ELECTRICITY

Electric Charge and Current

- A charge is a physical entity which is defined by excess or deficiency of electrons on a body.

- A body is said to be negatively charged, if it gains electrons, e.g, an ebonite rob rubbed with fur acquires negative charge.

- A body is said to be positively charged, if it loses electrons, e.g. A glass rod rubbed with a silk cloth acquires positive charge.

- The SI unit of electric charge coulomb (c) which is equivalent to the charge contained in nearly 6×10^8 electrons.

- The total charge acquired by a body is an integral multiple of magnitude of charge on a single electron. This principle is called quantisation of charge.

- Magnitude of charge on one electron,
  $e = -1.6 \times 10^{-19} C$

- Charge on 'n' electrons (Q),
  $Q = ne$
  $Q = ne = n \times 1.6 \times 10^{-19} C$

- Magnitude of charge on one proton,
  $e = +1.6 \times 10^{-19} C$

Electric Current (I)

- It is defined as the rate of flow of electric charge through any cross-section of a conductor in unit time.

- If 'q' amount of charges flows through a conductor in 't' time, then

$$\text{Electric Current} = \frac{\text{Charge}}{\text{Time}}$$

$$I = \frac{q}{t} = \frac{ne}{t}$$

- The SI unit of electric current is Ampere (A).

» Smaller units of current

1. Milliampere

$$1 mA = 10^{-3} A$$

2. Microampere

$$1 \mu A = 10^{-6} A$$

What is 1 Ampere (1 A)?

» When 1 coulomb of charge flows through any cross-section of a conductor in 1 second, then the electric current flowing through it is said to be 1 ampere.

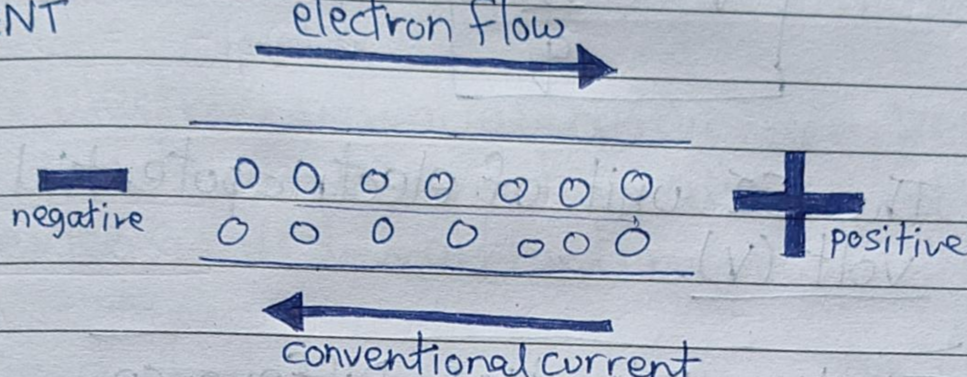
$$[1 A = 1 c/s]$$

Direction of Electric Current

» The direction of electric current is taken as opposite to the direction of the flow of electrons (negative charges).

» In an electric circuit, the current flows from positive terminal of the cell to the negative terminal.

DIRECT CURRENT



Ammeter

- Electric current is measured by ammeter.
- It is a low resistance device which is always connected in series with the device through which the current is to be measured.

Electric Potential

- It is defined as the amount of work done when a unit positive charge is moved from infinity to a point.
- If work done in moving a positive charge (q) from infinity to a point is (W), then electric potential (V) of that point is :

$$V = \frac{W}{q}$$ (Energy) / (Charge)

››› The SI unit of electric potential is volt (V).

Electric Potential Difference

››› The electric potential difference between two points is defined as the work done in moving a unit positive charge from one point to other point.

$$V = \frac{W}{q}$$

››› The SI unit of electric potential is volt (V).

What is 1 Volt (1V)?

››› The electric potential difference between two points in a current carrying conductor is said to be 1 volt, if 1 joule of work is done in moving 1 coulomb of electric charge from one point to other point.

›››

Voltmeter

›› The electric potential difference between two points in a circuit is measured using a device called voltmeter.

›› It is a high resistence device which is always connected in parallel with the component (s) through which potential difference is to be measured.

Electric Circuit

›› A closed and continuous path through which electric current flows is known as electric circuit.

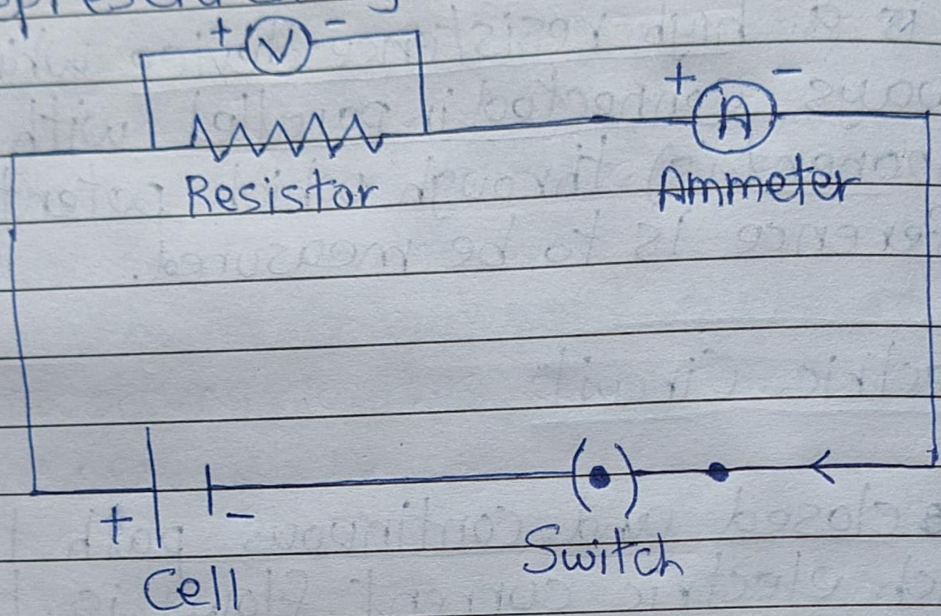
›› It has various components, including:

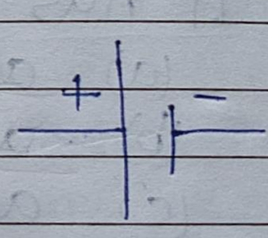
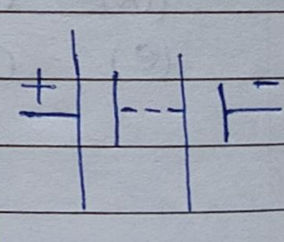
(a) a source of current (cell or battery)
(b) a load (a bulb or any other appliance)
(c) a switch / Key (to open/close a circuit)
(d) a fuse
(e) Connecting wires (to connect everything)

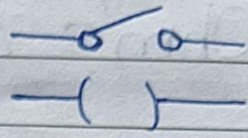
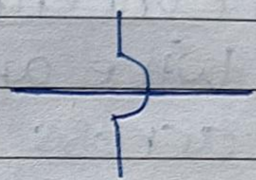
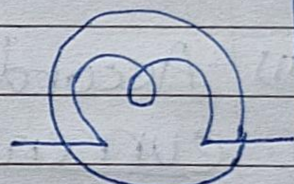
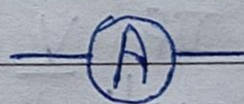
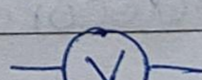
›››

Circuit diagram

» It is a schematic diagram which represents the relative positions and connections of various circuit components represented by their symbols.



Component	Description	Symbols
Electric cell	Provides constant potential difference b/w 2 points	
Battery	Combination of two or more cells connected in series	

Switch or plug key (open)	To open the circuit	
Switch or plug key (closed)	To close the circuit	
Wire joint		
Wire crossing without joining		
Electric bulb	A Circuit component	
Resistor	Control the current flowing through the circuit	
Rheostat	Provide variable resistance	
Ammeter	Measures current flowing through circuit	
Voltmeter	Measures potential difference b/w 2 points	

Ohm's Law

>>> This law was given by a German Physicist Georg Simon Ohm (1787-1854) in the year 1827.

>>> It gives a relationship between current (I) flowing in a metallic wire and potential difference (V) across its terminals.

>>> According to this law, the electric current flowing through a conductor is directly proportional to the potential difference applied across its ends, providing the physical conditions (such as temperature) remain unchanged.

~~$I \propto V$~~ ~~$V \propto I$~~

~~$V = IR$~~

>>> If V is the potential difference applied across the ends of a conductor through which current I flows, then according to Ohm's law,

>>>

$V \propto I$

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

where, R is the constant of ~~proportion-ality~~ proportionality called resistence of the conductor at a given temperature

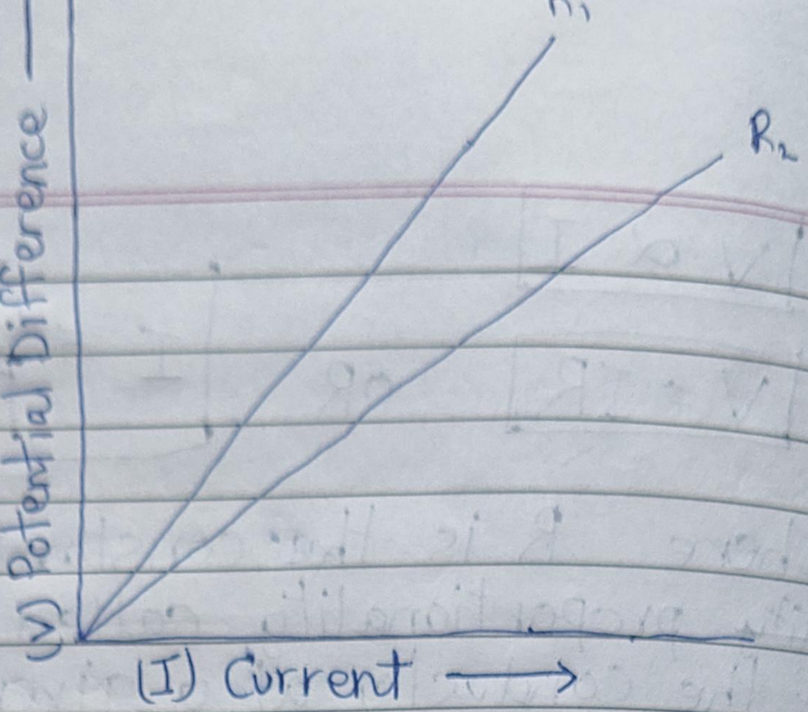
» From the above formula, it is clear that current is inversely proportional to resistance.

» If resistence is doubled, then current gets halved and if resistance is halved then current gets doubled.

If $R \rightarrow 2R$	If $R \rightarrow R/2$
then $I \rightarrow I/2$	then $I \rightarrow 2I$

V-I graph

» The graph between the potential difference (V) and the corresponding current (I) is found to be a straight line passing through the origin for ohmic (metallic) conductors.



RESISTANCE

- It is that property of a conductor by virtue of which it opposes/resist the flow of charges / current through it.

- Its SI unit is ohm and is represented by the Greek letter Ω (Omega).

What is 1 ohm?

- Resistance of a conductor is given by $R = \frac{V}{I}$ is said to be 1 ohm,

If a potential difference of 1 volt across the ends of the conductor makes a current of 1 ampere to flow through it.

$$1 \text{ ohm} = \frac{1 \text{ Volt}}{1 \text{ Ampere}}$$

$$1\,\Omega = \frac{1\,V}{1\,A} = 1\,VA^{-1} = \frac{1\,J}{1\,AC}$$

$[\because V = \frac{J}{C}][\frac{W}{q}]$

Factors on which the Resistance of a Conductor Depends

(i) Length of the conductor

»» The resistance of a conductor is directly proportional to its length

$$R \propto l$$

If $l \rightarrow 2l$ then $R \rightarrow 2R$	If $l \rightarrow \frac{1}{2}l$ then $R \rightarrow \frac{1}{2}R$

»» If length of a wire is doubled/halved, then its resistance also gets doubled/halved.

(ii) Area of cross-section of the conductor

»» The resistance of a conductor R is inversely proportional to its area of cross-section A.

$$R \propto \frac{1}{A}$$

If $A \rightarrow 2A$ then $R \rightarrow R/2$ | If $A \rightarrow A/2$ then $R \rightarrow 2R$

(iii) Nature of the material of the conductor

»» The resistence of a conductor depends on the nature of the material of which it is made.

»» Some materials have low resistence, whereas others have high resistence.

$$R \propto \frac{L}{A} \quad \text{or} \quad R = \rho \frac{L}{A}$$

where ρ is the constant of proportionality and is called electric resistivity or specific resistence of the material of the conductor

If $\rho \downarrow\downarrow\downarrow$, then $I \uparrow\uparrow\uparrow$
If $\rho \uparrow\uparrow\uparrow$, then $I \downarrow\downarrow\downarrow$

ρ = "rhow"

RESISTIVITY

» It is defined as the resistence of a conductor of unit length and unit area of cross-section.

$$R = \rho \frac{L}{A} \Rightarrow R = \rho \frac{1}{1} \Rightarrow R = \rho \text{ (resistivity)}$$

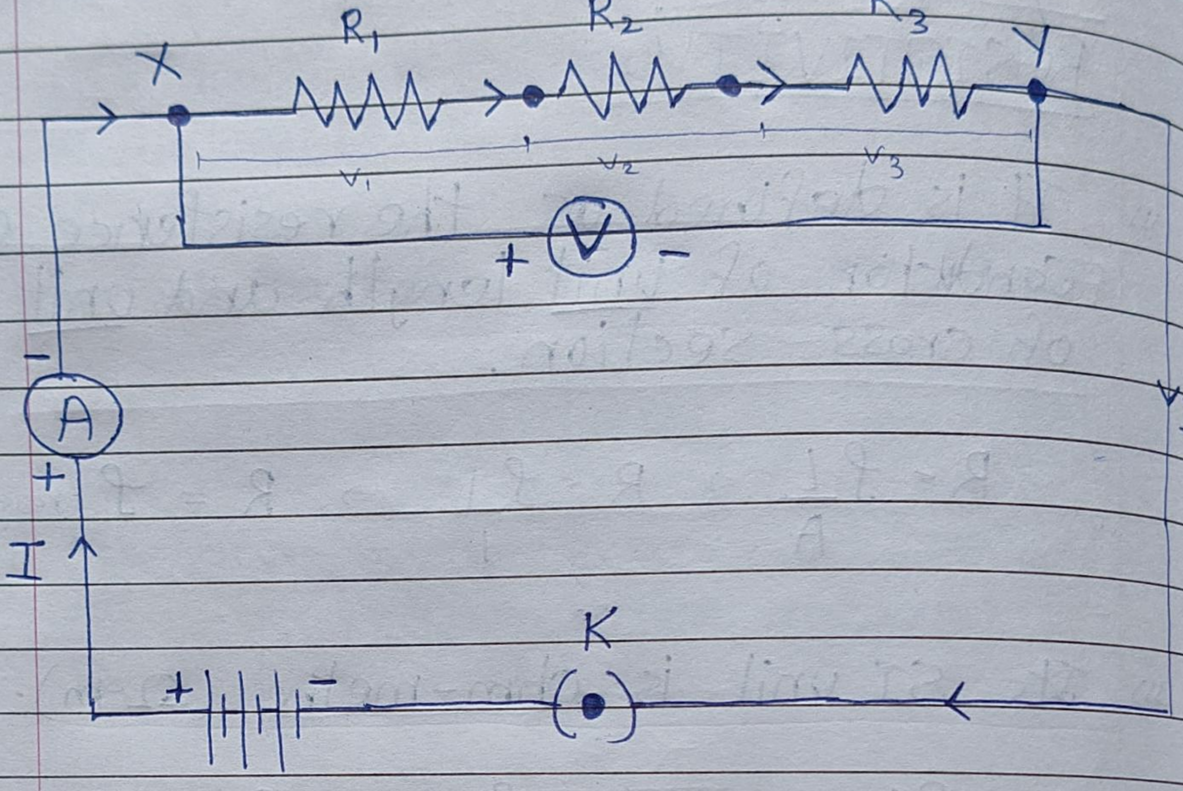
» Its SI unit is ohm-metre (Ω-m)

$$R = \rho \frac{L}{A} \Rightarrow \Omega = \rho \frac{m}{m^2} \Rightarrow \rho = \Omega m$$

» The resistivity of a material does not depend on its length or thickness but depends on the nature and temperature of the substance.

RESISTORS IN SERIES

›› When two or more resistors are connected end to end to each other, then they are said to be connected in series.



An applied potential V produces current I in the resistors R_1, R_2 and R_3

Total Potential difference

$$V = V_1 + V_2 + V_3$$

>>>

By ohm's law,

$V_1 = IR_1$

$V_2 = IR_2$ $\quad\quad V_a = IR_{eq}$

$V_3 = IR_3$

$IR_{eq} = IR_1 + IR_2 + IR_3$

$\cancel{I}(R_{eq}) = \cancel{I}(R_1 + R_2 + R_3)$

$$\boxed{R_{eq} = R_S = R_1 + R_2 + R_3}$$

Example

Q $R_1 = 3\,\Omega$

$R_2 = 11.5\,\Omega$

$R_3 = 12\,\Omega$

These are connected in series.
Find equivalent resistence.

⋙ $R_S = R_1 + R_2 + R_3$

$R_S = 3\,\Omega + 11.5\,\Omega + 12\,\Omega$

$$\boxed{R_S = 26.5\,\Omega}$$

Important points of resistors in series

1. The equivalent resistance is equal to the sum of all individual resistance

2. The equivalent is greater than each resistance.

3. The current through each resistor is same.

4. The potential difference across each resistor is different.

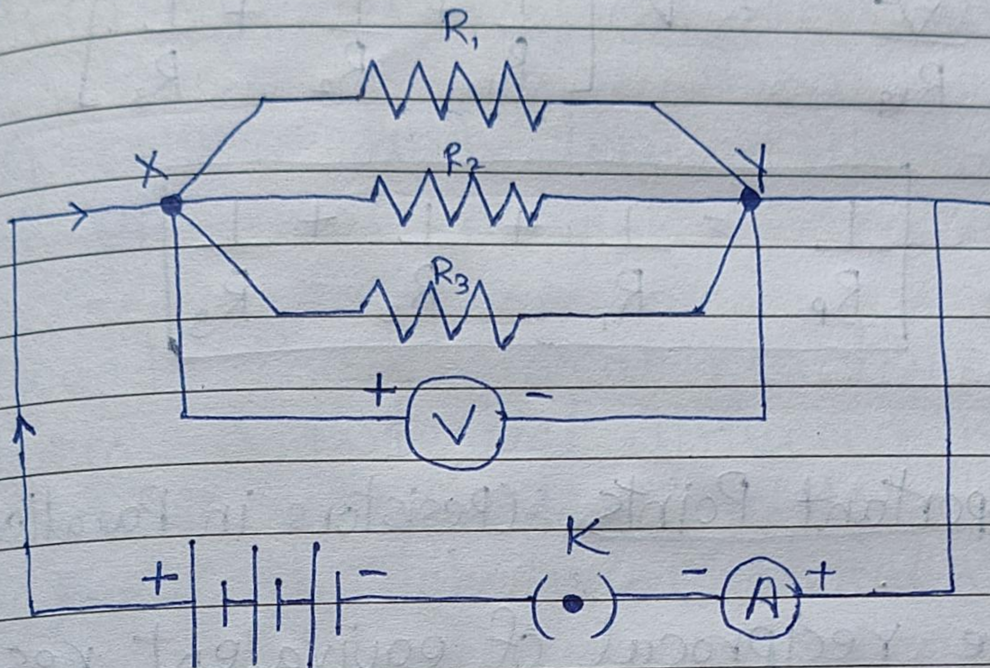
Disadvantages of series connection

1. In this combination, if any one component is damaged, then the circuit will break and none of the components will work.

2. It is not possible to connect a bulb and a heater in series because they both need different amount of current.

RESISTORS IN PARALLEL

» When two or more resistors are connected simultaneously between two points, then they are said to be in parallel connection.



An applied potential difference V produces current I_1 in R_1, I_2 in R_2 and I_3 and R_3.

By ohm's law,

$V = IR_{eq}$ $\quad V = I_1 R_1$

$V = I_2 R_2$

$V = I_3 R_3$

>>>

Total current

$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

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

$$\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Important Points (Resistors in Parallel)

- The reciprocal of equivalent resistence is equal to the sum of the reciprocal of individual resistances. $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

- The equivalent resistence is less than the resistence of either resistor. This is also known as minimum effective resistence.

- The current from the source is greater than the current through either resistor.

- The potential difference across each resistor is same.

HEATING EFFECT OF ELECTRIC CURRENT

- A cell or a battery is the source of electrical energy.

- Due to the chemical reactions inside them, a potential difference is set up which is responsible for the flow of current through any electrical circuit.

- So, to maintain this flow, the source continuously has to provide the energy. But only a part of this energy helps in maintaining the current consumed into useful work.

- Rest of it may be consumed in the form of heat by raising the temperature of the appliances.

- Therefore, when an electric current is passed through a high resistence wire like nichrome wire, then the wire becomes very hot and produces heat.

- In purely resistive circuits, the Source of energy continuously gets dissipated entirely in the form of heat.

- This is called the heating effect of current.

- This is obtained by the transformation of electrical energy into heat energy eg. electric heater, electric ion, etc.

CALCULATION OF HEAT GENERATING IN CONDUCTOR

Let I = Current flowing through a wire
R = Resistence of wire
W = Work done by current source
V = Potential difference
q = Charge

PROOF

To Prove: $H = I^2Rt$

Sol: $W = V \times q$

$I = \frac{q}{t}$, $q = I \times t$

$W = IR \times I \times t$ [$V = IR$, $q = I \times t$]

$W = I^2Rt$

This work done is later converted to heat energy/Assuming elec. work → heat energ

$H = I^2Rt$ ∴ Proved

»» This is known as Joule's law of heating

PRACTICAL APPLICATIONS OF HEATING EFFECT OF ELECTRIC CURRENT

1. Bulb
2. Electric Fuse (connected in series with main supply)

ELECTRIC POWER

- It is defined as the amount of electrical energy consumed in circuit per unit time.

- If W is the amount of electric energy consumed in a circuit in t seconds, then the electric power is given by

$$\boxed{P = \frac{W}{t}}$$

W = electric energy
t = time

$$W = V \times q$$

$$\therefore P = \frac{V \times q}{t}$$

$$I = \frac{q}{t}$$

$$\therefore \boxed{P = V \times I}$$

By Ohm's law, $V = IR$

$$P = IR \times I$$

$$\boxed{P = I^2 R}$$

&

$$\boxed{P = \frac{V^2}{R}}$$

$\because V = IR$
$I = \frac{V}{R}$
So, $I^2 R = \frac{V^2}{R^2} \cdot R$

>>> SI unit of Power is <u>watt</u> (W)

>>> 1 KW = 1000 W

[HP = Horse Power]

>>> 1 HP = 746 W

>>> 1 KWh = 3.6×10^6 J s

ALL FORMULAE

1. $Q = ne$

Q = charge [Coulomb (C)]
n = no. of electrons
$e = 1.6 \times 10^{-19}$

2. $I = \frac{Q}{t}$

I = Current [Ampere (A)]
t = time [seconds]

3. $V = \frac{W}{Q}$

V = Electric Potential [Volt (V)]
W = Work done [Joule (J)]

4. Ohm's Law

$V = IR$

R = Resistence [ohm (Ω)]

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

ρ = specific resistence [Ωm]
l = length (m)
$A = \pi r^2$ (Area) [m^2]

6. Resistors in series

$$R_s = R_1 + R_2 + R_3 + \dots + R_n$$

If $R_1 = R_2 = R_3 = R_n = R$

$R_s = \underbrace{R + R + R + \dots + R}_{n \text{ times}} \Rightarrow R_s = nR$

7. Resistors in Parallel

$$\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}}$$

If $R_1 = R_2 = R_3 = R_n = R$

$$\frac{1}{R_p} = \underbrace{\frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \dots + \frac{1}{R}}_{n \text{ times}}$$

$$\boxed{\frac{1}{R_p} = \frac{n}{R}}$$

8. Joule's law of heating

$$\boxed{H = I^2 R t}$$

H = Heat energy [Joule (J)]

Rate of heat energy

$$\boxed{\frac{H}{t} = I^2 R}$$

>>>

9. Power [Watt (W)]

① $$P = \frac{W}{t}$$ W = electric energy

② $$P = V \times I$$

③ $$P = I^2 R$$

④ $$P = \frac{V^2}{R}$$

1 KW = 1000 W
1 MW = 10^6 W
1 HP = 746 W

1 commercial units = 3.6×10^6 Js
1 KWh = 3.6×10^6 Js