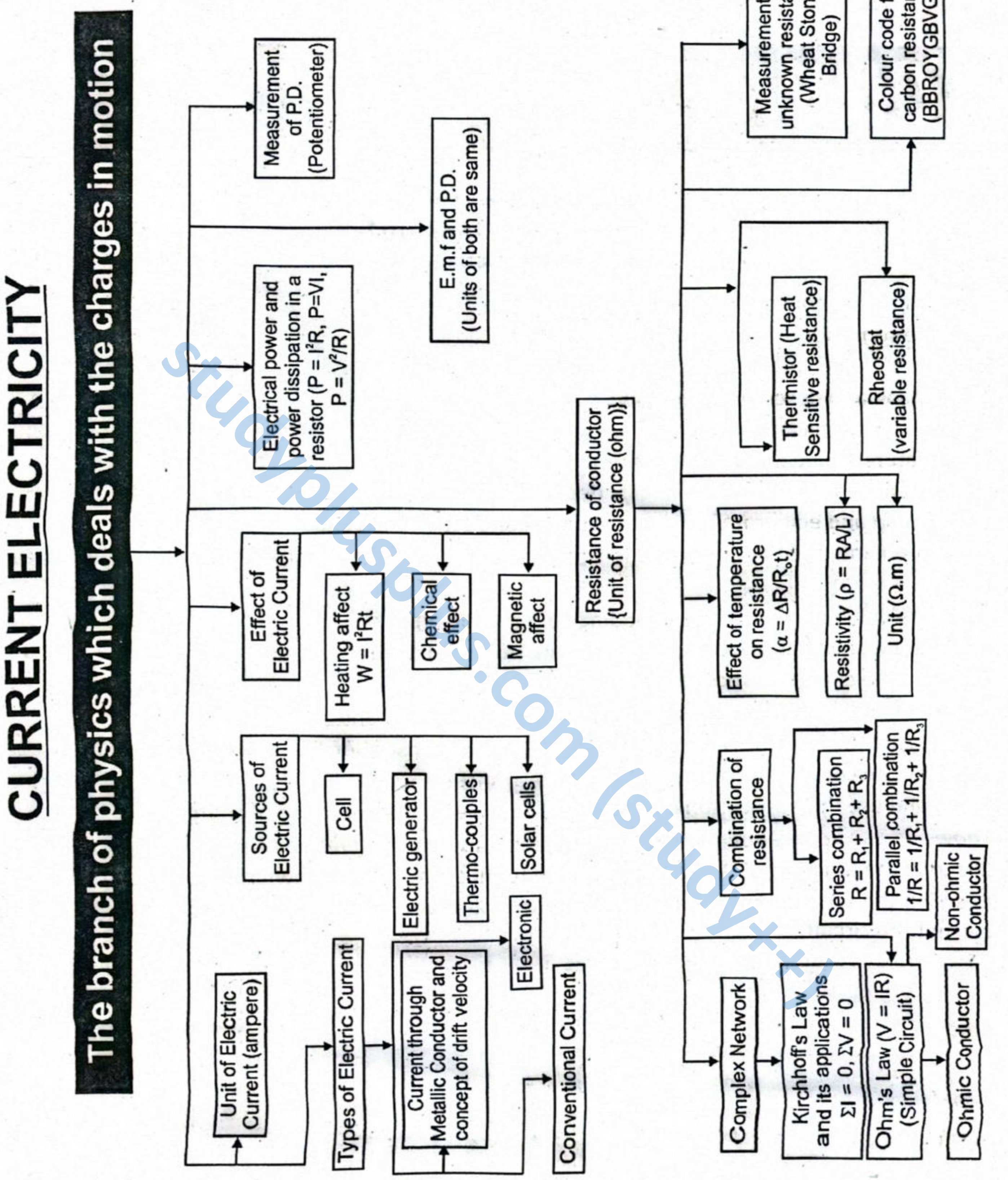
Chapter # 13
Current Electricity

Learning Objectives

- Understand the concept of steady current.
- Describe some sources of current.
- Recognize effects of current.
- Understand and describe Ohm's law.
- Sketch and explain the current-voltage characteristics of a metallic conductor at constant temperature, diode and filament lamp.
- Understand resistivity and explain its dependence upon temperature.
- Understand and elaborate conductance and conductivity of conductor.
- Solve problems relating the variation of resistance with temperature for one dimension current flow.
- Know the value of resistance by reading colour code on it.
- Know the working and use of rheostat in the potential divider circuit.
- Describe the characteristics of the thermistor.
- Use the energy considerations to distinguish between emf and p.d.
- Understand the internal resistance of source and its consequences for external circuits.
- Describe the conditions for maximum power transfer.
- Know and use the application of Kirchhoff's first law as conservation of charge.
- Know and use application of Kirchhoff's second law as conservation of energy.
- Describe the function of Wheatstone bridge to measure the unknown resistance.
- Describe the function of potentiometer to measure and compare potentials without drawing any current the circuit.

CONCEPT MAP



CURRENT ELECTRICITY
The branch of physics which deals with the charges in motion
Unit of Electric Current (ampere)
Types of Electric Current
Current through Metallic Conductor and concept of drift velocity
Electronic
Conventional Current
Sources of Electric Current
Cell
Electric generator
Thermo-couples
Solar cells
Effect of Electric Current
Heating affect W = I²Rt
Chemical effect
Magnetic affect
Electrical power and power dissipation in a resistor (P = I²R, P=VI, P = V²/R)
E.m.f and P.D. (Units of both are same)
Measurement of P.D. (Potentiometer)
Resistance of conductor {Unit of resistance (ohm)}
Complex Network
Kirchhoff's Law and its applications ΣI = 0, ΣV = 0
Ohm's Law (V = IR) (Simple Circuit)
Ohmic Conductor
Non-ohmic Conductor
Combination of resistance
Series combination R = R₁+ R₂+ R₃
Parallel combination 1/R = 1/R₁+ 1/R₂+ 1/R₃
Effect of temperature on resistance (α = ΔR/R₀t)
Resistivity (ρ = RA/L)
Unit (Ω.m)
Thermistor (Heat Sensitive resistance)
Rheostat (variable resistance)
Measurement of unknown resistance (Wheat Stone Bridge)
Colour code for carbon resistance (BBROYGBVGW)

Electrodynamics or current electricity is the branch of physics which deals with the study of moving charges through the conductors.

Applications

- The bulb glows due to current.
- The current that flows through the coil of motor causes its shaft to rotate.
- Most of the devices in the industry and in our homes operate with current.

Q.1 Define electric current and its unit. Also discuss its different causes.

Ans.

ELECTRIC CURRENT

Time rate of flow of charge through any cross section of conductor is called electric current.

Mathematically

If Δq charge passes through any cross section of a conductor in time Δt then the electric current is given by,

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

For your information

Electric current is a scalar quantity and not a vector even though we assign it a direction. The arrow head that we draw to indicate the direction of current only shows the sense of charge flow through the wire. **Current does not obey law of vector addition.**

Unit

The SI unit of current is **ampere.**

ampere

When one coulomb charge passes through any cross section of a conductor in one second, the current is said to be one ampere.

So, $$1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

Nature of charge carriers in different materials

Motion of electric charge which causes the electric current is due to flow of charge carriers.

(i) Metallic conductors

In metallic conductors, the charge carriers are free **electrons.**

(ii) Electrolytes

In electrolytes, the charge carriers are positive and negative charged **ions.**

(iii) Gases

In gases, the charge carriers are free **electrons** and **ions.**

(iv) Semiconductors

In semiconductors, the charge carriers are free **electrons** and **holes.**

Q.2 What are conventional and electronic currents? Explain direction of current flow through the conductor. (Lhr 2017 G I, Grw 2016, Mtn 2017)

Ans.

CONVENTIONAL CURRENT

The conventional current in a circuit is defined as *that current which passes from a point at high potential to a point of low potential as if it represented by a movement of positive charges.*

Interesting Information

When eel senses danger, it turns itself into a living battery. Any one who attacks this fish is likely to get a shock. The potential difference between the head and tail of an electric eel can be up to 600 V.

ELECTRONIC CURRENT

The electronic current in a circuit is defined as *that current which passes from a point of low potential to a pint of high potential as if it represented by a movement of negative charges.*

In view of early scientists, the electric current was due to the flow of positive charges. But later on, it was found that the current through a metallic conductor is actually due to the flow of negative charge carriers called electron.

Conventionally, we take the direction of current as the direction in which positive charges flow. Such a *current* is called conventional current.

The reason is that it has been found experimentally that *positive charges move in one direction is equivalent in all external effects to negative charge moving in opposite direction.*

As the current is measured by its external effects so a current due to motion of negative charges, after reversing its direction flow can be replaced by an equivalent current due to positive charges.

Q.3 Explain, how the current flows through a metallic conductor.

Ans.

CURRENT THROUGH METALLIC CONDUCTOR

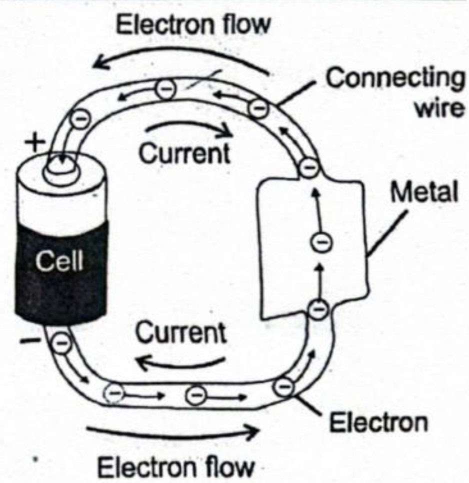


Fig. 13.1

The valance electrons in metals are not bound to the individual atoms but are free to move in metals. These electrons are called free electrons. *The speed of randomly moving electrons depend upon temperature.*

Motion of free electron in metals

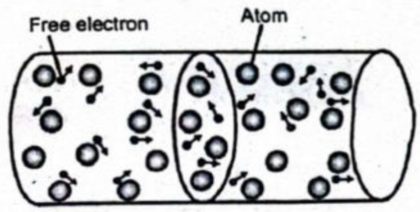
The free electrons in metals are in **random** motion just like the molecules of the gas in the container.

Current through metals when no battery is connected

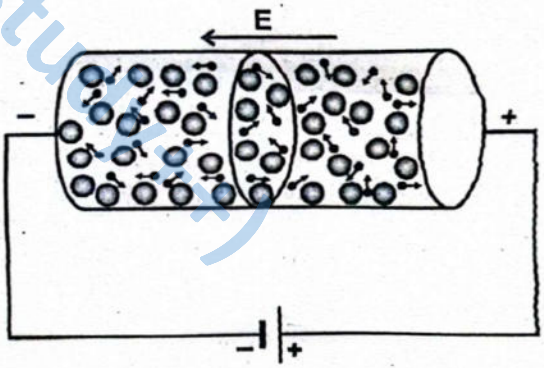
In this case, the rate at which free electrons passthrough it from right to left *is the same* as the rate at which they pass from left to right. As a result, the current through the wire is zero.

Current through metals when battery is connected

When the ends of wire are connected to a battery, an electric field is set up at every point within the wire. A force acts on the free electrons in a direction opposite to that electric field $\vec{E}$.Due to the applied field, the electron change their random motion in such a way that they drift slowly with a constant velocity in a direction opposite to the field. This velocity is called drift velocity. Hence, a current begins to flow through the conductor.



(a)



(b)

Drift velocity

The average constant speed with which free electrons drift (flow) when current flows through the conductor is called drift velocity.

The drift velocity is of the order of 10^{-3}**m/sec or 1mm / sec.**

Acceleration of electrons

Theforce experienced by the free electrons does not produce a net acceleration because the electrons keep on colliding with the atoms of the conductor.The overall effect of collisions is to transfer the energy of accelerating electrons to the lattice atoms.

A steady current is maintained in the wire when a constant potential difference is applied across it. It produces the necessary electric field $\vec{E}$ along the wire.

Note

The velocity of electrons at room temperature due to thermal motion is several hundred kilometers per second.

MCQ's From Past Board Papers

1. **In case of metallic conductors, the charge carriers are:** **(Bwp 2011, 14, Mtn 2013 Mir-II-13/1)**
(A) Protons (B) Positive and negative ions (C) Electrons (D) Protons and electrons

2. **Charge carriers in electrolytes are:** **(Lhr 2011, 2012, Grw 2014, Sgd 2015 Rwp 2014)**
(A) Protons (B) Electrons (C) Holes (D) Positive and Negative ions

3. **Current flows in the gases due to:** **(Lhr 2014, 15 Grw 2011)**
(A) electrons only (B) electrons and ions (C) positive and negative ions (D) electrons and holes

4. **A battery made a charge of 40 C around a circuit at constant rate in 20 sec. The current will be** **(Bwp 2015)**
(A) 2 A (B) 0.5 A (C) 80 A (D) 60 A

5. **Ampere second stands for the unit of:** **(Rwp 2015)**
(A) Charge (B) Emf (C) Energy (D) Power

6. **Drift velocity of electrons is** **(D.G.Khan 2015 Group I, 2017)**
(A) 10^{-1} m/s (B) 10^{-2} m/s (C) 10^{-3} m/s (D) 10^{-4} m/s

7. **The current which flow from a point at higher potential to a point at lower potential is called** **(Sgd 2017 G I)**
(A) Electric current (B) Conventional current (C) Either of these (D) None of above

8. **If 1×10^{7} electrons pass through a conductor in 1.0 μs, then the current is:-** **(Sgd 2018, Mtn 2017 G I)**
(A) 2A (B) 1.6A (C) 2.6×10^{-6} A (D) 1.6×10^{-6} A

9. **5A of current flows through a conductor in 2 minutes, charge in the wire is:** **(Sgd 2015, Grw 2018)**
(A) 500 C (B) 600 C (C) 400 C (D) 10C

ANSWER KEY'S

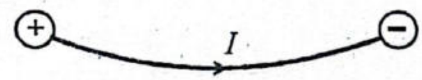
1.	C	2.	D	3.	B	4.	A	5.	A	6.	C	7.	B	8.	D	9.	B

Q.4 Describe different sources of current. **(Rwp 2017, Sgd 2016, Fsd 2017)**

Ans.

SOURCES OF CURRENT

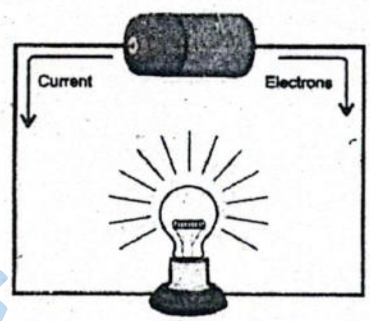
When two conductors at different potential are connected through a metallic wire, then the current will start to flow from higher potential to a lower potential until the potential of both the conductors become same, so the current will stop to flow.



Conventional current flows from higher to lower potential through a wire.

In order to have a constant current the potential difference should be maintained with a device known as source of current.

Source of current converts the some non-electrical energy into electrical energy.



A source of current such as battery maintains a nearly constant potential difference between ends of a conductor.

Types of current sources

There are many sources of currents, but some of them are described below.

(i) **Cells** (Primary or Secondary) convert the chemical energy into electrical energy.

(ii) **Electric generators** convert mechanical energy into electrical energy.

(iii) **Thermo-couples** convert heat energy into electrical energy.

(iv) **Solar cells** convert sunlight into electrical energy.

Do You Know?
Primary cells (dry cell, leclanche cell) are non-rechargeable, while **secondary** cells (Lead-acid cell, Nickel-cadmium alkaline cell) can be recharged bypassing current through them.

Q.5 Describe various effects of current. Also write their applications.

Ans.

EFFECTS OF CURRENT

The presence of electric current can be detected by the various effects which it produces. Some effects of current are given below.

1. ***Heating effect***
2. **Magnetic effect**
3. **Chemical effect**

For your information

$P = W/t$

$W = Pt$

$H = (I^2R)t$

(1) HEATING EFFECT

Current flows through the conductor due to the motion of free electrons. During the motion of free electrons, they collide with the atoms of metal. So, they lose their kinetic energy and transfer it to the atoms of metal. In this way, the vibrational kinetic energy of the atoms is increased, which produces heat in the wire.

If H heat is produced by a current I in the wire of the resistance R for the time interval t, then

$$H = I^2Rt \text{ (Joule's law)}$$

Applications of heating effect

Heating effect of current is used in electric heater, toaster and electric iron, kettles etc.

For Your Information

Heating effect of current Is used in electric kettle.

(2) MAGNETIC EFFECT

When the current passes through the wire then a magnetic field is produced around it. The strength of the magnetic field depends upon the magnitude of current and the distance from current carrying conductor.

Applications of Magnetic Effect

- Magnetic effect of current is used in the **detection and measurement of current.**
- All the **machines** involving electric motor also use the magnetic effect of current.

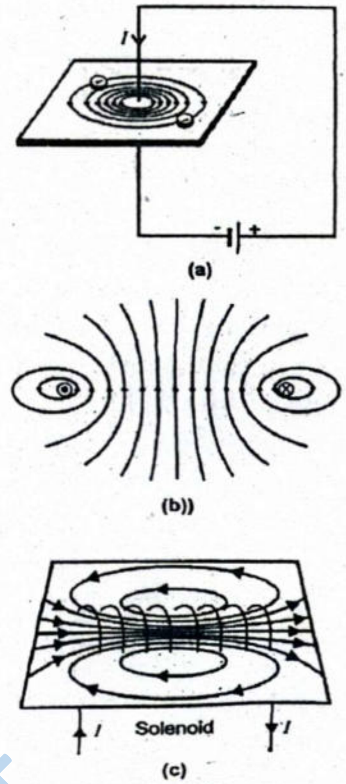


Fig. 13.5

(3) CHEMICAL EFFECT

There are certain liquids through which the electricity can pass due to some chemical reaction. The study of this process is called electrolysis.

The chemical changes produced during electrolysis of a liquid are due to the chemical effects of the current. *It depends upon nature of the liquid and the quantity of electricity passed through liquids.*

Applications of chemical effect

Chemical effect of current can be used for **electroplating** and **purification** of metals.

Electrolysis

The process of chemical decomposition of an electrolyte due to flow of current, is called electrolysis.

Main Components of Electrolysis

(1) Electrolyte

The liquid which conducts electric current is known as electrolyte.

(2) Electrode

The material which leads the current into or out of the electrolyte is called electrode.

(3) Anode

The electrode which is connected with the positive terminal of the current source is called anode.

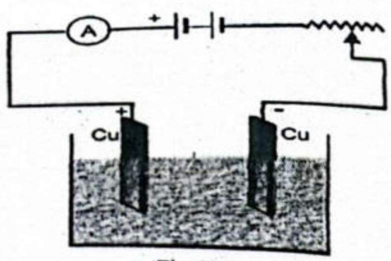


Fig.13.6

(4) Cathode

The electrode which is connected with the negative terminal of the current source is called cathode.

(5) Voltameter

It consists of a vessel containing electrolyte and two electrodes for electrolysis purpose, is called voltammeter.

Example

Let the voltameter contains the dilute solution of copper sulphate. When $CuSO_4$ solution is dissolved in water then Cu^{++} an SO_4^{--} ions are separated. When the current passed through the voltameter, Cu^{++} ions move towards cathode. So

$$Cu^{++} + 2e^- \longrightarrow Cu$$

Copper atoms thus formed are deposited at cathode plate. While Cu^{++} is being deposited at the cathode, the SO_4^{--} ions move towards the anode. Copper atoms from the anode go into the solution as copper ions which combine with sulphate ions to form copper sulphate. So

$$Cu^{++} + SO_4^{--} \longrightarrow CuSO_4$$

As the electrolysis continues, copper is continuously deposited on the cathode while an equal amount of copper is dissolved into the solution. So the density of copper sulphate solution remains the same.

Electroplating

Electroplating is the process of coating a thin layer of expensive metal (gold, silver) on a cheap metal (iron).

Q.6 State and explain the Ohm's Law. **Rwp 2014, Lhr 2016 G II, Fsd 2015**

Ans.

OHM'S LAW

Statement

The current flowing through a conductor is directly proportional to potential difference across the ends provided the physical state (such as temperature etc.) of the conductor does not change.

Mathematical Form

The Ohm's law can be expressed as

$$I \propto V$$

$$I = \frac{1}{R} V$$

OR

$$V = IR$$

Where R is the constant of proportionality and is called the resistance of the conductor.

> **For Your Information**
> Tungsten has highest melting point (3380°C) of any non-alloy metal and second highest of all elements after carbon. That is why it is used to make

Resistance

The opposition to the flow of charge through a conductor is called electrical resistance.

Unit

The SI unit of resistance is **ohm** (Ω). It can be expressed as,

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

Therefore $$1\text{ ohm} = \frac{1\text{ volt}}{1\text{ ampere}}$$

Ohm

Resistance is said to be one ohm, when one ampere current passes through the conductor due to the potential difference of one volt across its ends.

Dependence of Resistance of Conductor

Resistance of a conductor depends upon

i. **dimensions** of conductor(length and area of cross section)

ii. **Physical state** of conductor (temperature etc.)
iii. **Nature** of the conductor

Note

Stress (pressure) on a conductor changes its dimension and hence its resistance.

Q.7 What are ohmic and non-ohmic conductors?

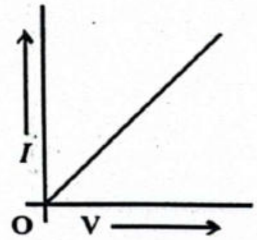
Ans.

OHMIC CONDUCTORS

A conductor, which obeys Ohm's law strictly, is called ohmic conductor.

Explanation

Graphically, if we sketch the graph between current and the potential difference for an ohmic conductor then the graph must be a straight line. So that value of resistance remains constant.



Current - voltage graph of an ohmic material.

Examples of ohmic conductors

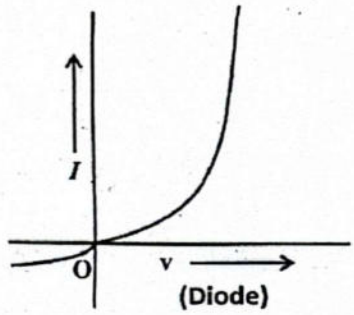
Metallic conductors are ohmic like copper, silver, gold etc.

Non-ohmic conductors

A conductor which does not obey ohm's law is called non-ohmic conductor.

Explanation

If we plot voltage verses current, we see that graph is not a straight line as shown figure.



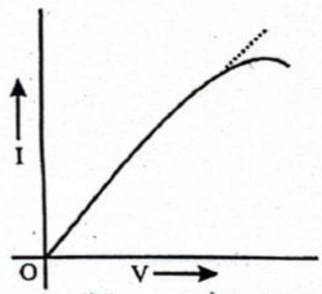
(Diode)

For tungsten filament bulb, the deviation of IV–graph from straight line is due to increase in resistance of the filament with temperature. As the current through the filament is increased from zero, the graph is a straight line in the initial stage because the change in resistance is zero. The resistance of the filament continues to increase with rise in temperature.

The other example of non – ohmic conductor is PN – junction diode.

Examples

Semiconductor diode, tungsten filament etc. are non – ohmic.



(Filament of bulb)

Q.8 Describe series and parallel combinations of resistances.

Ans.

SERIES COMBINATION OF RESISTORS

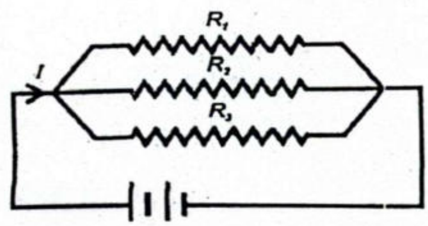
When the resistors are connected **end to end** such that the **same current** passes through all of them, then they are said to be in series. Their equivalent resistance is given as,

$$R_{eq} = R_1 + R_2 + R_3 + \text{-----}$$

Parallel Combination of Resistors

In parallel combination of resistors, the resistors are connected **side by side** with their ends joined together so **potential difference across each resister is same** as shown in figure. their equivalent resistance is given as,

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{------}$$



MCQ's From Past Board Papers

1. The graphical representation of Ohm's law is: (Mtn 2010, 12, 14, Bwp 2014, Lhr 2013, Grw 2014)
   (A) Hyperbola (B) Ellipse (C) Parabola (D) straight line.
2. A student has five resistances each of value $\frac{1}{5}\Omega$. The minimum resistance that can be obtained by combining them in parallel is: (D.G.Khan 13, Grw 2013 G II)
   (A) $\frac{1}{50}\Omega$ (B) $\frac{1}{25}\Omega$ (C) $\frac{1}{10}\Omega$ (D) $5\ \Omega$
3. Heat generated by a 40 *W* bulb in one hour is : (Lhr 2016 Group II, 2017)
   (A) 140 J (B) 1440 J (C) 14400 J (D) 144000 J
4. One Ohm is equal to: (Grw 2015)
   (A) VC^{-1} (B) CV^{-1} (C) AC^{-1} (D) VA^{-1}
5. Resistance tolerance of silver band is (Sgd 2017 G II)
   (A) 10% (B) 6% (C) 7% (D) 5%
6. For Ohmic device the graph between V and I is:- (Mtn 2017 G II)
   (A) A straight line (B) Curve (C) Hyperbola (D) Parabola
7. Thermo couple converts heat energy into (Rwp 2017)
   (A) Atomic energy (B) Solar energy (C) Electrical energy (D) Nuclear energy
8. The numerical value of black colour in carbon resistors is: (Lhr 2017 G I)
   (A) 0 (B) 1 (C) 2 (D) 3
9. The current through a resistance of 100Ω when connected across a source of 220V is: (Fsd 2018)
   (A) 22000A (B) 22A (C) 2.2A (D) 0.45A
10. The current flowing through each resistor of equal resistance in parallel combination is: (Mtn GI 2018)
    (A) Same (B) Difference (C) Zero (D) Infinite
11. A 100 W bulb is switched on for an hour. Heat lost due to flow of current is: (Sgd GII 2018)
    (A) 0.36 MJ (B) 18 MJ (C) 3 kJ (D) 0.18 MJ
12. Three reistances each of 4 Ω are connected to form a triangle, the resistance between any two terminals is: (Mtn 2013, Swl 2018)
    (A) 4Ω (B) 12Ω (C) 8/3Ω (D) 3/8Ω
13. Magnetic effect of current is used in: (Rwp 2018)
    (A) Toaster (B) Electric motor (C) Electric iron (D) D.C battery
14. The amount of heat produced in a resistor when a current is passed through it, can be found by using: (Federal 2017)
    (A) Joule's law (B) Kirchhoff's rule (C) Faraday's law (D) Lenz's law

ANSWER KEY'S

1.	D	2.	B	3.	D	4.	D	5.	A	6.	A	7.	C	8.	A	9.	C	10.	B
11.	A	12.	C	13.	B	14.	A												

Q.9 Explain the terms resistivity, conductivity and conductance. *LHR 2017*

Ans.

RESISTIVITY

Resistivity can be defined as *the resistance of a meter cube of a wire (material).*

It is the property of the **material** of which the wire is made.

Mathematical form

It has been observed experimentally that the resistance R of a wire is directly proportion to its length L and inversely proportional to its area of cross-section of the wire. i.e.

$$R \propto L \qquad (1)$$

and

$$R \propto \frac{1}{A} \qquad (2)$$

Combining (1) and (2), we get

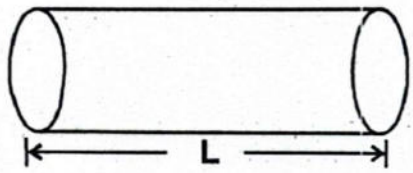
For your information

Metallic conductors are ohmic, while diodes, light bulbs, pn-junction junction diodes, battery acid or alkaline solutions are non-ohmic.

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

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

OR $$\rho = \frac{RA}{L} \quad \text{———— (3)}$$



Another definition of resistivity

If L = 1m and A = 1 m^2, then above equation becomes ρ = R. So,

Resistivity is defined as *the resistance of wire whose length is one meter and whose area of cross-section is one meter square.*

Unit

SI unit of resistivity is **ohm-meter (Ω m)**.

Dependence

Resistivity depends upon;

- **nature** of the material
- **temperature** of the material

Note

Resistivity is independent of dimensions of the conductor.

> **For your information**
>
> Conductance is the expression of ease with which the current flows through a substance.
>
> $$G = \frac{\sigma A}{L}$$

Conductance

It is another electrical property of a material. ***Conductance is reciprocal of resistance.***

$$G = \frac{1}{R}$$

Unit

The unit of conductance is mho or ohm^{-1} or siemens (S).

Conductivity

***The reciprocal of resistivity is called conductivity* (σ).**

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

Unit

Its SI unit is $(ohm\text{-}m)^{-1}$ or $mho\text{-}m^{-1}$ or $ohm^{-1}\ m^{-1}$

Table 13.1

Substance	ρ(Ωm)	α(K^{-1})
Silver	1.52×10^{-8}	0.00380
Copper	1.54×10^{-8}	0.00390
Gold	2.27×10^{-8}	0.00340
Aluminium	2.63×10^{-8}	0.00390
Tungsten	5.00×10^{-8}	0.00460
Iron	11.00×10^{-8}	0.00520
Platinum	11.00×10^{-8}	0.00520
Constanton	49.00×10^{-8}	0.00001
Mercury	94.00×10^{-8}	0.00091
Nichrome	100.0×0^{-8}	0.00020
Carbon	3.5×10^{-5}	-0.00005
Germanium	0.5	−0.05
Silicon	20-2300	−0.07

Q.10 What is the effect of temperature on the resistance and resistivity? Explain. *LHR 15, D.G.Khan 14*

Q.11 What is temperature coefficient of resistance and resistivity? *Grw 12, Lhr 16 G I, Rwp 15, Mirpur 14*

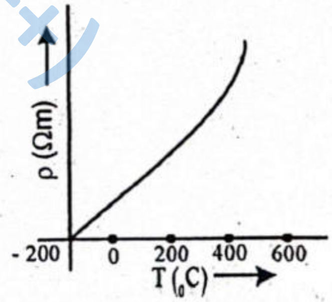
Ans.

EFFECT OF TEMPERATURE

The resistance and resistivity of a substance depend upon the temperature.

As the temperature of the conductor rises, the ***amplitude of vibration*** of the atoms in the lattice increases. So, the ***collision cross-section*** of the atoms increases.

Thus the atoms then offer a bigger target. This increases the probability of their collision with free electrons. Hence, resistance of conductor ***increases***.



Variation of resistivity of Cu with temperature.

Note

Experimentally, it is found that change in resistivity of a metallic conductor with temperature is linear over a considerable range **below and above 0°C**, as shown in figure. This shows that resistivity is not zero at 0°C.

Temperature Co-efficient of Resistance

The fractional change in resistance of a substance per kelvin is called temperature coefficient of resistance.

Mathematically,

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

Where,

R_o = resistance of material at 0°C

R_t = resistance of material at t°C

t = change in temperature

α= temperature coefficient of resistance

Temperature Co-efficient of Resistivity:

The fractional change in resistivity of a material per kelvin is called temperature coefficient of resistivity.

Mathematical form

As $$R = \rho\frac{L}{A}$$

So $R_t = \rho_t \frac{L}{A}$ and $R_o = \rho_o \frac{L}{A}$

Hence $$\alpha = \frac{\rho_t\left(\frac{L}{A}\right) - \rho_o\left(\frac{L}{A}\right)}{\rho_o\left(\frac{L}{A}\right)t}$$

OR $$\alpha = \frac{\rho_t - \rho_o}{\rho_o t}$$

Where

ρ_o = resistivity of material at 0°C

ρ_t = resistivity of material at t°C

t = change in temperature s

α= temperature coefficient of resistivity

Unit

SI unit of temperature coefficient of resistance/ resistivity is K^{-1}.

Q.12 What are carbon resistances? How can we determine their values by colour coding?

Ans.

Colour Code of Carbon Resistances

Carbon resistors consist of a high-grade ceramic rod or cone (called the substrate) on which a thin resistive film of carbon is deposited. They are commonly used in electrical equipments.

Colour code

The numerical value of carbon resistance is represented by colour code which consists of bands of different colours printed on it. Commonly, the code consists of four bands, starting from left to right.The codes of different colours are given in the following table

Colour	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

Interpretation of colour bands

i. The first band indicates the first digit of the value of resistance.

ii. The second band gives the second digit.

iii. The third band is decimal multiplier. It gives the number of zeros after the first two digits.

iv. The fourth band gives the tolerance value.

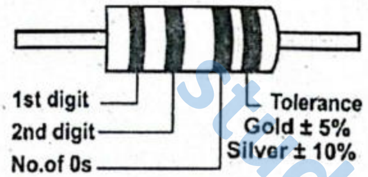
Tolerance

The possible variation in the resistance of a carbon resistor from marked value is called tolerance

- Silver band indicates the tolerance of ± 10%.
- Golden band indicates the tolerance of ± 5%.
- If there is no fourth band then the tolerance value is ± 20%.

Interesting information

Inspectors can easily check the reliability of a concrete bridge made with carbon fibers. The fibers conduct electricity. If sensors show that electrical resistance is increasing over time the fibers are separating because of cracks.



Resistor Colour Code

For Your Information

R = 27000 Ω (± 10%)

For Your Information

A zero-ohm resistor is indicated by a single black colour band around the body of the resistor.

Q.13 What is Rheostat? How it can be used as variable resistor and as potential divider?

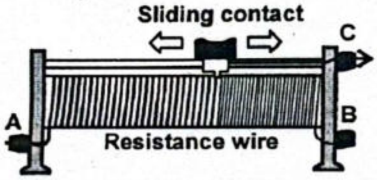
Ans.

RHEOSTAT

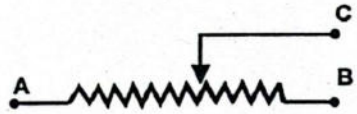
It is a wire wounded variable resistance.

Construction

1. It consists of a bare **manganin wire** (Cu, Fe, Mn, Ni alloy) wound on an insulating cylinder.
2. The ends of wire are connected to two fixed terminals A and B.
3. A third terminal C is attached to a sliding contact which can be moved over the wire.



(a) A Rheostat



(b) Its use as variable resistor

Working

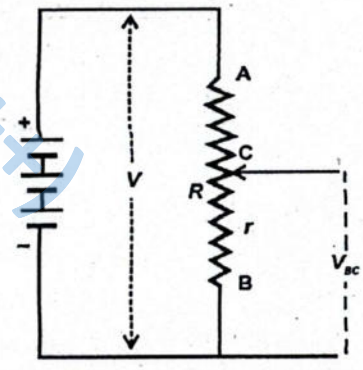
It can be used in two ways:

i. **As a variable resistor**

ii. **As a potential divider**

i) Rheostat as a variable resistor

If one of the fixed terminal say A and the sliding terminal C are connected in the circuit, the resistance of wire between A and sliding contact C is used. When the sliding contact is shifted away from A, then the resistance increases and when the sliding contact is moved towards A, the resistance decreases.



Use of rheostat as potential divider

ii) Rheostat as a potential divider

If the potential difference V is applied across the two fixed terminal A and B of rheostat, then the current flowing through it is

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

The potential difference between points B and C of the wire is V_{BC}. So,

$V_{BC} = I \times r$

Where r is the resistance of the portion BC of the wire

OR $$V_{BC} = \left(\frac{V}{R}\right) \times r$$

OR $$V_{BC} = \frac{r}{R} V$$

Do You Know

Rheostat is used where accuracy is required. For this purpose mangnin wire is used because its resistivity increases less with temperature than any other metal.

Thus, the potential can be varied from 0 to V volts which depend upon the position of sliding contact. If the sliding contact C is moved towards the end A, the length and hence the resistance r of the portion of wire increases which increases V_{BC}.and vice versa.

Q.14 What is a thermistor? Explain.

Ans.

THERMISTOR

It is a resistor whose resistance changes with temperature of its surrounding.

OR

A thermistor is a heat sensitive resistor

Types

There are two types of thermistor

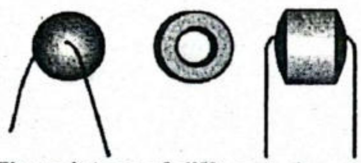
- Negative temperature coefficient thermistor(NTC)
- Positive temperature coefficient thermistor(PTC)

PTC-thermistors

They used for temperature compensations in electronic circuits. Currents in parts of a circuit may increase to dangerously high levels if the temperature of the circuit becomes unduly high. If a PTC-thermistor is included in the circuit, its increased resistance reduces the current.

Formation of thermistors

Thermistors are made from semiconductor materials (ceramics) such as NiO_2, MnO_2, CoO_2, CuO_2, FeO_2 etc. by heating them under high pressure. These are pressed into desired shapes and then baked at high temperature. *All these materials have ability to emit more charge carriers when heat energy is increased.*



Thermistors of different shapes

Shapes of thermistors

Thermistors are available in different shapes and sizes, like to be beads, rods, washers disc or probe etc.

Uses

1. High negative temperature coefficient thermistors are used to measure low temperature especially near **10K** very accurately.
2. They are used to measure and control the temperature in **oven.**
3. They are used to cancel the effect of temperature rise in other **electronic devices.** (PTC)
4. They are used as heat sensor in **fire alarm.**

Note

Thermistor behaves as the temperature sensor which may convert the change in temperature into electrical voltage.

MCQ's From Past Board Papers

1. **The SI unit of resistivity is:** **(Sgd 2016, Federal 2017) (Swl 2015) (Lhr 2014 Shl 2015)**
   (A) Ωm^{-2} (B) m^{-1} ✓(C) Ωm (D) Ω
2. **The potential difference between, the head and tail of an electric eel is:** **(Mtn 2015 G – I)**
   ✓(A) 600 volts (B) 700 volts (C) 800 volts (D) 900 volts
3. **In Carbon resistors, the value of Blue colour is:** **(Mtn 2015 G – II)**
   (A) 7 ✓(B) 6 (C) 8 (D) 9

4. **Specific resistance of material depends upon:** **(Bwp 2015, Sgd 2014 Grw 2011 Lhr 2015 G – I)**
(A) Length (B) Area (C) Temperature (D) Both A & B

5. **If the temperature of a conductor is increased, the product of resistivity and conductivity** **(Federal 14)**
(A) Increases (B) Decreases (C) Remains constant (D) May increase or decrease

6. **Tolerance for silver band is:** **(Mtn 2014 Grw 2013 G I)**
(A) $\pm$ 10% (B) $\pm$ 15% (C) $\pm$ 20% (D) $\pm$ 25%

7. **The substance having negative temperature co-efficient is:** **(Bwp 2017 G II) (Grw 2014 Lhr 2014 G I)**
(A) Carbon (B) Iron (C) Tungsten (D) Gold

8. **Resistivity at a given temperature depends upon:** **(Bwp 2014 Lhr 2014 G II)**
(A) Area of cross–section (B) Length
(C) Nature of material of conductor (D) Both length and area

9. **Colour codes are used to calculate the:** **(Mtn 2014 Sgd 2014)**
(A) Nature of resistor (B) Numerical value of resistance (C) Potential difference (D) Current

10. **The resistivity of a conductor increases with** **(Swl 2015 Grw 2010)**
(A) increase in tis length (B) increase in its area (C) increase in its temperature (D) decrease in its length

11. **Siemen is the unit of** **(Rwp 2014, Lhr 2015 Grw 2010, 2011, 14)**
(A) resistance (B) conductance (C) resistivity (D) conductivity

12. **A wire of resistance R is cut into two equal parts, its resistance becomes R/2. What happens to resistivity:** **(D.G.Khan, Swl 2017, Lhr 2012 G-II, Lhr 2011 G-I)**
(A) Double (B) Same (C) Half (D) One fourth

13. **In carbon resistors, what is the value of violet colour?** **(Fed 2011, Rwp 2014, 15)**
(A) 6 (B) 7 (C) 8 (D) 9

14. **Colour code of yellow colour is:** **(Grw 2016)**
(A) 2 (B) 3 (C) 4 (D) 5

15. **Resistance tolerance for gold colour is:-** **(Lhr 2018, Mtn 2016 Group II)**
(A) 50% (B) 30% (C) 20% (D) 5%

16. **Temperature coefficient of resistance (α) is equal to** **(Sgd 2016 Group I)**
(A) $\frac{R_t + R_o}{R_o\Delta t}$ (B) $\frac{R_o - R_t}{R_o\Delta t}$ (C) $\frac{R_t - R_o}{R_o\Delta t}$ (D) None of these

17. **A certain wire has a resistance R, the resistivity of another wire of an identical material with the first, except for twice its diameter is:** **(Bwp 2016)**
(A) $\frac{1}{4}$R (B) 4R (C) 2R (D) Same as R

18. **If fourth band is missing on resistance, its tolerance is** **(Swl 2016)**
(A) ± 5% (B) ± 10% (C) ± 15% (D) ± 20%

19. **The unit of temperature co-efficient of resistivity is** **(Mirpur 2015, D.G.Khan 2016 Group II)**
(A) K (B) K^{-1} (C) Ω (D) °C

20. **The heat produced by the passage of current through a resistor is;** **(Mirpur 2016)**
(A) $H = I^2Rt$ (B) $H = IR^2t$ (C) $H = \frac{1}{Rt}$ (D) $H = \frac{I^2}{Rt}$

21. **If the resistance of 500 Ω have fourth band of silver colour then its upper maximum resistance *will be:*** **(Fsd 2014, Lhr 2015 Group II)**
(A) 600 Ω (B) 550 Ω (C) 450 Ω (D) 400 Ω

22. **The reciprocal of resistance is called** **(D.G.Khan 2015 Group II)**
(A) Capacitance (B) Resistance (C) Conductance (D) Inductance

23. **The thermistors convert of temperature into:** **(AJK 2018, Fsd 2015)**
(A) Light energy (B) Electric voltage (C) Heat (D) sound

24. **Thermistors with high negative temperature coefficient are very accurate for measuring low temperature specially near.** **(Azad Kashmir 2017)**
(A) 45K (B) 10K (C) 75K (D) 120K

25. **By increasing the temperature of conductor, the flow rate of charge** **(Grw 2017)**
(A) increases (B) remain constant (C) change exponentially (D) decreases

26. **Heat sensitive resistors are called:** **(Fsd 2017)**
(A) Resistors (B) Capacitors (C) Thermistors (D) Inductors

27. **What is the resistance of a carbon resistor which has bands brown, black and brown?** **(Bwp GI 2018)**

(A) 100 Ohm (B) 1000 Ohm (C) 10 Ohm (D) 1. 0 Ohm

28. What is the colour code for 52MΩ ± 5% resistance? (Bwp GII 2018)
(A) Red Green Blue Gold (B) Green Red Blue Gold (C) Yellow Red Blue Gold (D) Green Red Violet Gold

29. The resistance of a conductor of length L, cross-sectional area 'A' and resistivity 'ρ' is given by: (Grw 2018)
(A) $R = \frac{\rho}{AL}$ (B) $R = \rho AL$ (C) $R = \rho\frac{L}{A}$ (D) $R = \rho\frac{A}{L}$

30. The reciprocal of resistance is called: (D.G.Khan 2015, Sgd GI 2018)
(A) Reactance (B) Inductance (C) Conductance (D) Conductivity

31. mho m^{-1} is the SI unit of: (Lhr GI 2018)
(A) Conductance (B) Conductivity (C) Resistance (D) Resistivity

ANSWER KEY'S

1.	C	2.	A	3.	B	4.	C	5.	C	6.	A	7.	A	8.	C	9.	B	10.	C
11.	B	12.	B	13.	B	14.	C	15.	D	16.	C	17.	D	18.	D	19.	B	20.	A
21.	B	22.	C	23.	B	24.	B	25.	D	26.	C	27.	C	28.	C	29.	C	30.	C
31.	B																		

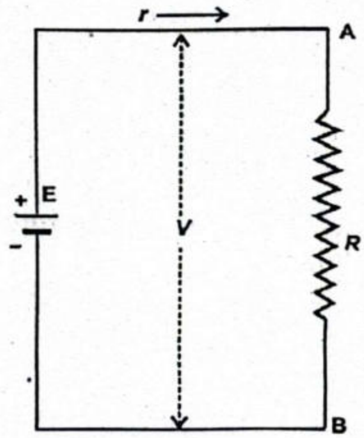
Q.15 Define Electric Power. Derive an expression for the power dissipated in a resistors. Fsd 14, Lhr 15

Ans.

ELECTRICAL POWER

Electrical power of the battery is *the rate at which work is done to maintain the steady current in a circuit.*

$$\text{Electrical power} = \frac{\text{Energy supplied}}{\text{time taken}}$$



The power of a battery appears as the power dissipated the resistor R.

Power dissipation in resistors

Let us consider a circuit consisting of a battery E and a resistance R in series. When a potential difference V is applied between the terminals A and B of resistance R, a steady current I flows through the circuit.
The work done in moving a charge ΔQ up through potential difference V in time Δt is given by,

$$\Delta W = V \times \Delta Q$$

This is the energy to maintain the steady current in the circuit.

As $$\text{Electrical power} = \frac{\text{Energy Supplied}}{\text{Time taken}}$$

OR $$P = \frac{\Delta W}{\Delta t}$$

Thus $$P = V\frac{\Delta Q}{\Delta t}$$

$$P = VI \qquad [\because \ I = \frac{\Delta Q}{\Delta t}]$$

According to law of conservation of energy, the electrical power dissipated (lost) through the resistor R in the form of heat is equal to the electrical power supplied by battery. Therefore

Power dissipation, $P = VI$ ________ (1)

From ohm's law $V = IR$

Therefore $P = (IR)\, I$

OR $P = I^2R$ __________ (2)

> **Watt:**
> If one ampere current passes through a conductor due to applied potential difference of one volt be one watt.

From ohm's law $I = \frac{V}{R}$

Therefore $P = \left(\frac{V}{R}\right)^2 R$

OR $P = \frac{V^2}{R}$ ________ (3)

Unit

SI unit of electric power is **watt**.

MCQ's From Past Board Papers

1. Power of an electric generator of voltage (V) and driving current (I) through an appliance is _____. (Fed 12)
   (A) $P = VI$ (B) $P = I^2R$ (C) $P = \frac{V^2}{R}$ (D) All of these
2. Electrical energy is measured in: (Lhr 10 Grw 2015, Bwp 2012)
   (A) watt (B) horse power (C) kilowatt (D) kilowatt hour

ANSWER KEY'S

1.	D	2.	D

Q.16 What is electromotive force (emf) and terminal potential difference? Explain.

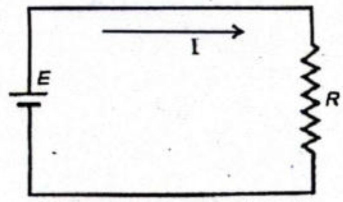
Ans.

ELECTROMOTIVE FORCE (EMF) AND POTENTIAL DIFFERENCE

The energy supplied to a unit charge in moving it from negative to positive electrode inside the source, is called electromotive force.

OR

It is defined as ***the energy supplied to the unit charge by the source.***



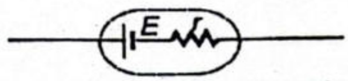
Electromotive force of a cell.

Explanation

Consider a battery connected across a resistance to maintain the steady current through it. The cell continuously supplies energy which is dissipated in the resistance of the circuit. Let ΔQ is charge passing through any cross-section of circuit in time Δt and ΔW is energy supplied to the positive charge to force it to go to the point of higher potential. Then, emf of a source is,

$$E = \frac{\text{energy supplied}}{\text{charge}}$$

OR $E = \frac{\Delta W}{\Delta q}$ ________ (1)



An equivalent circuit of a cell of emf E and internal resistance r.

Unit

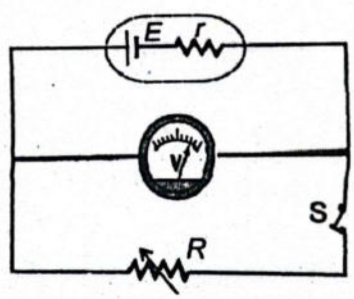
SI unit of emf is **J/C or volt.**

Internal resistance

The resistance offered by electrolyte present between two electrodes of a cell to the flow of ions is called internal resistance of the cell. It is denoted by r.

Terminal potential difference

The potential difference across the terminals of a cell (battery) when current is being drawn from it is called terminal potential difference.



The terminal potential difference V of a cell is EI - R.

Relation between terminal potential difference and electromotive force.

Consider a cell (source) of emf E having internal resistance r connected in a circuit as shown in the figure. Let, V is the potential difference across the external resistance R. The current I flowing through the circuit is given by

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

OR $$E=IR+Ir \quad \text{\_\_\_\_\_\_\_\_\_\_ (2)}$$

OR $$E=V_t+Ir$$

From equation (2), V_t is called terminal potential difference.

Special cases

1. If the internal resistance of cell is zero (r = 0), then terminal potential difference becomes equal to emf. i.e.

$$V_t = E - Ir$$
$$V_t = E - I(0)$$
$$V_t = E$$

2. The terminal voltage in the presence of current is less than emf E by a factor Ir.

$$V_t = E - Ir$$

Explanation of equation $E=IR+Ir$ on the basis of energy

$$E = IR + Ir$$

E =energy gained by unit charge as it passes through the cell from its negative to positive terminal.
Ir =energy dissipated into the cell as heat.
IR = energy is dissipated into the external resistance R.

Conclusions

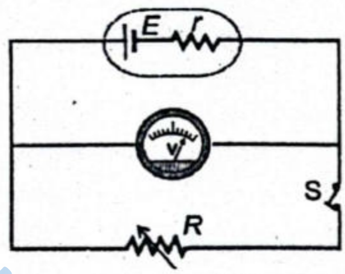
- emf is the **energy supplied** to the unit charge by the cell and potential drop across different components is the **energy dissipated** as the unit charge passes through these components.
- The emf is the **cause** and potential difference is the **effect**.
- The emf is always present even no current is drawn through the battery but the potential difference across the conductor is zero in the absence of current.

Q.17 Describe the condition for maximum power output delivered to the load resistance by a battery.

Ans.

MAXIMUM POWER OUTPUT

Consider the circuit as shown in figure, when the current flows through the resistance R. The charges lose their potential energy while moving from higher to a lower potential.



The terminal potential difference V of a cell is EI - R.

The loss of energy per second is VI and is known as power delivered to R by current I.

So, power delivered to R is

$$P = VI$$
$$P = (IR)I \qquad [\because V = IR]$$
$$P = I^2R$$
$$P = \left(\frac{E}{R+r}\right)^2 R \qquad [\because I = \frac{E}{R+r}]$$
$$P = \frac{E^2R}{(R+r)^2}$$
$$P = \frac{E^2R}{R^2 + r^2 + 2Rr}$$

> **For your information**
> Internal resistance of a cell depends upon the composition of electrolyte distance between electrodes (i.e. central rod and case) and their area

$$P = \frac{E^2R}{R^2 + r^2 + 2Rr + 2Rr - 2Rr}$$

$$P = \frac{E^2R}{(R-r)^2 + 4Rr}$$

When R = r, then denominator becomes minimum.
Hence, value of power output becomes maximum. Thus

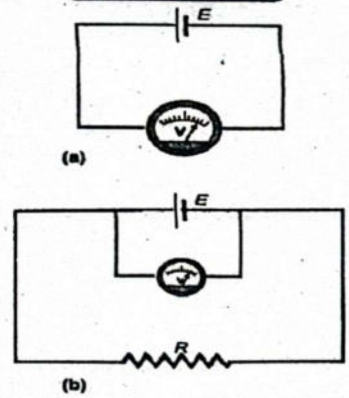
$$P_{max} = \frac{E^2r}{(r-r)^2 + 4rr}$$

$$P_{max} = \frac{E^2r}{0 + 4r^2}$$

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

This is the maximum output power delivered to a load resistance.

Do You Know



A voltmeter connected across the terminals of a cell measure (a) the emf of the cell on open circuit, (b) the terminal potential difference on a closed circuit.

MCQ's From Past Board Papers

1. **The unit of electromotive force is.** **(Grw 2014,Mtn 2015, Sgd 2015 G – I)**
   (A) Newton (B) Pascal (C) Volt (D) Ampere
2. **Which equation represents the maximum output power?** **(Fsd 2014, Bwp 15 Fed 11, Grw 13, Fsd 2014, Lhr 2010)**
   (A) $P = \frac{E^2}{4R}$ (B) $P = \frac{E^2}{4r}$ (C) $P = \frac{E^2}{4R^2}$ (D) $P = \frac{E^2}{4r^2}$
3. **emf is induced due to change in:** **(Fsd 2016)**
   (A) Charge (B) Current (C) Magnetic flux (D) Electric field
4. **When the internal resistance of a source is equal to the load, the maximum power dissipated is:** **(Lhr 2014, Mir-II-13, Supp Mirpur 09)**
   (A) $\frac{E}{4r}$ (B) $\frac{E^2}{4r}$ (C) $\frac{E}{4r^2}$ (D) $\frac{E^2}{4r^2}$
5. **For a closed circuit:** **(Lhr 2011, D.G.Khan 2013Mirpur 2009)**
   (A) $E = V_t$ (B) $E > V_t$ (C) $E < V_t$ (D) $E = V_t - Ir$
6. **The 'emf' is always ______ even when no current is drawn through the battery or cell.** **(Lhe 2012 G I, Grw 2012, 2014)**
   (A) Zero (B) Present (C) Absent (D) Maximum
7. **The maximum power (P_{out}) is delivered to a load resistance R, when the internal resistacne of the source is:** **(D.G.Khan 2018, Bwp 2017 G I)**
   (A) $r = \infty$ (B) $r = R$ (C) $r = 0$ (D) $r = \frac{R}{4}$
8. **An ideal current source shall have reistance:** **(Swl 2018)**
   (A) zero (B) finite but not zero (C) infinite (D) depends upon requirement

ANSWER KEY'S

1.	C	2.	B	3.	C	4.	B	5.	B	6.	B	7.	B	8.	A

Q.18 Define Simple and Complex Networks and explain the Kirchhoff's Rules. **Grw 17 Lhr 14 Sgd 09, 17**

Ans.

A SIMPLE CIRCUIT

A simple electrical circuit may consist of more than one resistors but a single voltage source.

A simple circuit can be solved by using

- **Ohm's law**
- Rules of **series and parallel** combinations of resistance.

A COMPLEX NETWORK

When an electrical circuit consists of number of resistances and a number of electrical voltage sources, then such circuit is called complex network.

A complex network can be solved by using the Kirchhoff's rules.

KIRCHHOFF'S FIRST RULE

This rule is in accordance with **law of conservation of charge**

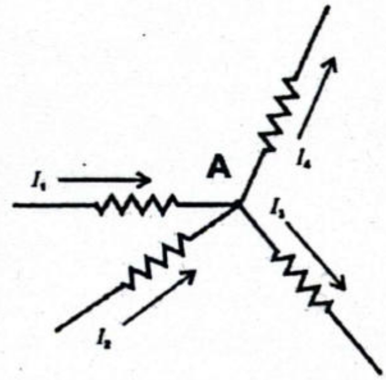
It states that*sum of all the currents meeting at a point in a circuit is zero.*

OR

The sum of all the currents flowing towards a point is equal to the sum of all currents flowing away from the point.

Mathematically,

$$\sum I = 0$$



According to Kirchhoff's 1st rule $I_1 + I_2 = I_3 + I_4$.

Explanation

Consider four resistance wires meeting at a point A, as shown in figure. The currents flowing towards the point A are I_1 and I_2 and the currents flowing away from point A are I_3 and I_4.

Sigh convention

The current flowing towards a point is taken as positive and flowing away from the point is taken as negative.

Thus, we can write,

$$I_1 + I_2 + (-I_3) + (-I_4) = 0$$

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

OR $$I_1 + I_2 = I_3 + I_4$$

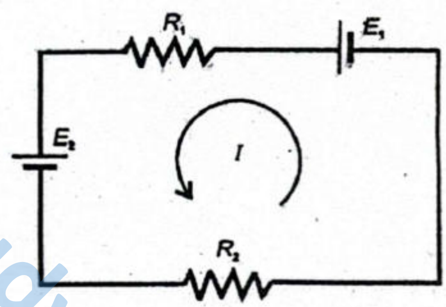
Which is in accordance to the law of conservation of charge.

Kirchhoff's first rule is also known as **Kirchhoff's point rule.**

Important note

If there in no **sink** (negative terminal) or the **source of charge** (positive terminal of battery) at the point, the total charge flowing towards the point is equal to the total charge flowing away from the point.

KIRCHHOFF'S SECOND RULE



According to Kirchhoff's 2nd rule $E_1 - IR_1 - E_2 + IR_2 = 0$.

This rule is in accordance with law of conservation of **energy.**

The algebraic sum of potential changes along a closed loop is equal to zero.

Explanation

Consider a circuit consisting of two batteries E_1 and E_2 and two resistors R_1 and R_2 as shown in figure. The direction of current I flowing through closed circuit depends upon the cell having greater emf.

Let E_1 is greater than E_2. Then the current flows in anticlockwise direction. Now when the positive charge ΔQ due to current I in the *closed* circuit passes through the cell E_1 from low to high potential, it gains energy because work is done on it. So

$$\text{Energy gained} = E_1 \Delta Q$$

When the current passes through the cell E_2, it loses energy because in this case, the charges pass from high potential to low potential. So

Energy lost = $-E_2\Delta Q$

When the current passed through the resistor R_1, the charge ΔQ loses energy. So

Energy lost = $-IR_1\Delta Q$

When the current passed through the resistor R_2, the charge ΔQ loses energy. So

Energy lost = $-IR_2\Delta Q$

Where IR_1 and IR_2 are the potential drops across the resistors R_1 and R_2.

Finally, the current approaches the negative terminal of the cell E_1.

According to law of conservation of energy, the total change in energy must be zero. So,

$$E_1\Delta Q - IR_1\Delta Q - E_2\Delta Q - IR_2\Delta Q = 0$$

$$\Delta Q(E_1 - IR_1 - E_2 - IR_2) = 0$$

$$\Rightarrow \quad E_1 - IR_1 - E_2 - IR_2 = 0 \qquad [\because \Delta Q \neq 0]$$

Which expresses the Kirchhoff's 2nd rule.

Rules of finding the potential changes

The following rules can be applied to find the potential changes.

1) If the source of emf is traversed from negative to positive terminal, the potential change is positive.
2) If the source of emf is traversed from positive to negative terminal, the potential change is negative.
3) If a resistor is traversed in the direction of current, the change in potential is negative.
4) If a resistor is traversed in the opposite direction of current, the change in potential is positive.

Q.19 Describe the procedure for solution of circuit problems. **Federal 2013, Grw 2016**

Ans.

PROCEDURE OF SOLUTION OF CIRCUIT PROBLEM

The following steps should be used in solving the circuit problem by use of Kirchhoff's rules.

(i) Draw the circuit diagram.

(ii) Choose the loop in such a way that each resistance is included at least once in the selected loop.

(iii) Assume the current in each loop, all the loop currents should be in same sense.

(iv) Write the loop equations for each loop. For writing each loop equation the voltage change across each component is positive if traversed from low to higher potential and it is negative if traversed from higher to low potential.

(v) Solve these equations for unknown quantities.

MCQ's From Past Board Papers

1. Kirchhoff's first rule is the manifestation of the law of conservation of: (Bwp 2014, Fsd 2014, Swl 2014, Lhr 2011)
   (A) Mass (B) Charge (C) Energy (D) Momentum
2. Kirchhoff's voltage rule is a way of stating conservation of (D.G.Khan 2018, Rwp 2016)
   (A) Energy (B) Momentum (C) Charge (D) Angular momentum

ANSWER KEY'S

1.	B	2.	A

Q.20 What is Wheatstone bridge? How it can be used to find the unknown resistance?

D.G.Khan – 2009, 2015 G II, BWP – 2014, Lhr 2016 G II

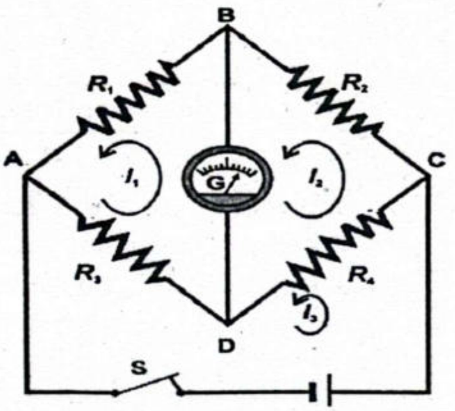
Ans.

WHEATSTONE BRIDGE

It is the basic electrical circuit which is used to measure the value of unknown resistance. It was firstly devised by Charles Wheatstone and hence it is known as Wheatstone bridge.

Construction

The wheat stone bridge consists of four resistances R_1, R_2, R_3 and R_4 joined together in such a way so that it forms a loop ABCDA. A source of emf E with a switch S is connected between A and C and a sensitive galvanometer G is connected between B and D.



Working

When the switch S is closed, the current flows through the galvanometer.

Balancing condition

If the points B and D are at same potential, then no current will pass through the galvanometer. So galvanometer shows no deflection and bridge is said to be balanced.

Mathematical Analysis

We can analyses the circuit by using the Kirchhoff's rules. Assume the anti-clockwise direction of current in each loop. Let I_1, I_2 and I_3 are the currents in loops ABDA, BCDB and ADCA respectively. Then by Kirchhoff's 2nd rule,

For Loop ABDA

The voltage equation is,

$$-I_1R_1 - (I_1 - I_2)R_g - (I_1 - I_3)R_3 = 0 \quad \text{\_\_\_\_\_\_ (1)}$$

For Loop BCDB

The voltage equation is,

$$-I_2R_2 - (I_2 - I_3)R_4 - (I_2 - I_1)R_g = 0 \quad \text{\_\_\_\_\_\_ (2)}$$

Under balanced condition, the potential at points B and D becomes same. So the potential difference becomes zero and the current passing through the galvanometer will be zero (i.e., $I_1 - I_2 = 0$ or $I_1 = I_2$)

So equation (1) becomes

$$-I_1R_1 - (0)R_g - (I_1 - I_3)R_3 = 0$$

OR

$$-I_1R_1 - (I_1 - I_3)R_3 = 0$$

OR

$$-I_1R_1 = (I_1 - I_3)R_3 \quad \text{\_\_\_\_\_\_ (3)}$$

Also, the equation (2) becomes

$$-I_2R_2 - (I_2 - I_3)R_4 - (0)R_g = 0$$

$$-I_2R_2 - (I_2 - I_3)R_4 = 0$$

$$-I_2R_2 = (I_2 - I_3)R_4$$

$$-I_1R_2 = (I_1 - I_3)R_4 \quad \text{\_\_\_\_\_\_ (4)} \qquad [\because I_1 = I_2]$$

> **wheat stone bridge**
>
> It is used to detect the temperature changes by connecting thermistor in the fourth arm. Also, it is used to measure load (weight) in the electronic balance.

> **For your information**
>
> Practical application of wheat stone bridge are slide wire bridge and post office box apparatus etc.

Dividing equation (3) by (4)

$$\frac{-I_1R_1}{-I_1R_2} = \frac{(I_1 - I_3)R_3}{(I_1 - I_3)R_4}$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Which is the condition of balancing the wheat stone bridge.

Determination of unknown resistance

Let R_4 be the *unknown* resistance. Then, the values of R_1, R_2 and R_3 are *so adjusted* that the galvanometer *shows* no deflection. In such condition, from known values of R_1, R_2 and R_3, the unknown resistance R_4 *can be* determined by using the relation.

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

OR $$R_4 = \frac{R_3}{R_1} R_2$$

Q.21 What is potentiometer? Discuss the construction and working of potentiometer in detail?

Ans.

Commonly, the potential difference is measured with the help of voltmeter. The resistance of the voltmeter should be large as compared to circuit resistance. Otherwise an appreciable current will pass through the voltmeter which will change the circuit current and potential difference to be measured. So for accurate measurement of potential difference the resistance of voltmeter should be large. So it will not draw any current from the circuit across which it is connected. *An ideal voltmeter has infinite resistance.*

Cathode ray oscilloscope or digital voltmeter can be used for the same purpose. But these instruments are very costly. So, very simple instrument potentiometer is used for this purpose

POTENTIOMETER

Potentiometer is an accurate device which is used to ***measure or compare the potentials without drawing any current from the circuit.***

For your Information

Potentiometer gives us the continuously varying (point to point) potential difference while rheostat provides us potential difference which varies in steps (turn to turn).

Principle

When a steady current flows through a wire of uniform cross-section area then the potential difference across any length of wire is directly proportional to its length. i.e.

$$V \propto \ell \quad \text{, when I = constant}$$

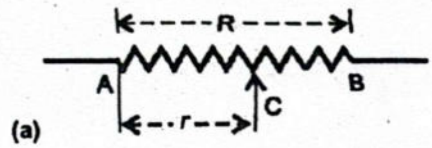
Construction

Potentiometer consists of a resistor in form of a wire of length L on which a terminal C can slide. Let, R is the resistance of wire. As the sliding contact moves from A to B, the resistance between A and C changes from o to R.

Working as potential divider

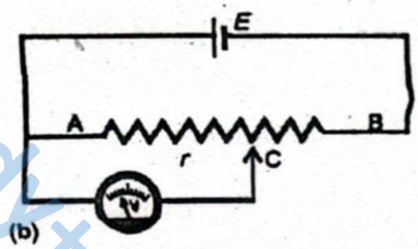
Let E be the emf of the cell. The current flowing through it is,

$$I = \frac{E}{R} \quad \text{——— (1)}$$



If r be the resistance between A and C then the potential drop between *these points* will be

$$V_{AC} = I\,r$$

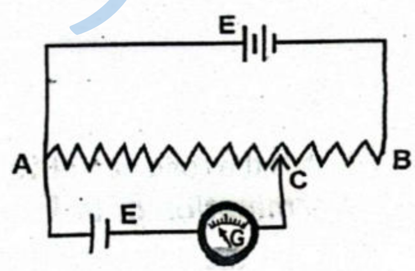


Putting value of I from equation (1), we get

$$V_{AC} = \left(\frac{E}{R}\right) r$$

OR $$V_{AC} = \left(\frac{r}{R}\right) E$$

As E and R are constant for a given circuit; therefore, the potential drop can be varied by changing the value of r. Such an arrangement is called potential divider.



Measurement of emf

A potentiometer can also be used for measuring the unknown emf of a cell. It consists of a resistance wire R of uniform cross-sectional area.

Let E_x is the unknown emf of the cell. It should be noted that positive terminal of the cell and that of potential divider are connected to the same point A. When the terminal C and negative terminal of E_x are at same potential. Then no current will flow through the galvanometer. Under this condition, the emf E_x of the cell is equal to the potential difference between A and C. (i.e. $E_x = V_{AC}$). Now

$$V_{AC} = \left(\frac{r}{R}\right)E$$

Therefore,

$$E_x = \left(\frac{r}{R}\right)E$$

In case of a wire of uniform cross-sectional area. The resistance is directly proportional to length. i.e., $R \propto L$ and $r \propto \ell$

So the above equation becomes

$$E_x = \frac{\ell}{L}E \quad \text{(2)}$$

$$\left(\because R = \rho\frac{L}{A} \text{ and } r = \rho\frac{\ell}{A} \quad \therefore \frac{r}{R} = \frac{\rho\frac{\ell}{A}}{\rho\frac{L}{A}} = \frac{\ell}{L}\right)$$

Where ℓ is length of wire between A and C and L is the total length of wire.

Comparison the emfs of two cells

The method which is used to measure the emf of a cell can also be used to compare E_1 and E_2 of two cells.

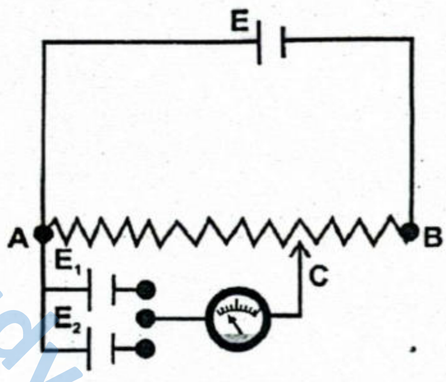
Let ℓ_1 and ℓ_2 are the balancing lengths for emfs of two cells E_1 and E_2 respectively. ℓ_1 and ℓ_2 are found separately for each cell. Thus

$$E_1 = \frac{\ell_1}{L}E$$

And $$E_2 = \frac{\ell_2}{L}E$$

Dividing E_1 by E_2

$$\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$$



So the ratio of emfs is equal to the ratio of their balancing length.

Uses of Potentiometer

It can be used

(1) to determine the **emf** of a cell.

(2) to **compare** the emf of two cells.

(3) as a continuously **potential divider**.

(4) to measure the **internal resistance** of the cell.

MCQ's From Past Board Papers

1. *Potentiometer* can be used as ________. (Federal 2013)
   (A) Ohm meter (B) Ammeter (C) Galvanometer (D) Potential Divider

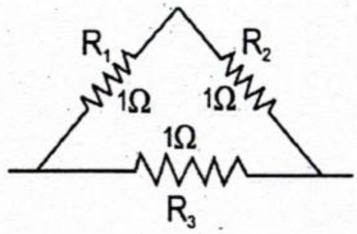
2. The relation of emfs of two cells $\frac{E_1}{E_2}$ is = ________: (Fsd 2016)
   (A) $\frac{\ell_2}{\ell_1}$ (B) $\frac{\ell_1}{\ell_2}$ (C) $\frac{1}{\ell_1\ell_2}$ (D) $\ell_1 \times \ell_2$

ANSWER KEY'S

1.	D	2.	B

1. Three resistors each of one ohm are arranged in form of a triangle then calculate their equivalent resistance across any two terminals?

Ans. Equivalent Resistance of R_1 and R_2



$$R' = R_1 + R_2$$
$$= 1 + 1$$
$$= 2\,\Omega$$

Equivalent resistance of R' and R_3

$$\frac{1}{R_{eq}} = \frac{1}{R'} + \frac{1}{R_3}$$
$$\frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{1}$$
$$\frac{1}{R_{eq}} = \frac{3}{2}$$
$$R_{eq} = \frac{2}{3}\,\Omega$$

2. Differentiate between resistance and resistivity?

Ans. **Resistance:**

(i)The opposition in the flow of electrons through the conductor is called electrical resistance.

(ii) It depends upon the length and area of cross-section of the wire of a conductor (i.e. $R = \rho\frac{L}{A}$).

(iii) Its unit is Ohm (Ω)

Resistivity:

(i)It is the resistance of a meter cube of a wire.

(ii) It is independent of dimension of the conductors, it depends upon the nature and temperate of the material of the wire.

(iii) Its SI unit is ohm-meter (Ω-m)

3. Why we prefer potentiometer in place of voltmeter for measuring potential difference? (Rwp 2015)

Ans. An accurate potential difference measuring device in one which will not draw any current from the circuit. An ideal voltmeter has infinite resistance.

In case of potential – meter when we take the measurements at balanced position, no current is drown from the circuit. So it is much more accurate device as compare to ordinary voltmeter.

FORMULAE

1	**Electric current**	$I = \frac{\Delta q}{\Delta t}$		
2	**Heat produced in a conductor**	$H = I^2Rt$		
3	**Ohm's Law**	$I = \left(\frac{1}{R}\right)V$	$V = IR$	
4	**Resistance**	$R = \frac{V}{I}$	$R = \rho\frac{L}{A}$	$R = \frac{1}{G}$
5	**Parallel combination of resistances**	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$		
6	**Series combination of resistances**	$R = R_1 + R_2 + R_3$		
7	**Conductance**	$G = \frac{1}{R}$	$G = \sigma\frac{A}{L}$	
8	**Resistivity**	$\rho = \frac{RA}{L}$	$\rho = \frac{1}{\sigma}$	
9	**Conductivity**	$\sigma = \frac{1}{\rho}$		
10	**Temperature coefficient of resistance**	$\alpha = \frac{R_t - R_o}{R_o t}$		
11	**Temperature coefficient of resistivity**	$\alpha = \frac{\rho_t - \rho_o}{\rho_o t}$		
12	**Electrical power of a battery**	$P = \frac{\Delta W}{\Delta t}$	$P = V\frac{\Delta q}{\Delta t}$	$P = VI$
13	**Electrical power dissipated in resistors**	$P = VI$	$P = I^2R$	$P = \frac{V^2}{R}$
14	**Emf of a battery**	$\varepsilon = \frac{\Delta W}{\Delta q}$		
15	**Relation between emf and potential difference**	$E = IR + Ir$	$E = V_t + Ir$	$V_t = E - Ir$
16	**Maximum power output of a battery**	$P_{max} = \frac{E^2}{4r}$		
17	**Kirchhoff's current rule**	$\sum I = 0$		
18	***Kirchhoff's voltage rule***	$\sum V = 0$		

19	Wheat stone bridge	$\frac{R_1}{R_2} = \frac{R_3}{R_4}$	$R_1R_4 = R_2R_3$	
20	Emf of a cell	$E_x = \frac{\ell}{L}E$		

UNITS

1	Electric current	A	Cs^{-1}	
2	Electric charge	C	As	
3	Resistance	Ω	VA^{-1}	
4	Resistivity	Ω m		
5	Conductance	Ω^{-1}	mho	siemen
6	Conductivity	$\Omega^{-1}m^{-1}$	mho m^{-1}	siemen m^{-1}
7	Temperature coefficient of resistance	K^{-1}		
8	Electrical power	J/s	watt	
9	Electromotive force	J/C	volt	
10	Dielectric constant	no unit		
11	Energy density	J/m^3		
12	RC-time constant	second		

CONSTANTS

1	Drift velocity of electrons	$1\times10^{-3}ms^{-1}$

SOLVED EXAMPLES

Example 13.1:

1.0×10^7 electrons pass through a conductor in 1.0 μs. Find the current in ampere flowing through the conductor. Electronic charge is 1.6×10^{-19} C.

Given data:

Number of electrons = n = 1.0×10^7

Time taken = Δt = 1.0 μs = 1.0×10^{-6} sec

Charge on electron = e = 1.6×10^{-19} C

To find:

Electric current = I = ?

Calculations:

As $I = \frac{\Delta Q}{\Delta t}$

$I = \frac{ne}{\Delta t}$ As ΔQ = ne

Putting the values, we get

$$I = \frac{1.0\times10^{7}\times1.6\times10^{-19}}{1.0\times10^{-6}}$$

$$I = 1.6\times10^{7-19+6}$$

$$\boxed{I = 1.6\times10^{-6}\ A}$$

Example 13.2:

0.75 A current flows through an iron wire when a battery of 1.5 V is connected across its ends. The length of the wire is 5.0 m and its cross sectional area is 2.5×10^{-7} m^2. Compute the resistivity of iron.

Given data:

Current = I = 0.75 A

Potential difference = V = 1.5 V

Length of the wire = L = 5.0 m

Area of cross-section of wire = A = 2.5×10^{-7} m^2

To find:

Resistivity of wire = ρ = ?

Calculations:

As $R = \rho\frac{L}{A}$

or $\rho = \frac{RA}{L}$ ----------(1)

As according to Ohm's law

$V = IR$

or $R = \frac{V}{I}$ Putting values, we get

So $R = \frac{1.5}{0.75} = 2.0\Omega$

Putting the values in equ. (1), we get

$$\rho = \frac{2\times2.5\times10^{-7}}{5}$$

$$\boxed{\rho = 1.0\times10^{-7}\ \Omega m}$$

Example 13.3:

A platinum wire has resistance of 10 Ω at 0°C and 20 Ω at 273°C. Find the value of temperature *coefficient* of resistance of platinum.

Given data:

Resistance at 0°C = R_o = 10 Ω

Resistance at 273°C = R_t = 20 Ω

Initial temperature = t_1 = 0°C = 0 + 273 = 273 K

Final temperature = t_2 = 273°C = 273 + 273 = 546 K

Temperature difference = $t = t_2 - t_1$ = 546 − 273 = 273 K

To find:

Temperature co-efficient of resistance = α = ?

Calculations:

As $$\alpha = \frac{R_t - R_o}{R_o t}$$

Putting the values, we get

$$\alpha = \frac{20-10}{10\times 273}$$

$$\alpha = \frac{10}{10\times 273}$$

$$\alpha = \frac{1}{273}$$

$$\boxed{\alpha = 3.66\times 10^{-3}\ K^{-1}}$$

Example 13.4:

The potential difference between the terminals of a battery in open circuit is 2.2 V. When it is connected across a resistance of 5.0 Ω, the potential falls to 1.8 V. Calculate the current and the internal resistance of the battery.

Given data:

Potential difference = E = 2.2 V

Resistance = R = 5.0 Ω

Fall in potential = V = 1.8 V

To find:

(i) Current = I = ?

(ii) Internal resistance = r = ?

Calculations:

(i) According to Ohm's law

$$V = IR$$

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

Putting values, we get

$$I = \frac{1.8}{5}$$

$$\boxed{I = 0.36\ A}$$

(ii) Internal resistance 'r' can be calculated by using the following relation

$$E = V + Ir$$

or $$r = \frac{E-V}{I}$$

Putting values, we get

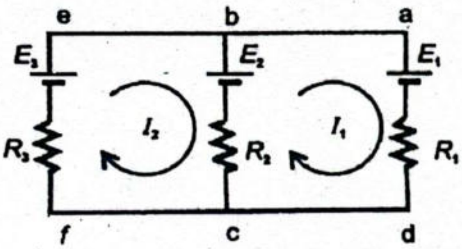
$$r = \frac{2.2-1.8}{0.36}$$

$$r = \frac{0.4}{0.36}$$

$$\boxed{r = 1.11\ \Omega}$$

Example 13.5:

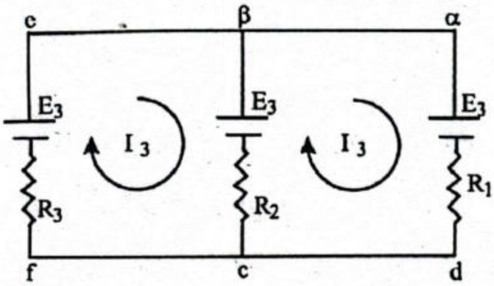
Calculate the currents in the three resistances of the circuit shown in Fig. 13.22.



$R_1 = 10\ \Omega$, $R_2 = 30\ \Omega$, $R_3 = 15\ \Omega$

$E_1 = 40$ V, $E_2 = 60$ V, $E_3 = 50$ V

Fig. 13.22



Given data:

Resistance $R_1 = 10\ \Omega$

Resistance $R_2 = 30\ \Omega$

Resistance $R_3 = 15\ \Omega$

Voltage of battery $E_1 = 40$ V

Voltage of battery $E_2 = 60$ V

Voltage of battery $E_3 = 50$ V

To find:

Current through R_1 = ?

Current through R_2 = ?

Current through R_3 = ?

Calculations:

$R_1 = 10\ \Omega$, $R_2 = 30\ \Omega$, $R_3 = 15\ \Omega$

$E_1 = 40$ V, $E_2 = 60$ V, $E_3 = 50$ V

There are two loops "abcda" and "befcb" in the given circuit diagram.

Let I_1 and I_2 be the current flowing through these loops. These currents are flowing in the clockwise direction. Starting from point 'a' and applying Kirchoff's second rule.c

For loop abcda:

According to Kirchoff's second rule for that loop, we have

$$-E_1 - I_1R_1 - (I_1 - I_2)R_2 + E_2 = 0$$

Putting the values, we get

$$-40 - I_1 \times 10 - (I_1 - I_2) \times 30 + 60 = 0$$

$$-40 - 10I_1 - 30I_1 + 30I_2 + 60 = 0$$

$$-40I_1 + 30I_2 + 20 = 0$$

$$-40I_1 + 30I_2 = -20$$

or $4I_1 - 3I_2 = 2$ ......(1)

For loop befcb:

Applying Kirchoff's second rule to that loop, we have

$$-E_2 - (I_2 - I_1)R_2 - I_2R_3 + E_3 = 0$$

Putting the values, we get

$$-60 - (I_2 - I_1) \times 30 - I_2 \times 15 + 50 = 0,$$

$$-60 - 30I_2 + 30I_1 - 15I_2 + 50 = 0$$

$$30I_1 - 45I_2 - 10 = 0$$

$$30I_1 - 45I_2 = 10$$

$$6I_1 - 9I_2 = 2 \qquad ......(2)$$

In order to solve these equations for I_1 and I_2, multiplying equation (1) by 3 and equation (2) by 2, we get

$$12I_1 - 9I_2 = 6 \qquad ......(3)$$

$$12I_1 - 18I_2 = 4 \qquad ......(4)$$

Subtracting equation (4) from equation (3), we get

$$9I_2 = 2$$

$$\boxed{I_2 = \frac{2}{9}\text{A}}$$

Putting the value of I_2 in equation (1), we get

$$4I_1 - 3 \times \frac{2}{9} = 2$$

$$4I_1 - \frac{2}{3} = 2$$

$$4I_1 = \frac{8}{3}$$

$$\boxed{I_1 = \frac{2}{3}\text{A}}$$

From figure, it is clear that I_1 and I_2 are the actual currents passing through resistance R_1 and R_3.
The actual current through R_2 is the difference of I_1 and I_2 and its direction is along the *larger* current. Thus

(i) *Current through R_1* $= I_1 = \frac{2}{3}\text{A} = 0.66\text{A}$

The direction of this current is from a to d.

(ii) Current through R_2 $= I_1 - I_2 = \frac{2}{3} - \frac{2}{9} = \frac{4}{9}\text{A} = 0.44\text{ A}$

The direction of this current in from c to b.

(iii) Current through R_3 $= I_2 = \frac{2}{9}\text{A} = 0.22\text{A}$

The direction of this current is from f to e.

SHORT QUESTIONS OF THE EXERCISE

13.1 A potential difference is applied across the ends of a copper wire. What is the effect on the drift velocity of free electrons by

(i) increasing the potential difference

(ii) decreasing the length and the temperature of the wire

(Grw 2010, DG khan 2009, Mirpur 2011)

Ans. (i) The drift velocity of free electrons ***increases*** by increasing the potential difference

Reason:

The drift velocity of free electrons in conductor of length ℓ and area of cross section A is given by

$$v_d = \frac{I}{neA}$$

$$v_d = \frac{V}{neAR} \qquad \left(I = \frac{V}{R}\right)$$

This equation shows that by increasing potential difference, I increases and hence v_d increases.

(ii) The drift velocity of electrons ***increases*** by decreasing the length and temperature.

Reason

The drift velocity of free electrons in conductor of length ℓ and area of cross section A is given by

$$v_d = \frac{I}{neA}$$

$$v_d = \frac{V}{neAR}$$

As $R \propto \ell$ and $R \propto T$

When length and temperature decrease, the resistance of conductor decreases, So I increases $\left(I = \frac{V}{R}\right)$.

Hence v_d increases.

13.2 Do bends in a wire affect its electrical resistance? Explain.

(Grw 2009, Lhr 2009, Bwp 2009, DG khan 2009, Mirpur 2011)

Ans. ***No***, bends in a wire do not affect its electrical resistance.

Reason:

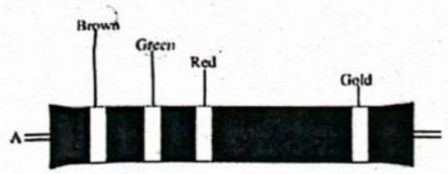
The resistance R of a wire is given by

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

As bends in a wire ***do not affect length or area of cross-section*** of wire, so R remains constant.

13.3 What are the resistances of resistors given in the figures A and B? What is the tolerance of each? Explain what is meant by the tolerance?

Ans. From figure A



According to colour code

Brown has value 1

Green has value 5

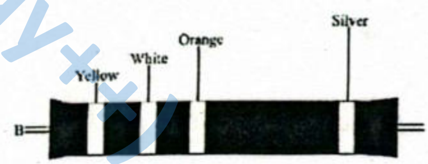
Red has value 2

Gold band shows tolerance equal to $\pm 5\%$

Therefore,

$R = 1500\ \Omega\ (\pm 5\%)$

From figure B



According to colour code

Yellow has value 4

White has value 9

Orange has value 3

Silver band shows tolerance equal to $\pm 10\%$

Therefore,

$R = 49000\Omega \pm 10\%$

Tolerance

The possible variation in the resistance of a carbon resistor from the marked value is called tolerance.

For example

a 1000 Ω resistor with the tolerance ± 10% will have an actual value anywhere between 900 Ω and 1100Ω.

13.4 Why does the resistance of a conductor rise with temperature?
(Grw 2009, Lhr 2009, Bwp 2009, DG khan 2009, Mirpur 2011)

Ans. **Reason**

As the temperature of the conductor rises,

The ***amplitude*** of vibration of the atoms in the lattice increases and hence the probability of their collision with free electrons also increases. We can say that the atoms then offer a bigger target i.e. collision cross-section of the atoms increases with temperature. So, the resistance of conductor increases.

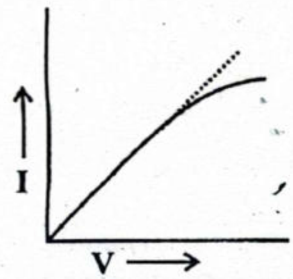
13.5 What are the difficulties in testing whether the filament of a lighted bulb obeys Ohm's law?
(Grw 2009,11, Lhr 09, 10, 14 Bwp 08, 13)

Ans. The main difficulty is the ***rise in temperature*** of filament with increase in current.

Reason

When the current passing through the filament is small then the energy dissipation is also very small. So the temperature and hence resistance remains constant i.e. Ohm's law is obeyed.

As the current is further increased, the resistance of filament continues to increase due to rise in temperature. So, Ohm's law is not obeyed as shown in figure.



13.6 Is the filament resistance lower or higher in a 500W, 220V light bulb than in a 100W,220 bulb?
(Rwp 2014 Grw 2010,11,14 Lhr 08, 11, 14)

Ans.

Solution

Data

$P_1 = 500W$

$V_1 = 220$

$R_1 = ?$

Calculations

$$P_1 = \frac{V_1^2}{R_1}$$

$$\Rightarrow \quad R_1 = \frac{V_1^2}{P_1} = \frac{(220)^2}{500}$$

$R_1 = 96.8\Omega$

Solution

Data

$P_2 = 100W$

$V_2 = 220V$

$R_2 = ?$

Calculations

$$P_2 = \frac{V_2^2}{R_2}$$

$$\Rightarrow \quad R_2 = \frac{V_2^2}{P_2} = \frac{(220)^2}{100}$$

$R_2 = 484\ \Omega$

Result

So ***100W*** light bulb has ***greater*** resistance.

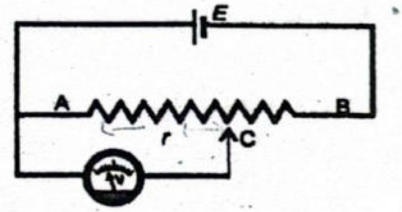
13.7 Describe a circuit which will give a continuously varying potential.
(Rwp 2013 Bwp 2008, DG khan 2009 2014)

Ans. A ***potentiometer*** can be used as a potential divider to give a continuously varying potential.

Explanation:

A potentiometer consists of a resistor R in the form of a wire on which a terminal C can slide as shown in figure. If a battery of emf E is connected across R, then

$$I = \frac{E}{R} \quad \text{———— (1)}$$



If r = resistance betwe en points A and C.

Then

$$V_{AC} = Ir = \frac{E}{R} r \qquad \text{[by equation (1)]}$$

Thus as C is moved from A → B, r varies from o → R and V_{AC} varies from

o → E.

13.8	**Explain why the terminal potential difference of a battery decreases when the current drawn from it is increased? (Lhr 2014 Fsd 2011, Rwp 2016, Federal 2015)**

Ans. **Reason**

When the current drawn from the battery is increased, the potential drop across the internal resistance also increases (i.e. the ***energy dissipation as heat*** into the battery is increased). Therefore, according to following relation,

$$V_t = E - Ir$$

the terminal potential difference is decreased.

13.9	**What is Wheatstone bridge? How can it be used to determine an unknown resistance? (Grw 2014 Lhr 2008,10, Bwp 2009, 13)**

Ans. **Wheatstone Bridge**

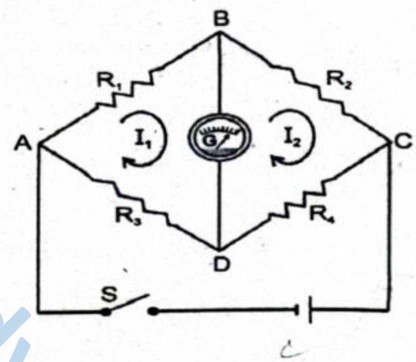
It is an electrical circuit which provides an accurate method for the measurement of an ***unknown resistance***.

Determination of unknown resistance

The wheatstone bridge circuit is shown in figure. When the switch is closed the current passes through the galvanometer.

The resistances R_1, R_2 and R_3 are so adjusted in such a way that no current flows through galvanometer. Under this condition the following relation is satisfied.

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$



Exercise Problems

13.1	***How many electrons pass through an electric bulb in one minute if the 300 mA current is passing through it?***

Given data:

Time = t = *1 min* = 60 seconds

Current = I = 300 mA = 300×10^{-3} A

Charge on electron = e = 1.6×10^{-19} C

To find:

Number of electrons passing through bulb = n = ?

Calculations:

The total charge 'Q' on 'n' electrons is given by

$$Q = ne$$

or $$n = \frac{Q}{e}$$

As $$I = \frac{Q}{t}$$

So $$n = \frac{It}{e} \quad \text{or} \quad Q = It$$

Putting the values, we get

$$n = \frac{300\times10^{-3}\times60}{1.6\times10^{-19}}$$

$$\boxed{n = 1.125\times10^{20}}$$

13.2 A charge of 90 C passes through a wire in 1 hour and 15 minutes. What is the current in the wire?

Given data:

Electric charge = Q = 90 C

Time = t = 1 hour and 15 minutes = (3600 + 900)sec = 4500 sec

To find:

Electric current = I = ?

Calculations:

Using the relation

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

Putting the values, we get

$$I = \frac{90}{4500} = \frac{1}{50} = 0.02\text{A}$$

or $$I = 0.02\times1000 \text{ mA}$$

or $$\boxed{I = 20 \text{ mA}}$$

13.3 Find the equivalent resistance of the circuit (Fig. P. 13.3), total current drawn from the source and the current through each resistor.

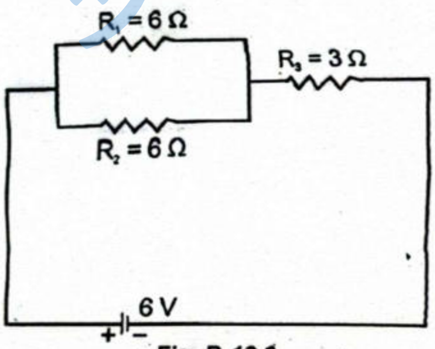


Fig. P. 13.3

Given data:

First resistance $R_1 = 6\Omega$

Second resistance $R_2 = 6\Omega$

Third resistance $R_3 = 3\Omega$

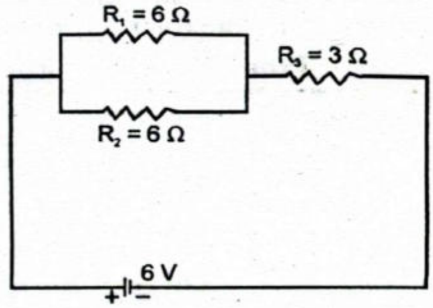
Voltage of battery = V = 6 volts

To find:

(i) Equivalent resistance of circuit = R_e = ?

(ii) Total current drawn from the source = I = ?

(iii) Current flowing through each resistor i.e., I_1, I_2 and I_3 = ?



Calculations:

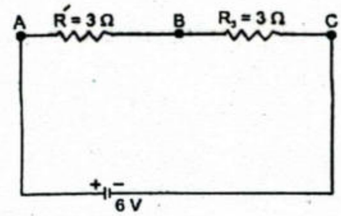
(i) Since R_1 and R_2 are parallel,

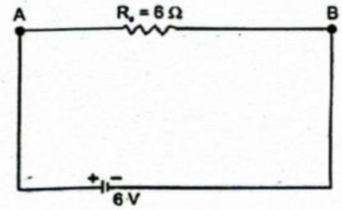
So their equivalent resistance is

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R'} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6} = \frac{1}{3}$$

or $R' = 3\Omega$





Now R_3 and R' are in series, so their equivalent resistance 'R_e' is

$$R_e = R_3 + R'$$

$$R_e = 3 + 3$$

$$\boxed{R_e = 6\Omega}$$

(ii) Total current drawn from the source

$$\text{Total current drawn} = \frac{\text{total voltage}}{\text{total resistance}}$$

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

$$I = \frac{6}{6}$$

$$\boxed{I = 1.0A}$$

(iii) Now current through each resistor:

For calculating current through each register, we first find potential difference across each resistor of circuit.

Potential difference across $R_3 = V_{BC}$

and $V_{BC} = IR_3 = 1 \times 3 = 3V$

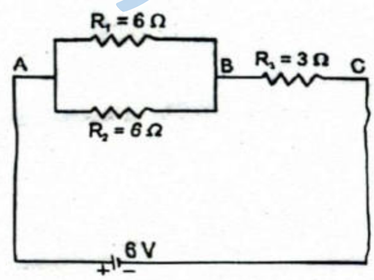
Potential difference across R_1 and R_2 is V_{AB}, Thus

$V_{AB} = V_{AC} - V_{BC} = 6 - 3 = 3V$

Now

$$\text{Current through } R_1 = I_1 = \frac{V_{AB}}{R_1} = \frac{3}{6}$$

$$\boxed{I_1 = 0.5A}$$



$$\text{Current through } R_2 = I_2 = \frac{V_{AB}}{R_2} = \frac{3}{6}$$

$$\boxed{I_2 = 0.5A}$$

$$\text{Current through } R_3 = I_3 = \frac{V_{BC}}{R_3} = \frac{3}{3}$$

$\boxed{I_3 = 1.0A}$ (i.e., total current)

13.4 A rectangular bar of iron is 2.0 cm by 2.0 cm in cross section and 40 cm long. Calculate its resistance if the resistivity of iron is 11×10^{-8} Ωm.

Given data:

Length of iron bar = $L = 40\text{ cm} = 40 \times 10^{-2}$ m

Area of cross-section of bar = $2.0 \times 2.0\text{ cm}^2$

$= 4.0\text{ cm}^2$

Or $A = \dfrac{4.0}{100 \times 100} = 4.0 \times 10^{-4}\text{ m}^2$

Resistivity of bar = $\rho = 11 \times 10^{-8}$ Ωm

To find:

Resistance of bar = R = ?

Calculations:

As $R = \rho \dfrac{L}{A}$

Putting the values, we get

$$R = 11 \times 10^{-8} \times \frac{40 \times 10^{-2}}{4.0 \times 10^{-4}}$$

$$R = \frac{11 \times 40}{4.0} \times 10^{-6} = 110 \times 10^{-6}$$

$$\boxed{R = 1.1 \times 10^{-4}\ \Omega}$$

13.5 *The resistance of an iron wire at 0°C is 1×10^4 Ω. What is the resistance at 500°C if the temperature coefficient of resistance of iron is $5.2 \times 10^{-3}\text{ K}^{-1}$?*

Given data:

Resistance of wire at 0°C = $R_o = 1 \times 10^4$ Ω

Initial temperature = t_1 = 0°C = 0 + 273 = 273 K

Final temperature = t_2 = 500°C = 500 + 273 = 773 K

Change in temperature = $t = t_2 - t_1$ = 773 − 273 = 500 K

Temperature coefficient of resistance = $\alpha = 5.2 \times 10^{-3}\text{ K}^{-1}$

To find:

Resistance at 500°C = R_t = ?

Calculations:

As formula for the temp. coefficient of resistance is

$$\alpha = \frac{R_t - R_o}{R_o \times t}$$

$$\alpha R_o t = R_t - R_o$$

or $R_t = R_o(1 + \alpha t)$

Putting the values, we get

$$R_t = 1 \times 10^4(1 + 5.2 \times 10^{-3} \times 500)$$

$$R_t = 1 \times 10^4(1 + 2.6) = 1 \times 10^4 \times 3.6$$

$$\boxed{R_t = 3.6 \times 10^4\ \Omega}$$

13.6 Calculate terminal potential difference of each of cells in circuit of Fig. P. 13.6.

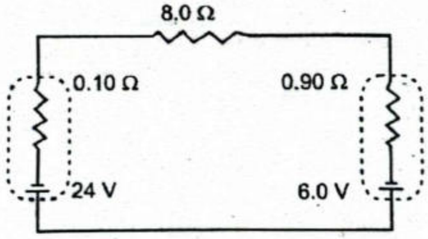


Fig. P. 13.6

Given data:

Potential of cell $E_1 = 24$ V

Resistance of cell $E_1 = r_1 = 0.10\ \Omega$

Potential of cell $E_2 = 6.0$ V

Resistance of cell $E_2 = r_2 = 0.9\ \Omega$

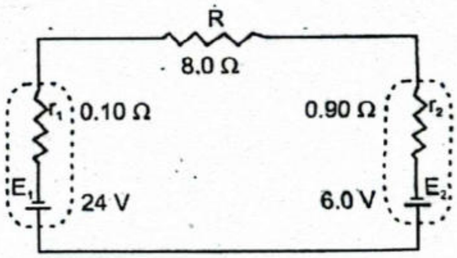
Resistance in circuit = R = 8

To find:

Terminal potential difference of $E_1 = V_{t1} = ?$

Terminal potential difference of $E_2 = V_{t2} = ?$

Calculations:



As r_1, r_2 and R are in series, so their equivalent resistance 'R_e' is

$$R_e = r_1 + r_2 + R$$

$$R_e = 0.10 + 0.90 + 8$$

$$R_e = 9.0\ \Omega$$

As two batteries are opposite to each other, so effective emf (i.e., net voltage) in the circuit is

$$E = E_1 - E_2$$

$$E = 24 - 6 = 18\ V$$

Thus current 'I' in the circuit is

$$I = \frac{E}{R_e} = \frac{18}{9} = 2A$$

Terminal P.D. of cell E_1 is V_{t1} and is given as

$$V_{t1} = E_1 - Ir$$

$$V_{t1} = 24 - 2 \times 0.10 = 24 - 0.20$$

$$\boxed{V_{t1} = 23.8\ V}$$

The current in battery E_2 flows in reverse direction to its conventional current, so it is taken as –ive. Thus terminal P.D. of cell E_2 is

$$V_{t2} = E_2 - (-I)r_2$$

$$V_{t2} = E_2 + Ir_2$$

Putting the values, we get

$$V_{t2} = 6.0 + 2.0 \times 0.9$$

$$V_{t2} = 6.0 + 1.8$$

$$\boxed{V_{t2} = 7.8\ V}$$

13.7 Find the current which flows in all the resistances of the circuit of Fig. P.13.7

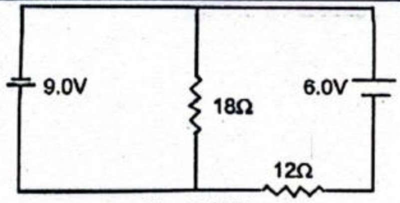
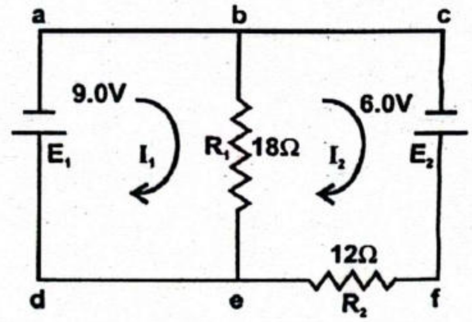


Fig. P. 13.7



Given data:

Voltage of battery $E_1 = 9$ V

Voltage of battery $E_2 = 6$ V

Resistance $R_1 = 18\ \Omega$

Resistance $R_2 = 12\ \Omega$

To find:

Current flowing through resistance $R_1 = I_1 = ?$

Current flowing through resistance $R_2 = I_2 = ?$

Calculations:

Let 'I_1' and 'I_2' be the current flowing through loops "abcda" and "befcb" respectively in clockwise direction.

Applying Kirchhoff's second rule on loop 'abcda'

$$-E_1 - (I_1 - I_2)R_1 = 0$$

Putting the values, we get

$$-9 - (I_1 - I_2)18 = 0$$

$$-(I_1 - I_2)18 = 9 \quad \text{or} \quad (I_1 - I_2) = -\frac{9}{18}$$

or $\quad I_1 - I_2 = -0.5 \quad$ ......(1)

Now applying Kirchhoff's 2nd rule on loop 'befcb'

$$-E_2 - I_2R_2 - (I_2 - I_1)R_1 = 0$$

Putting the values, we get

$$-6 - I_2 \times 12 - (I_2 - I_1)18 = 0$$

$$-6 - 12I_2 - (I_2 - I_1)18 = 0$$

$$-1 - 2I_2 - (I_2 - I_1)3 = 0$$

Dividing throughout by 6, we get

$$-1 - 2I_2 - 3I_2 + 3I_1 = 0$$

$3I_1 - 5I_2 = 1 \quad$ ......(2)

Multiplying eq. (1) by 3 and then subtracting eq. (2) from eq. (1)

$$3I_1 - 3I_2 = -1.5$$

$$3I_1 - 5I_2 = +1$$

$$- \quad + \quad -$$

$$2I_2 = -2.5$$

$$I_2 = -\frac{2.5}{2}$$

$$I_2 = -1.25\text{ A}$$

Where –ve sign *shows* that actual direction of current I_2 is in the anti-clock direction.

Putting the value of 'I_2' in eq. (1), we get

$$I_1 - (-1.25) = -0.5$$

$$I_1 + 1.25 = -0.5$$

$I_1 = -0.5 - 1.25$

$I_1 = -1.75$ A

This current also flows in the anti-clock direction.

Thus,

Current through $R_1 = I_1 - I_2$

$I_1 - I_2 = 1.75 - 1.25$

$\boxed{I_1 - I_2 = 0.5 \text{ A}}$

Current through $R_2 = I_2$

and $\boxed{I_2 = 1.25 \text{ A}}$

13.8 Find the current and power dissipated in each resistance of the circuit, shown in Fig. P. 13.8.

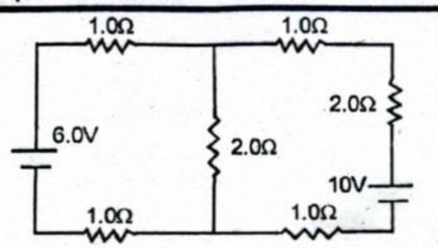


Fig. P. 13.8

Given data:

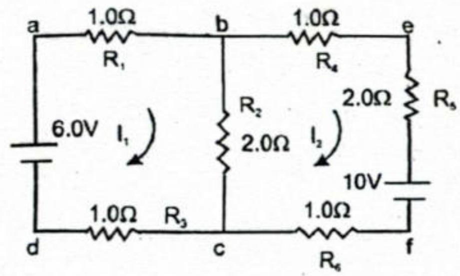
EMF of first cell = $E_1 = 6$ V

EMF of 2nd cell = $E_2 = 10$ V

$R_1 = 1.0\ \Omega$, $R_2 = 2.0\ \Omega$

$R_3 = 1.0\ \Omega$, $R_4 = 1.0\ \Omega$

$R_5 = 2.0\ \Omega$, $R_6 = 1.0\ \Omega$



To find:

(i) Current through each resistance:

$I_1 = ?, I_2 = ?, I_3 = ?$

$I_4 = ?, I_5 = ?, I_6 = ?$

(ii) Power dissipated in $R_1, R_2, R_3, R_4, R_5, R_6$

Calculations:

Suppose I_1 and I_2 are the current flowing through loop 'abcda' and 'befcb' respectively in the clockwise direction as shown in figure.

Now applying Kirchhoff's 2nd rule on loop 'abcda'

$$E_1 - I_1R_1 - (I_1 - I_2)R_2 - I_1R_3 = 0$$

Putting values, we get

$$6 - I_1(1.0) - (I_1 - I_2)(2) - I_1(1.0) = 0$$

$$6 - I_1 - 2I_1 + 2I_2 - I_1 = 0$$

$$6 - 4I_1 + 2I_2 = 0$$

$$3 - 2I_1 + I_2 = 0$$

$$-2I_1 + I_2 = -3 \qquad ......(1)$$

Using Kirchhoff's 2nd rule for the loop 'befcb' we get

$$-E_2 - I_2R_6 - (I_2 - I_1)R_2 - I_2R_4 - I_2R_5 = 0$$

$$-10 - I_2(1.0) - (I_2 - I_1)(2.0) - I_2(1.0) - I_2(2.0) = 0$$

$$-10 - I_2 - 2I_2 + 2I_1 - I_2 - 2I_2 = 0$$
$$-10 - 6I_2 + 2I_1 = 0$$
$$2I_1 - 6I_2 = 10 \qquad \text{......(2)}$$

Adding eq. (1) and (2), we get

$$-2I_1 + I_2 = -3$$
$$+2I_1 - 6I_2 = +10$$
$$-5I_2 = 7$$

or $I_2 = -\frac{7}{5}$

or $\boxed{I_2 = -1.4\ A}$

Putting I_2 in eq. (1), we get

$-2I_1 - 1.4 = -3$ or $-2I_1 = -1.6$

or $\boxed{I_1 = 0.8\ A}$

Negative sign with I_2 shows that current in loop 'befcb' is in anti-clock direction.

(i) Current through each resistance

Current through $R_1 = 0.8$ A

Current through $R_2 = I_1 - I_2 = 0.8 - (-1.4) = 0.8 + 1.4 = 2.2$ A

Current through $R_3 = 0.8$ A

Current through $R_4 = 1.4$ A

Current through $R_5 = 1.4$ A

Current through $R_6 = 1.4$ A

(ii) Power dissipated in each resistance

As formula for power dissipation is $P = I^2R$, thus

Power dissipated in $R_1 = P_1 = I_1^2R_1 = (0.8)^2 \times (1.0) = 0.64$ W

Power dissipated in $R_2 = P_2 = (I_1 + I_2)^2R_2 = (0.8 + 1.4)^2 \times 2 = 9.68$ W

Power dissipated in $R_3 = P_3 = I_1^2R_3 = (0.8)^2 \times (1.0) = 0.64$ W

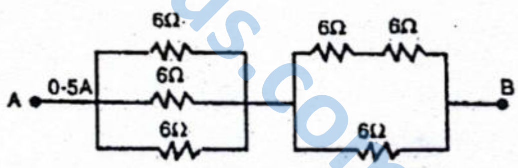
Power dissipated in $R_4 = P_4 = I_2^2R_4 = (1.4)^2 \times (1.0) = 1.96$ W

Power dissipated in $R_5 = P_5 = I_2^2R_5 = (1.4)^2 \times (2.0) = 3.92$ W

Power dissipated in $R_6 = P_6 = I_2^2R_6 = (1.4)^2 \times (1.0) = 1.96$ W

MCQ's From Past Board Papers

1. **Four bulbs of 10W, 20W, 30W and 40W are connected in parallel, the bulb that will shine more is**
   (a) 10W (b) 20W (c) 30W (d) 40W
2. **A current of 10A flows in a conductors of 10 Ω resistance for 1 minute the heat produce will be**
   (a) 10^2 J (b) 6×10^2 J (c) 6×10^3 J (d) 6×10^4 J
3. **Thermisters with high negative temperature coefficient are very accurate for measuring low temperature:**
   (a) 10 K (b) 20 K (c) 30 K (d) 40 K
4. **The temperature of a conductor is increased. The product of resistivity and conductivity**
   (a) increases (b) decreases (c) remains constant (d) may increases or decrease
5. **If wire of resistance 12ohm is bent to form a circle then resistance along any two points on diameter will be**
   (a) 12ohm (b) 6ohm (c) 24ohm (d) 3ohm
6. **Three resistors each of resistance 2ohm are connected to form a triangle then equivalent resistance about any two ens will be**
   (a) 3/4ohm (b) 4/3ohm (c) 4ohm (d) 2/3ohm
7. **If a battery is short circuited then terminal potential difference will be equal to**
   (a) ZERO (b) equal to emf (c) Less than emf (d) greater than emf
8. **A wire of resistance 'R' is stretched till its radius is half of the original value. Then the resistance of stretched wire is**
   (a) 2R (b) 4R (c) 8R (d) 16R
9. **Identify the dimensions of resistance**
   (a) $[ML^2T^{-3}A^{-2}]$ (b) $[ML^{-2}T^{-3}A^{-1}]$ (c) $[ML^2T^2A^{-2}]$ (d) $[ML^1T^2A^{-2}]$
10. **Resistances of 6Ω each are connected in the manner shown in the Fig. The potential difference $V_A - B_B$**
    (a) 7.2 V (b) 3.6 V (c) 6 V (d) 3.0 V



11. **n equal resistors are first connected in series then in parallel, then ratio of their equivalent resistances is**
    (a) n (b) $\frac{1}{n^2}$ (c) n^2 (d) $\frac{1}{n}$

Answers Key

1.	d	2.	d	3.	a	4.	c	5.	d
6.	b	7.	a	8.	d	9.	a	10.	d
11.	c								

IMPORTANT PREVIOUS BOARDS SHORT QUESTIONS

1. Define temperature coefficient of resistance and write its formula. **(Lhr GI 2018)**
2. Write two uses of rheostat and draw their diagrams. **(Lhr GI 2018)**
3. What is meant by tolerance? Find the resistance of a resistor with red, green, orange and gold respective bands. **(Lhr GII 2018)**
4. What are the difficulties in testing whether the filament of a lighted bulb obeys Ohm's law? **(Lhr GII 2018)**
5. Distinguish between resistivity and conductivity. **(Lhr GII 2018)**
6. How many electrons pass through an electric bulb in one minute if the 300 mA current is passing through it? **(Bwp GI 2018)**
7. Explain why the terminal potential difference of a batter decreases when the current drawn from it is increased? **(Bwp GI 2018)**
8. What is Thermistor? Describe its main uses. **(Bwp GI 2018)**
9. Is the filament resistance lower or higher in a 500 W, 220V light bulb then in a 100W, 220V bulb? **(Fsd 2018) (Swl 2018) (Bwp GII 2018)**
10. State Ohm's Law and Basic Principle of Electroplating. **(Bwp GII 2018)**
11. Define resistivity and electrolysis. **(D.G.Khan GI 2018)**
12. Explain why the terminal potential difference of a battery decreases when the current drawn from it is increased? **(D.G.Khan GI 2018)**
13. Do bends in a wire affect its electrical resistance? Explain. **(Grw 2018) (Sgd GI 2018) (Mtn GI 2018) (Mtn GII 2018) (D.G.Khan GI 2018) (D.G.Khan GII 2018)**
14. What is difference between *emf* and terminal potential difference? **(D.G.Khan GII 2018)**
15. Write the name of sources of current. **(Fsd 2018)**
16. A voltmeter cannot read the exact emf of a cell. Why? **(Fsd 2018)**
17. Briefly describe the current through a metallic conductor and drift velocity. **(Grw 2018) (Azad Kashmir 2018)**
18. Define Drift Velocity. What is its value at room temperature? **(Mtn GI 2018)**
19. Find the resistance in a 440 W and 220 V lighted bulb. **(Mtn GI 2018)**
20. What is the resistance of a Carbon resistor if its first band is red, second band is green, third band is orange and fourth band is gold? **(Mtn GII 2018)**
21. Write name of any two effects of current. **(Mtn GII 2018)**
22. Describe a circuit which will give a continuously varying potential. **(Sgd GI 2018) (Sgd GII 2018) (Grw 2018)**
23. Name the device that will (c) permit flow of direct current but oppose the flow of alternating current. **(Sgd GI 2018)**
24. Differentiate between resistance and resistivity, give their units. **(Sgd GII 2018)**
25. What is effect on drift velocity of free electrons by increasing potential difference? **(Swl 2018)**
26. Explain why the terminal potential difference of a battery decreases when the current drawn from it is increased. **(Swl 2018)**
27. Define ohm's law. Also define ohmic and non-ohmic devices. **(Rwp 2018) (Sgd GI 2018)**
28. Why does the resistance of a conductor rise with temperature? **(Sgd GII 2018) (Bwp GII 2018) (D.G.Khan GII 2018) (Rwp 2018)**
29. State Ohm's law with mathematical formula. **(Azad Kashmir 2018)**
30. What is wheat stone bridge? Draw its circuit diagram. **(Azad Kashmir 2018) (Rwp 2018)**
31. What are practical uses of a potentiometer? **(Mtn GI 2018)**
32. Define Volt and Ohm. **(Mtn GI 2018)**
33. Is tungsten filament an Ohmic device? **(Mtn GI 2018)**

IMPORTANT PREVIOUS BOARDS LONG QUESTIONS

Q1. The resistance of an iron wire at 0°C is $1 \times 10^4 \Omega$. What is the resistance at 500°C if the temperature co-efficient of resistance of iron is $5.2 \times 10^{-3} K^{-1}$? **(Lhr GI 2018) (D.G.Khan GI 2018)**

Q2. State Ohm's law and derive its expression. Discuss why filament of a lighted bulb is non-ohmic by graph, Also give any two examples of non-ohmic devices. **(Lhr GII 2018)**

Q3. What is Wheatstone bridge? Describe its construction and how can it be used to measure the unknown resistance? **(Bwp GI 2018) (Sgd GII 2018)**

Q4. What is Wheatstone bridge? Give its principle, construction and working. How it is used to find the unknown low resistance? **(Bwp GII 2018)**

Q5. A rectangular bar of iron is 2cm by 2 cm in cross section and 40 cm long. Calculate its resistance if the resistivity of the iron is 11×10^{-8} Ωm. **(Azad Kashmir 2018) (Rwp 2018)Q6.**

Q8. What is potentiometer? How can it be used as **(Grw 2018) (Fsd 2018)**

(i) Potential divider (ii) Measuring of emf of a cell

Q9. 1.0×10^{7} electrons pass through a conductor in 1μs. Find the current in ampere flowing through the conductor. Electronic charge is 1.6×10^{-19}C. **(Mtn GI 2018)**

Q10. What is Rheostat? How can it be used as a variable resistor as well as potential divider? **(Mtn GII 2018)**

Q12. A platinum wire has resistance of 10Ω at 0°C and 20Ω at 273°C. Find the value of temperature co-efficient of resistance of platinum. **(Swl 2018)**