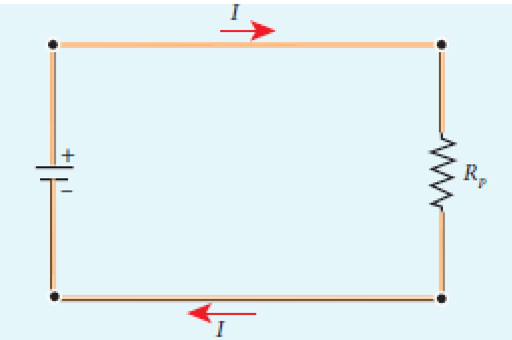
$$I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3}$$

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

$$I = \frac{V}{R_P}$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad (2.26)$$

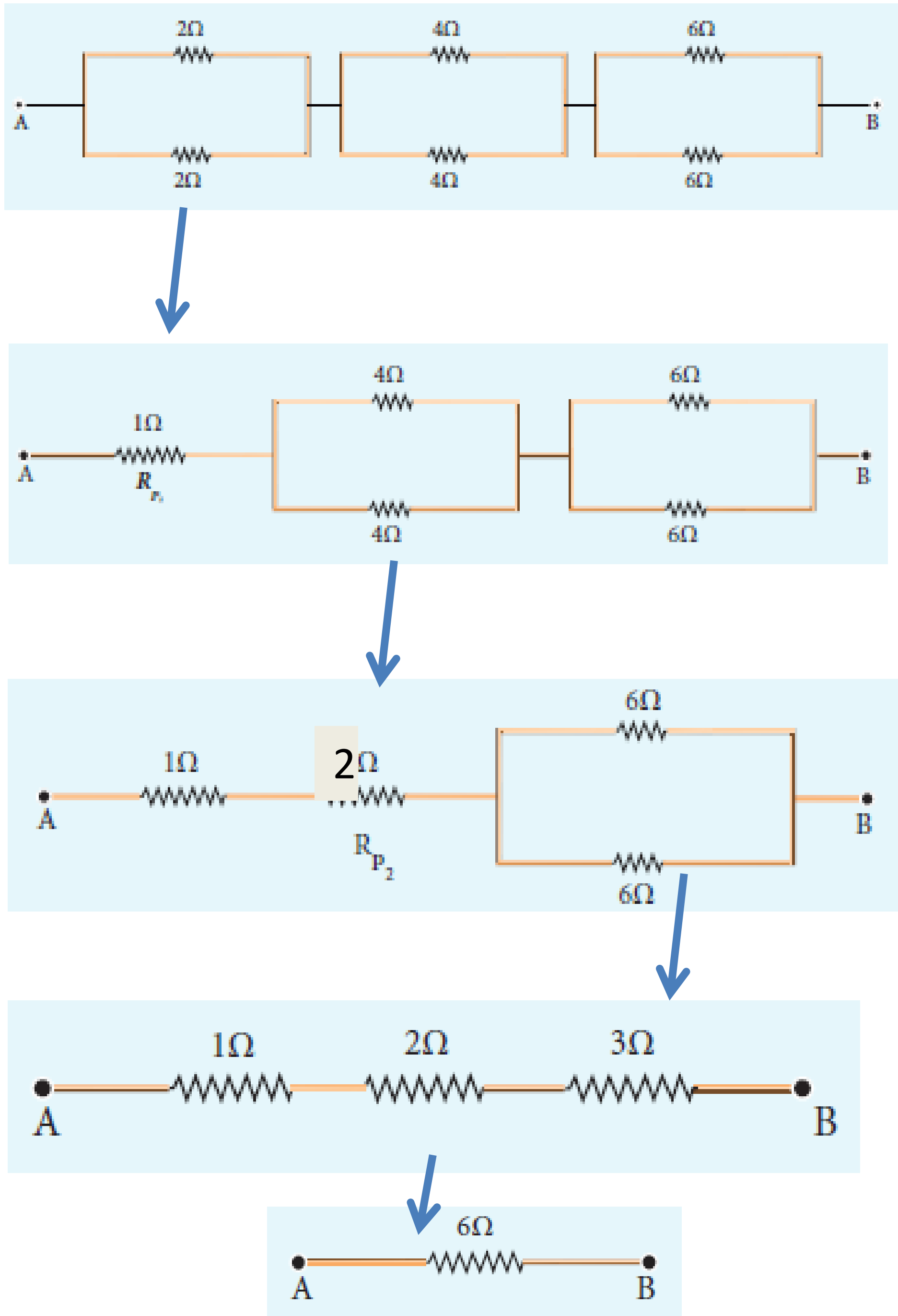
Potential across all resistors is the same.



(b) Equivalent resistance (R_P) has the same current

Note: The value of equivalent resistance in parallel connection will be lesser than each individual resistance.

Reducing the net work (Example 2.11)

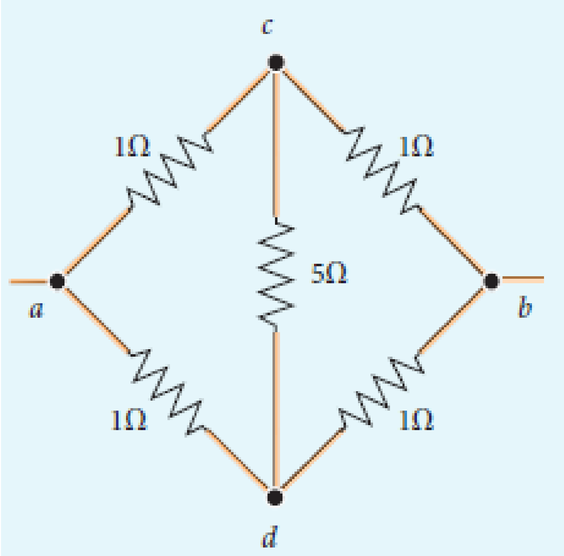


Parallel

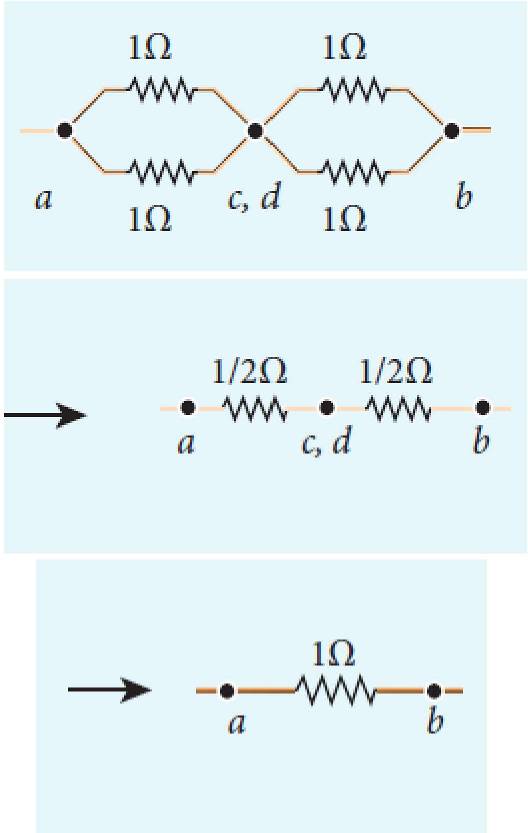
Parallel

Parallel

Series



- To find the equivalent resistance between the points a and b.
- we assume that current is entering the junction a.
- Since all the resistances in the outside loop are the same (1Ω), the current in the branches ac and ad must be equal.
- So the electric potential at the point c and d is the same hence no current flows into 5 Ω resistance.



2.2.3 Color code for Carbon resistors

Figure 2.11 Resistance used in our laboratory

Note While reading the colour code, hold the resistor with colour bands to your left. Resistors never start with a metallic band on the left.

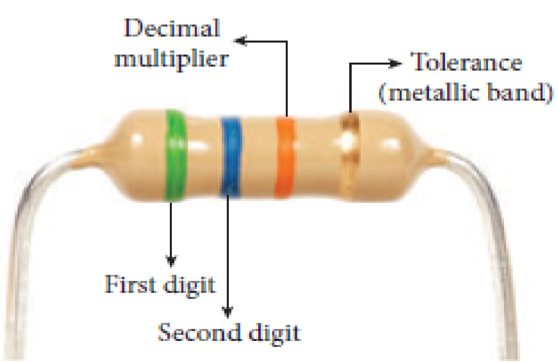


Figure 2.12 Resistor color coding

Table 2.2 Color Coding for Resistors

Color	Number	Multiplier	Tolerance
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5%
Sliver		10^{-2}	10%
Colorless			20%

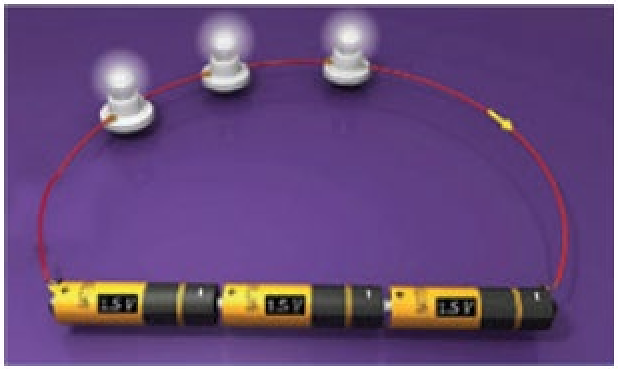
2.2.4 Temperature dependence of resistivity

$$\rho_T = \rho_\circ\left[1+\alpha\left(T-T_\circ\right)\right]$$

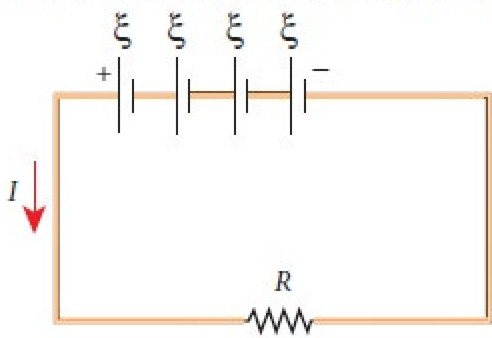
$$R_T = R_\circ\left[1+\alpha\left(T-T_\circ\right)\right]$$

2.3 ENERGY AND POWER IN ELECTRICAL CIRCUITS

2.4 ELECTRIC CELLS AND BATTERIES



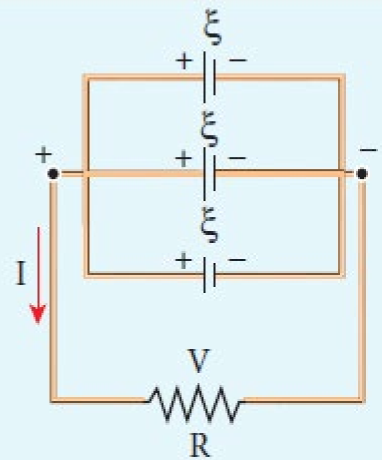
Cella in series (Schematic diagram)



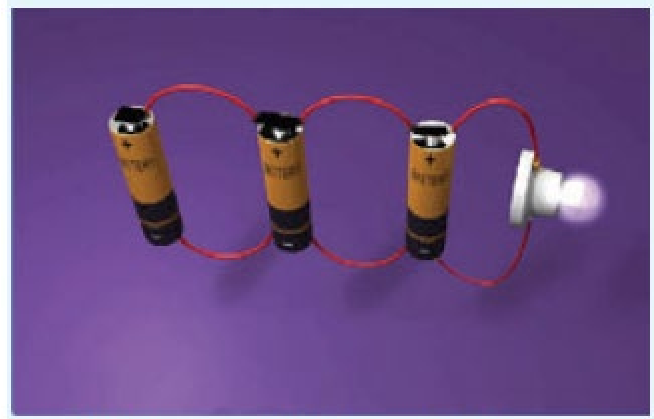
Cells in series (circuit diagram)

Figure 2.21 cells in series

Series



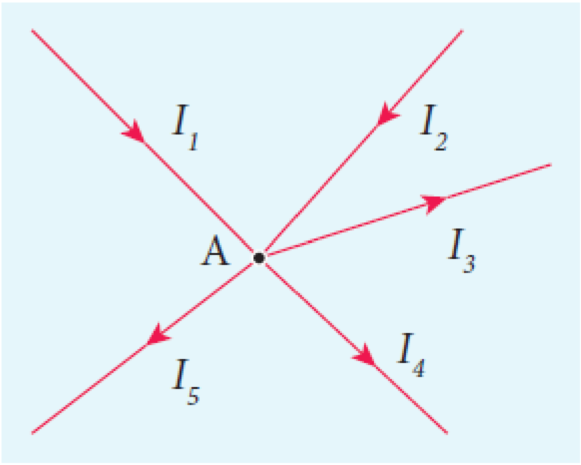
cells in parallel (Circuit diagram)



Cells in parallel (Schematic diagram)

Parallel

2.5.1 Kirchhoff's first rule (Current rule or Junction rule)



$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

(or)

$$I_1 + I_2 = I_3 + I_4 + I_5$$

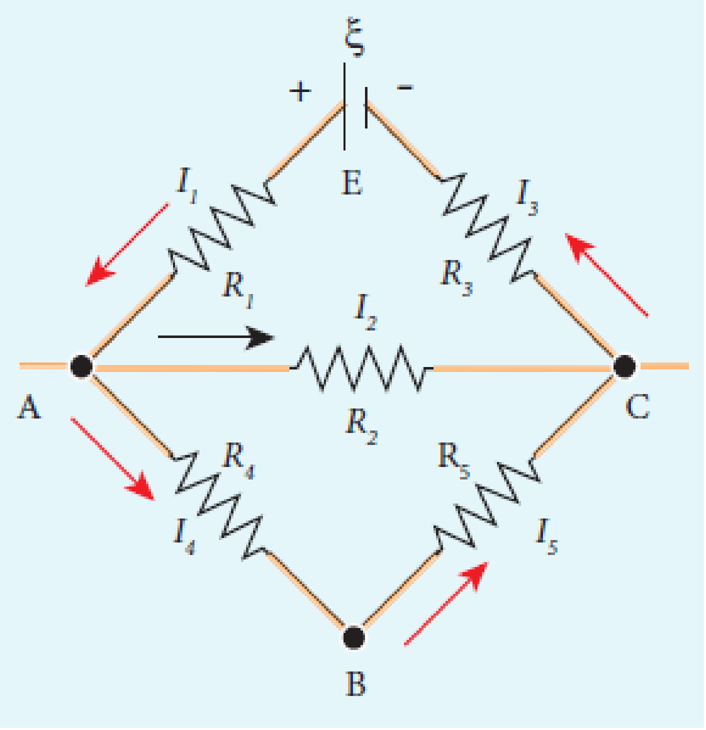
2.5.1 Kirchhoff's first rule (Current rule or Junction rule)

It states that the algebraic sum of the currents at any junction of a circuit is zero. It is a statement of conservation of electric charge.

2.5.2 Kirchhoff's Second rule (Voltage rule or Loop rule)

It states that in a closed circuit the algebraic sum of the products of the current and resistance of each part of the circuit is equal to the total emf included in the circuit.

This law follows from the law of conservation of energy for an isolated system (The energy supplied by the emf sources is equal to the sum of the energy delivered to all resistors).



Thus applying Kirchoff's second law to the closed loop EACE

$$I_1R_1 + I_2R_2 + I_3R_3 = \xi$$

and for the closed loop ABCA

$$I_4R_4 + I_5R_5 - I_2R_2 = 0$$

Application of Kirchhoff law

2.5.3 Wheatstone's bridge

2.5.4 Meter bridge

2.5.5 Potentiometer

2.6

HEATING EFFECT OF ELECTRIC CURRENT

2.7 THERMOELECTRIC EFFECT

Conversion of temperature differences into electrical voltage and vice versa is known as thermoelectric effect.

Seebeck Effect

[Thomas Johann Seebeck]

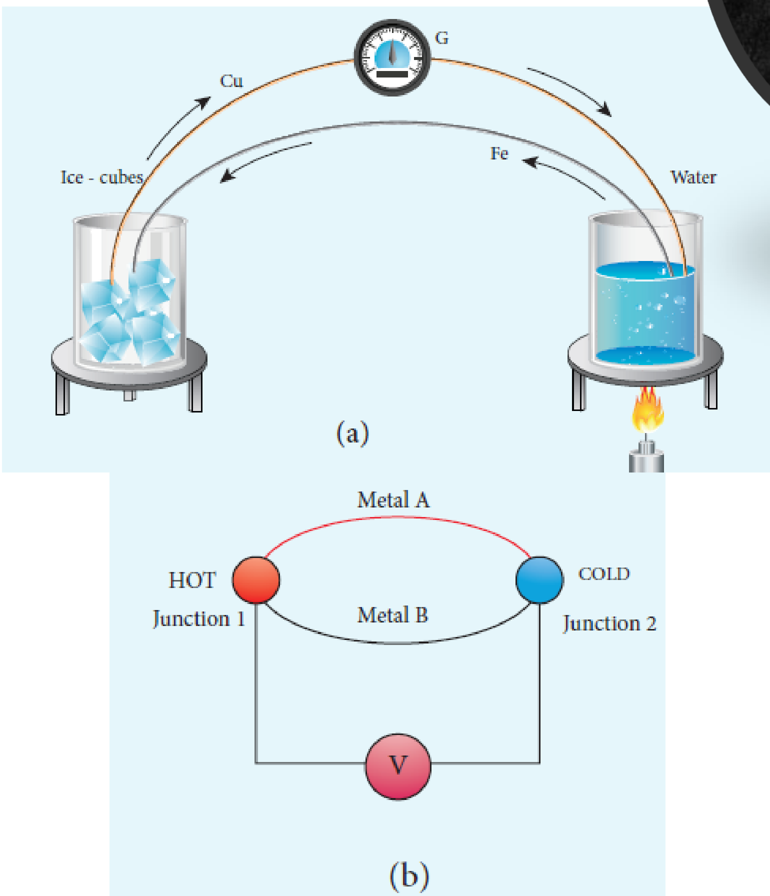


Figure 2.35 Seebeck effect (Thermocouple)

Seebeck discovered that in a closed circuit consisting of two dissimilar metals, when the junctions are maintained at different temperatures an emf (potential difference) is developed.

The current that flows due to the emf developed is called thermoelectric current.

The two dissimilar metals connected to form two junctions is known as thermocouple.

If the hot and cold junctions are interchanged, the direction of current also reverses. Hence the effect is reversible.

The magnitude of the emf developed in a thermocouple depends on

(i) the nature of the metals forming the couple and

(ii) the temperature difference between the junctions.

Seebeck arranged the metals in a series in which any two metals can be used to construct the thermocouple.

2.7.2 Peltier effect

In 1834, Peltier discovered that

when an electric current is passed through a circuit of a thermocouple, heat is evolved at one junction and absorbed at the other junction.

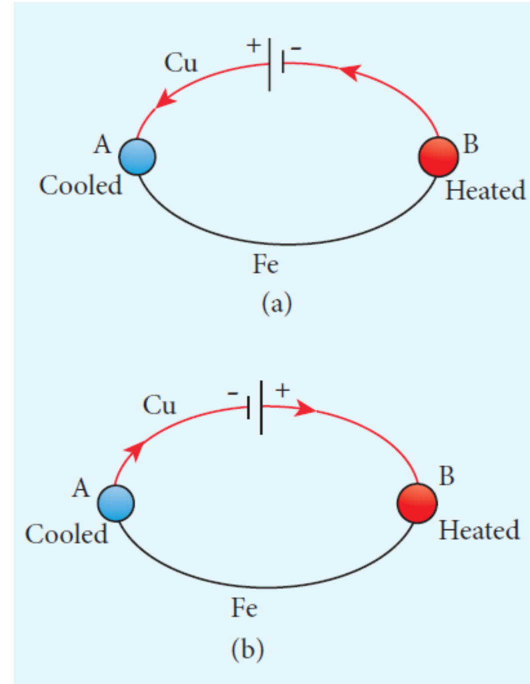


Figure 2.36 Peltier effect: Cu – Fe thermocouple

Peltier effect is reversible – changing the polarity (direction of current flow) changes the hot and cold junctions

Peltier Thermoelectric Cooler Module

2.7.3 Thomson effect

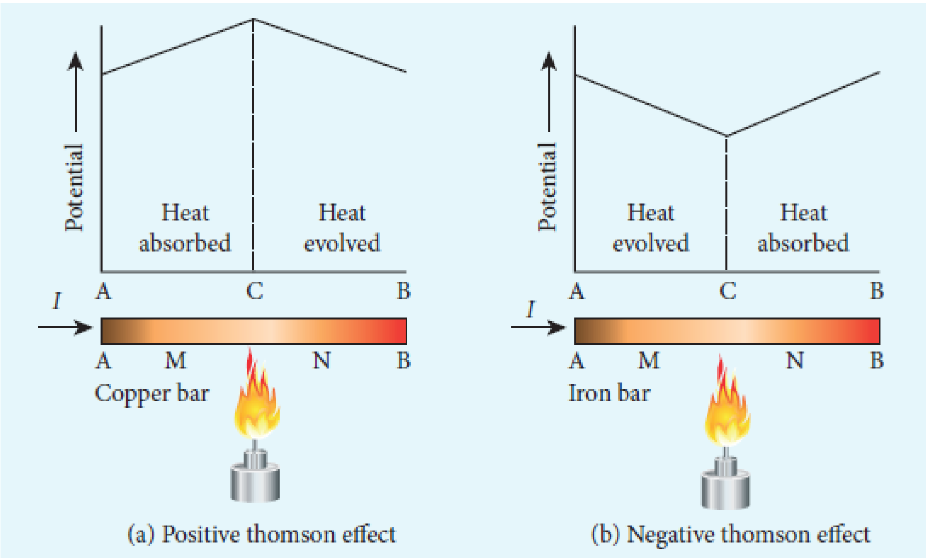
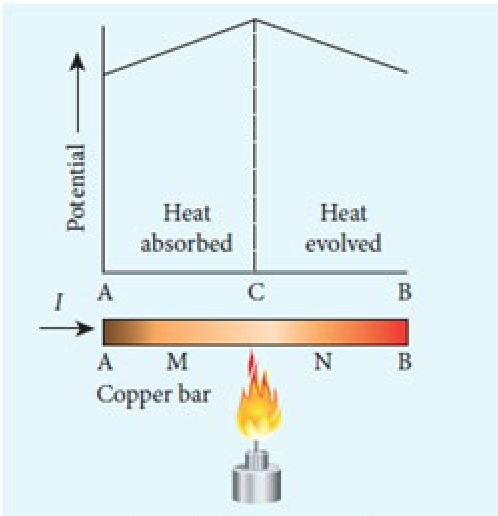


Figure 2.37 (a) Positive Thomson effect (b) Negative Thomson effect

Thomson showed that if two points in a conductor are at different temperatures, the density of electrons at these points will differ and as a result the potential difference is created between these points. Thomson effect is also reversible.

Thomson effect, the evolution or absorption of heat when electric current passes through a circuit composed of a single material that has a temperature difference along its length.



(a) Positive thomson effect

Thomson Effect is reversible

(i) When no current flows, M and N at equidistant from middle point C will be at the same temperature.

(ii) When current flows (in the direction shown), N will be at higher temperature compared to M. (B at higher temperature than A)

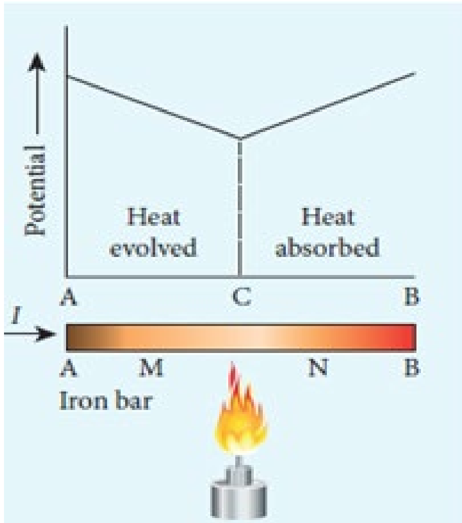
(iii) From A to C heat is absorbed and C to B heat is evolved

Positive Thomson effect. Cu shows this behavior

Negative Thomson effect. Fe shows this behavior

(i) When current flows (in the direction shown), M will be at higher temperature compared to N. (A at higher temperature than B)

(ii) From A to C heat is evolved and C to B heat is absorbed



(b) Negative thomson effect


THANK YOU