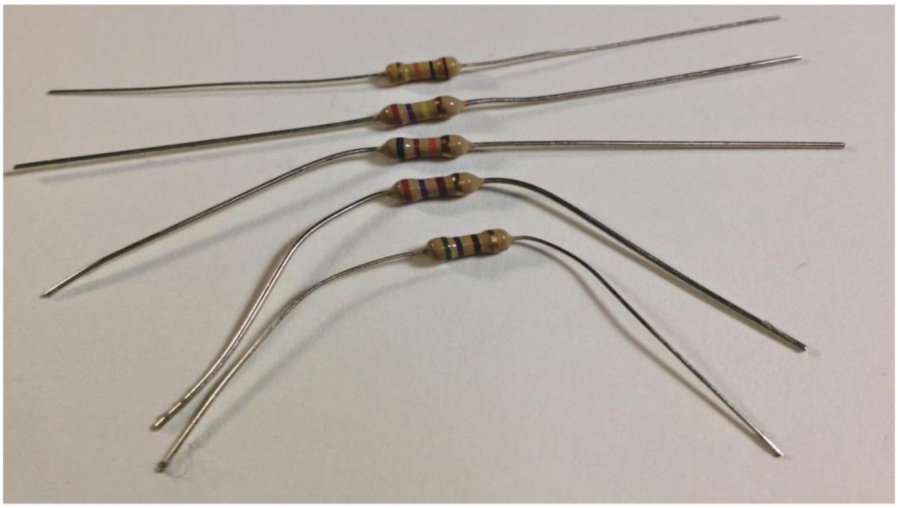
S4 New Curriculum Physics

Theme: Electricity

Chapter 2 – Voltage, resistance and Ohm's Law



RESISTANCE

Resistance is the opposition of a conductor to the flow of current.

A good conductor has low resistance while a good insulator has high resistance.

In general metals such as copper, silver are good conductors so they have low resistance. However, alloys like constantan, nichrome have high resistance. The unit of resistance is **ohm** (**Ω**).

Ohm

Ohm is the resistance of a conductor in which the current is 1A when a potential difference of 1V is applied across its ends.

Ohm's law

Ohm's law state that; the current through a metallic conductor is directly proportional to the potential difference across its ends provided temperature and other physical conditions are kept constant.

OR $V \propto I$

$V = RI$

Where R is the proportionality constant which is the resistance of the conductor.

Example 1

Calculate the resistance of a 240V lamp if the 10A flow through it.

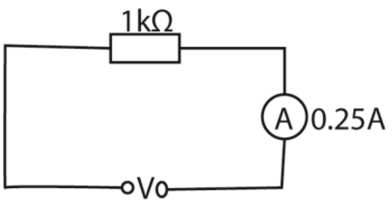
V = 240V I = 10A

V = RI

240=10R

24Ω = R

Trial 1



Find the voltage V in the circuit in the above figure. [250V]

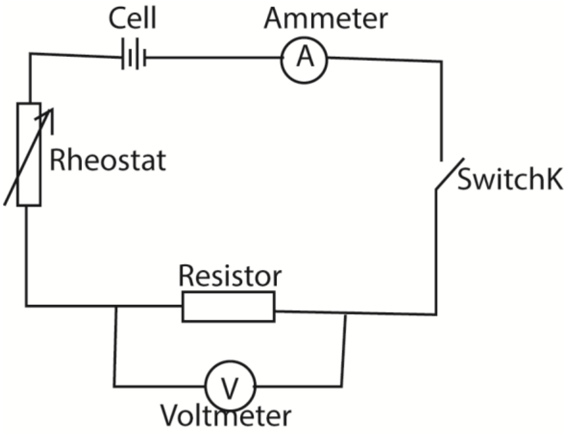
Ohmic conductors

These are substances which obey ohm's law. Ohm's law applies to metals and some alloys like constantan.

Non-ohmic Conductors

These are substances which do not obey ohm's law where by the current is not directly proportional to the potential difference when temperature and other physical conditions are Kept constant.

Experiment to verify ohm's law.

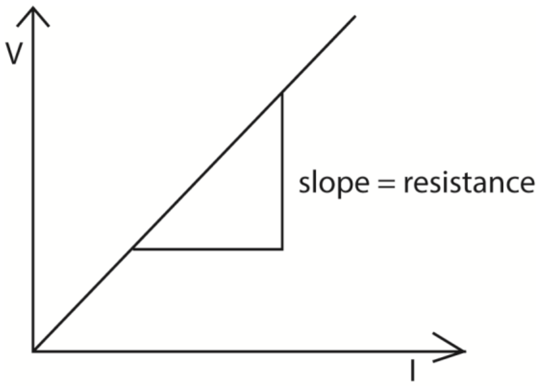


(i) The rheostat is adjusted to the maximum value when the switch **K** is closed. The reading of ammeter "I" and voltmeter "V" are noted and tabulated.

(ii) The setting of the rheostat is gradually reduced and a series of values for V and I are noted and tabulated as below:

V (V)	I (A)

A graph of **V** against current **I** is plotted.



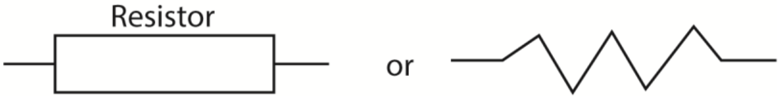
Note

- The above experiment can also be used to describe how potential difference varies with current in a conductor.
- The experiment can be used to describe the determination of the resistance of conductor like lamp, by replacing the resistor with lamp.

Resistor

A resistor is a conductor intended to have resistance.

Circuit symbol for resistor



Factors affecting resistance of a resistor

(a) **Length of conductor:** Increasing length of conductor increases the resistance of a conductor because this would be similar to connecting several resistors in series.

(b) **Cross sectional area:** Increasing the cross sectional area (thickness increase) decreases the resistance of conductor because a larger cross-sectional area provides more pathways for electrons to move, resulting in **fewer collisions between electrons, atoms, and impurities**.

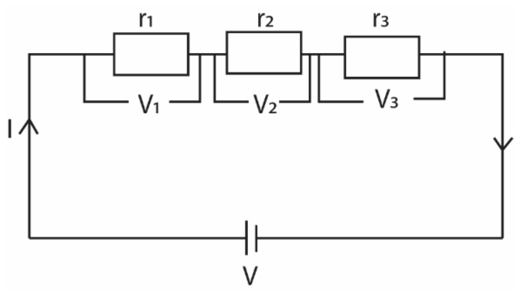
(c) **Temperature**

For pure metals, the resistance is increased when temperature increases because when the temperature of a conductor (like copper or aluminium) goes up, the atoms in its structure start to vibrate more intensely. These vibrations make it harder for free-flowing electrons (which carry electric current) to move through the material smoothly.

For semiconductors and carbon, increasing temperature decreases the resistance due to increase in free conducting electrons.

Resistance in combination

(i) Series combination



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

For r_1, $V_1 = r_1I$ ………………. (i)

For r_2, $V_2 = r_2I$ ………………. (ii)

For r_3, $V_3 = r_3I$ ………………. (iii)

$V = V_1 + V_2 + V_3$

$= r_1I + r_2I + r_3I$

$= I(r_1 + r_2 + r_3)$

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

Hence, the resultant resistance is the sum of resistance of each resistor in the circuit.

Advantages of series arrangement

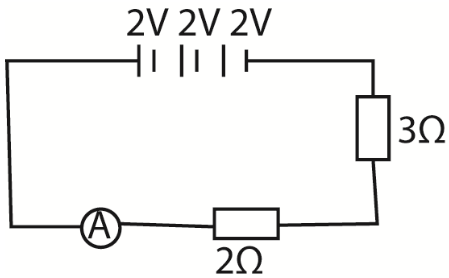
- The main advantage of series arrangement is that a low voltage appliance can be connected to a high voltage supplier because the supplied voltage is shared among loads connected in series.
- All appliances will receive the same current irrespective of value of resistance.

Disadvantage of series arrangement

- A disconnection in any of the appliances causes rest not work.
- If one of the appliances is faulty, all of them have to be checked in order to find the faulty one.
- The effective resistance is greater than that of the smallest resistor.

Example 2

Three cells each of e.m.f 2V and negligible internal resistance are connected to two resistors as shown in the circuit in the figure below.



Find the reading of the ammeter.
Solution

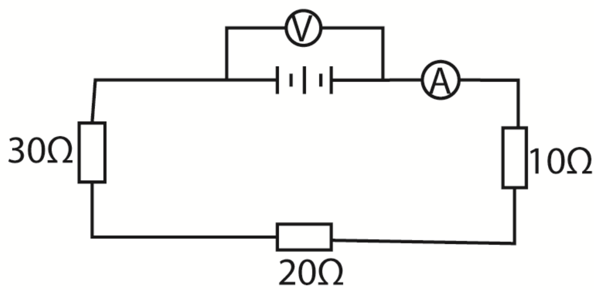
Total p.d = 2 x 3 = 6V

Total resistance = 2 + 3 = 5Ω

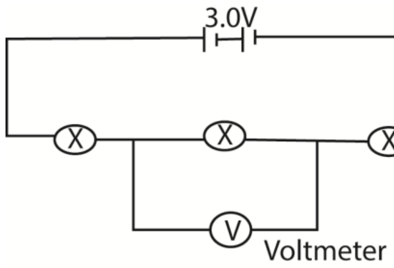
Current = $\frac{V}{R} = \frac{6}{5}$ = 1.2

Trial 2

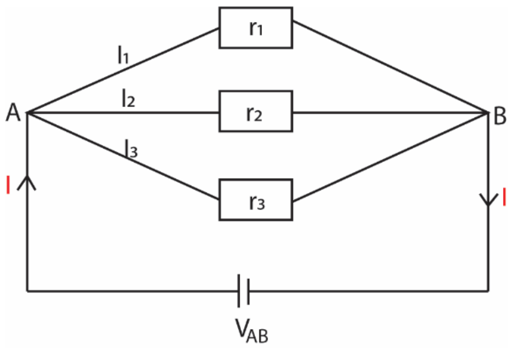
(a) In the circuit diagram in the figure above, the ammeter reading is 0.2A. The reading in volts shown by the voltmeter is [60Ω]



(b) Three identical lamps are connected as shown above. What is the reading on the voltmeter? [1Ω]



(ii) Parallel arrangement



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

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

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

$$\therefore I = \frac{V_{AB}}{r_1} + \frac{V_{AB}}{r_2} + \frac{V_{AB}}{r_3}$$

$$= V_{AB}\left[\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_2}\right]$$

$$\frac{1}{R} = \frac{I}{V_{AB}} = \left[\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_2}\right]$$

Advantages of parallel arrangement of resistors (appliances)

- Each appliance or load operates at the full mains voltage supply. i.e., each appliance operates at a voltage the same as that of the source of electrical energy.
- If one of the appliances has a disconnection the others continue operating normally.
- It is easier to find the faulty appliance as it does not require checking all appliances connected in parallel.
- The effective resistance is less than the resistance of the smallest resistor connected in parallel.

Disadvantages of parallel arrangement of appliances.

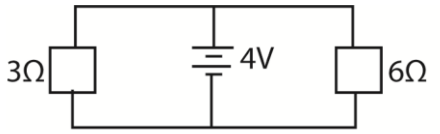
- Low voltage appliances cannot be connected to high voltage supply since appliances in series operates at full mains voltage supply. So supplied voltage is not shared.

Example 3

(a) State ohm's law?

Ohm's law state that; the current through a metallic conductor is directly proportional to the potential difference across its ends provided temperature and other physical conditions are kept constant.

(b) Two resistors of resistances 3Ω and 6Ω are connected across a battery of 4V of negligible internal resistance as shown in the above figure.



Find the

(i) combined resistance

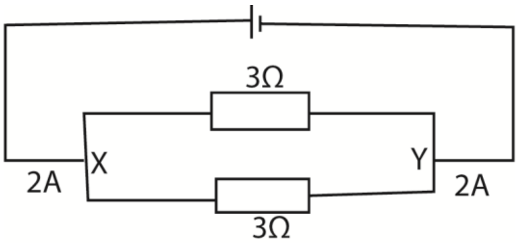
Combined resistance $= \frac{3 \, x \, 6}{3+6} = 2\Omega$

(ii) current supplied by the battery

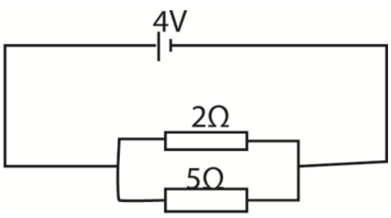
Current $= \frac{V}{R} = \frac{4}{2} = 2A$

Trial 3

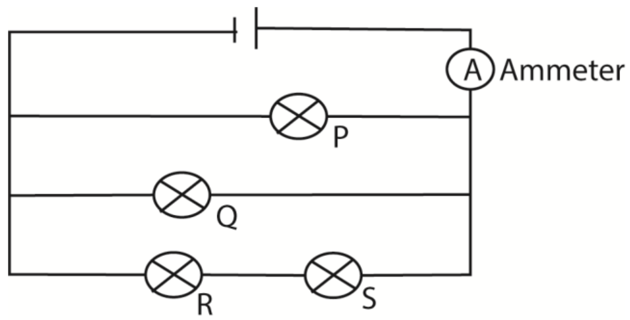
(a) A current of 2A flows in a circuit in which two resistors each of 3Ω, are connected as shown in figure below. Calculate p.d across XY [3V]



(b) Calculate the current in the 2Ω resistor in the circuit in the figure below [2A]



(c) The ammeter in the diagram below indicates the current through



A. lamp P only

B. lamps P and Q

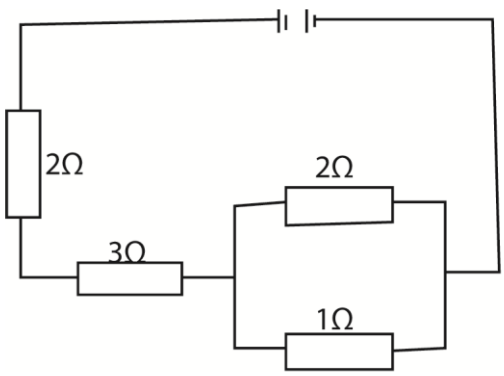
C. lamps Q,R and S

D. lamps P,Q,R and S [D]

Example 4

Calculate the effective resistance of each of the following:

(a)



For parallel part

$\frac{1}{R} = \frac{1}{1} + \frac{1}{2} = \frac{2+1}{2}$

$\frac{1}{R} = \frac{3}{2}$

$\frac{2}{3}\Omega = R$

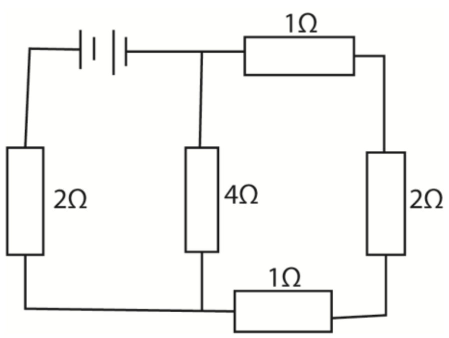
R = 0.67Ω

Effective resistance of circuit

R = 2 + 3 + 0.67

= 5.67**Ω**

(b)



For parallel

Resistors 1Ω, 2Ω, 1Ω, are in series so

$R = 1 + 2 + 1 = 4\Omega$

This is in parallel with other 4Ω resistor

$I/R = ¼ + ¼$

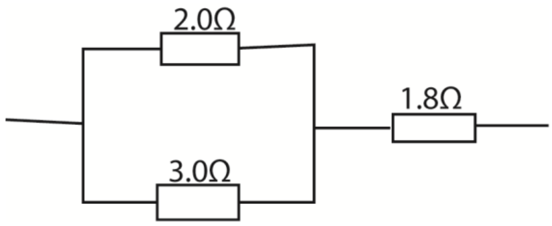
$= \frac{1+1}{4} = \frac{2}{4} = ½$

$R = 2\Omega$

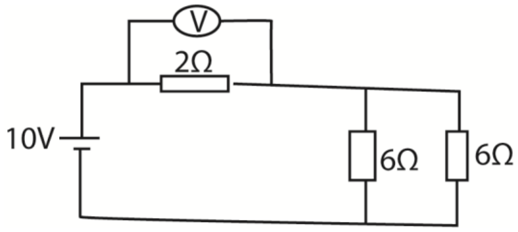
So effective resistance = 2 + 2 = 4Ω

Trial 4

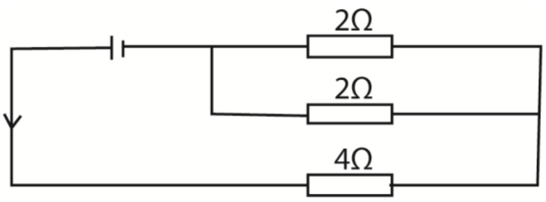
1. Calculate the effective resistance for the arrangement in figure below



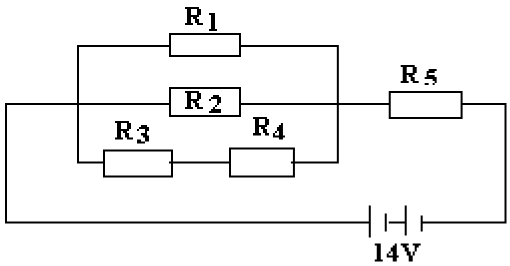
2. What is the reading of voltmeter V in the circuit in the figure below? [4V]



3. The total resistance in the above circuit is



4. A source of e.m.f of 14V is connected as shown in the above figure . If $R_1 = R_2 = R_3 = R_4 = R_5 = 1\Omega$, find

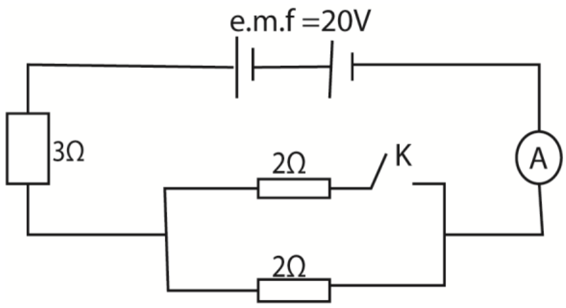


(i) The equivalent resistance of the circuit [1.5Ω]

(ii) the current flowing through R_5. [9.3A]

(ii) The current through R_3 [2.325V]

5. A source of e.m.f. 20V and negligible internal resistance is connected to resistors of 2Ω, 2Ω and 3Ω as shown in figure below



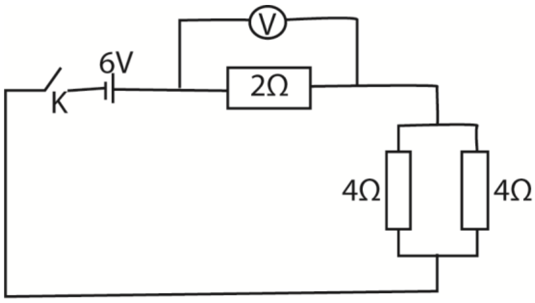
Find the ammeter reading when switch K is

(i) open [4A]

(ii) closed [5A]

6. (a) Define the volt.

(b)



(i) What is the effective resistance in the circuit in the figure. (The cell has negligible resistance. [4Ω]

(ii) What will be the reading of the voltmeter when the key K is closed? [3V]

7. **(a)** Define the ohm as a unit of resistance. *(01 mark)*

(b)

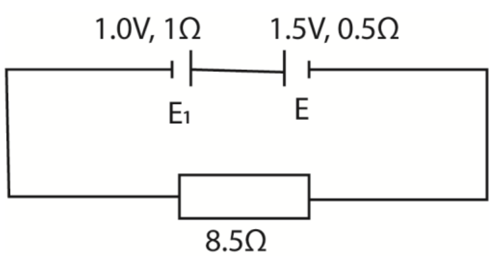
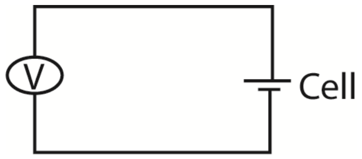


Figure above shows two cells E_1 and E of e.m.f 1.0 V and 1.5 V and internal resistances of 1.0 Q and 0.5 Q respectively connected in series with an 8.5 Q resistor. Calculate the current flowing through the circuit. [0.25A]

Electromotive force

Open circuit

An open circuit is one which is not supplying current to the external load.

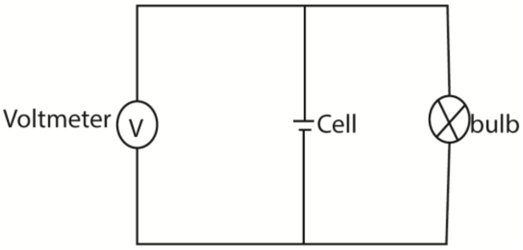


When a circuit is connected to the cells as shown above, **the voltmeter** gives a potential difference called **electromotive force** (emf). It is measured in volts (V).

For instance, if e.m.f of cell is **1.5V**, this means that the energy of **1.5J** is supplied by the source of electrical energy to transfer **1C** of charge round a complete circuit which include source

Closed circuit

A closed circuit is when the cell or source of electrical energy is supplying current through the external circuit as shown below.



In this case, the voltmeter reading is the terminal potential difference or potential difference across a bulb/load.

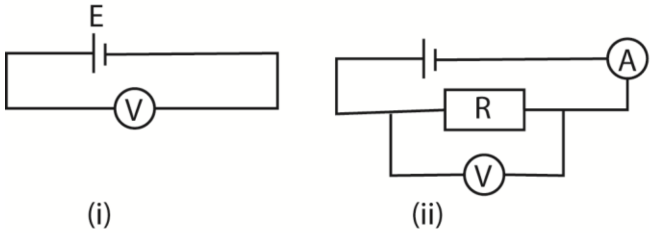
Internal resistance

Internal resistance(r) is the opposition to flow of current inside cell or source of electrical energy.

Note that

- When a cell is connected to a resistor of resistance, R, the total resistance in the circuit is r + R, where r is the internal resistance of the cell.
- If the emf of the cell is E, then E = I(r + R), where I is the current flowing in the circuit.
- If V is the potential difference across the resistor, R, then V = E – Ir.

Experiment to determine internal resistance of a cell



- A voltmeter is connected directly across the terminals of the cell and its reading E is recorded.
- the cell is then connected in series with the ammeter and a resistor of known resistance, R
- The voltmeter V is connected across the resistor and readings I and V from the ammeter and voltmeter respectively are recorded.
- Internal resistance, r = $\frac{E - V}{I}$

Examples 5

A voltmeter reads 3V when connected across the terminals of battery on an open circuit and 2.6V when the battery sends 0.2A through a lamp. Calculate

(i) Electromotive force of the battery

e.m.f = voltmeter reading when circuit is open

= 3.0V

(ii) Terminal p.d = Reading of voltmeter when current is being supplied.

= 2.6V

iii) Internal resistance of the battery

$E = V_T + V_r$

$3.0 = 2.6 + V_r$

$3.0 - 2.6 = 0.4V = V_r$

But $\mathbf{V_r = r\,I}$

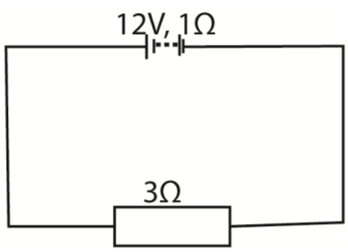
I = 0.2A

0.4 = rx0.2

$\frac{\mathbf{0.4}}{\mathbf{0.2}} = \mathbf{r}$

2Ω = r

Examples 6



Calculate:

(i) current flowing in the circuit

E= 12V, r = 1Ω R = 3 Ω

E= I (R + r)

12 = I(3 +1)

12 = 4I

$\frac{12}{4} = \mathrm{I}$

3A = I

(ii) p.d across 3Ωresistor

R = 3Ω, I = 3A

V = RI

= 3 x 3

= 9V

Trial 5

An ammeter connected in series with a cell and a 2Ω resistor reads 0.5A. When the 2Ω resistor is replaced by a 5Ωresistor, the ammeter reading drops to 0.25A. Calculate

(i) The internal resistance of the cell [1Ω]

(ii) the emf of the cell [1.5V]

Electric power and energy

Power is the rate at which energy is changed from one form to another. So **electric power** is the rate at which electrical energy is changed to other form of energy.

The SI unit of power is watt (W).

A **watt** is the rate of working of $1Js^{-1}$. i.e. $1W = 1Js^{-1}$.

So a lamp with a mark 100W means that 100J of electrical energy changes into heat and light each second.

Electrical Power = $\frac{\text{Electrical energy}}{\text{time taken}}$

$$P = \frac{VIt}{t}$$

P = IV

Units: watts

From ohm's law V = 1R

Then P = IV

I x IR

$P = I^2R$

Also from ohm's I = V/R

P = V/R x V

P = V/R

$P = V^2/R$

Example 7

A device connected to a 12V supply a current of 12A. Calculate

(i) Electrical power consumed by the device

V = 12V , I =12A

P = VI

= 12x 12

=144W

(ii) Energy consumed in 1 hour

t =1h = 60x60s

V=12V I =12A

Energy = VIt

= 12x 12 x 60x60

= 518400J

Example 8

An electrical flat iron is marked 250V, 1000W. Calculate

(i). the current through the electrical flat iron

V = 250V P=1000W

P = VI

1000 = 250 x I

1000/250 = I

4A = I

(iii). its resistance

P = 1000W I = 4A

P = I^2R

1000 = 4 x 4 x R

1000 = 16 R

62.5Ω

Trial 7

1. An electrical appliance is rated 240V 60W
   (a) What do you understand by this statement?
       When connected to 240V, the appliance dissipates $60Js^{-}1$
   (b) Calculate the current flowing through and the resistance of the appliance when the appliance is operated at the rated values [0.25A]

Commercial unit of electricity

The commercial unit of electrical energy is **kilowatt hour (kWh)**

A kilowatt hour is the electrical energy used by a 1000W appliance in 1 hour.

Relationship between kWh and joule (J)

1kWh = 1000W x 1h

= **$1000Js^{-1}$x 60 x 60s (since 1000W = $1000Js^{-1}$ and 1h = 60 x 60s)**

= 3,600,000J = 3.6×10^6J

When calculating the total cost of electricity the following should be noted:

(i) Total power consumed should be expressed in kiloWatt (kW)

(ii) Total time taken should be expressed in hours

(iii) Then

Total cost = Total power (P) in **kW** x Time in **hours** (t) x Cost per unit

Note: Kilowatt hour is usually called unit.

Example 9

Calculate the cost of running four 60W lamps and five 100W lamps for 5 hours if electrical energy costs 10/= per unit.

Total power = 4 x 60 + 5 x 100= 240 +500 =740W

For commercial

Total power in kW = $\frac{740}{1000}$ **kW**

Total time = 5 hours

Cost per unit = 10 /=

Total Cost = $\frac{740}{1000}$ X 5 x10

=37/=

Note; An electric lamp marked240V; 60W means that when the lamp is connected to a 240V supply, it dissipates energy at the rate of $60Js^{-1}$

Example 10

A lamp of 100W is run for 5 hours on 250V mains. Find (a) current taken from the mains

V = 250V, Power = 100w

Watt = Volt x Ampere

100 = 250 x Ampere

$\frac{100}{250}$ = Ampere

Amp = 0.4A is the current taken.

(b). resistance of the lamp filament

Power = 1^2R

100 = 0.4x 0.4xR

100 = 0.16 xR

$\frac{100}{0.16}$ = R

625Ω = R

(c) Energy dissipated in 5 hours

Energy = VIt

V =250V I = 0.4A t = 35 x 3600s

Energy = 250 x 0.4 x 5 x 3600

= $l.8x10^6$J

(d) Cost of the energy consumed if the cost per unit is 60/=

Total power = 100W

For commercial

Total power = 100W =$\frac{100}{1000}$ =0.1kW

Total time = 5 hours

Cost = 0.1 x 5 x 60

= 30/=

Trial 8

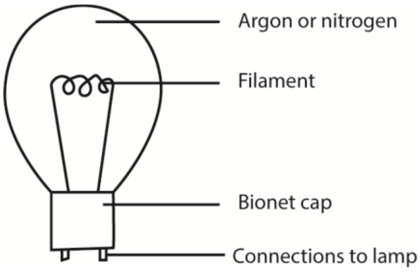
1. A 2kW electric heater is used for 10 hours each week and a 100 W lamp is used for 10 hours each day. Find
   (i) the total energy consumed each week. [27kWh]
   (ii) total cost for each week if each unit cost sh100 [2700/=]

2. A house contains the following appliances; 2.0kW electric kettle, 30W DVD player, five 75W bulbs, two 100W bulbs and 3.5kW fridge. If the fridge is used for 5h , kettle for 45minutes , 100W bulb for 10h , 75W bulb for 10h and DVD player for 5h calculate the ;
   (i) Total electrical energy consumed in a day. [24.9kWh]
   (ii) Cost of electricity used in a month of 30 days. If the cost per unit is sh.400 [298,800/=]

Filament lamp

Filament is a small coil of tungsten wire which becomes white hot when current flows through it. The greater the potential difference across, the greater the rate at which electrical energy is changed into heat and light.

Tungsten metal is commonly used for making filaments for bulbs because tungsten has a very high melting point that can withstand too much heat dissipated by high resistance of the filament. Glass bulb Argon or nitrogen filament bayonet cap connections to lamp.



Filament lamp contains nitrogen or argon gas not air to reduce evaporation of tungsten which would otherwise condense on the bulb and blacken it. The coiled coil, being compact, is cooled less by convection currents in the gas.

Fluorescent lamp

Structure

A Fluorescent tube is made of a glass tube containing mercury vapour. The inside part is coated with a fluorescent powder. The tube has electrodes at either end.

Action

When the fluorescent tube is switched on, the current from the electrodes causes the mercury vapour to emit ultraviolet radiation. This ultraviolet radiation causes the powder to fluoresce

Advantages of a fluorescent lamp over a filament lamp:

(i) Fluorescent lamp do not heat up unlike the filament lamp for which 90% of the electrical energy supplied becomes heat and only 10% becomes light.

(ii) Fluorescent lamp is five times efficient compared to filament lamp.

(iii) Fluorescent lamp lasts 3000h compared with 1000h life of filament lamp.

(iv) Though costs more to install but the running cost are much less for fluorescent lamp compared with filament lamp

Electric heating

Heating elements are made from nichrome wire which is an alloy of nickel and chromium because nichrome is not oxidized when current heats it red hot.

Sources of electromotive force (e.m.f)

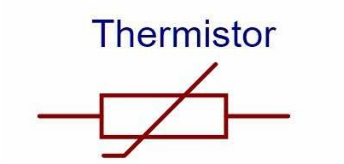
i) Cells
ii) Accumulators
iii) Ac and d.c generators
iv) Thermo couples
v) Photo cell

Thermistors

Thermistors is a heat sensitive device whose resistance changes very rapidly with temperature.

- **NTC (Negative Temperature Coefficient)** thermistors: Their resistance *decreases* as temperature increases. These are commonly used in temperature sensing and control applications.
- **PTC (Positive Temperature Coefficient)** thermistors: Their resistance *increases* with rising temperature. These are often used for overcurrent protection or self-regulating heating elements

Symbol of a thermistor



Uses of thermistors

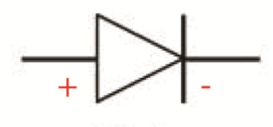
- Thermistors are used in**Digital thermometers** and thermostats for precise temperature readings
- They are uses to monitor temperature in electric vehicles.

- They are used in refrigerators, microwaves and air conditioners to regulate temperature
- They protect rechargeable batteries by preventing overheating during charging

Diodes

Diode is an electronic component which can allow electric current to flow through it in one direction.

Symbol of diode



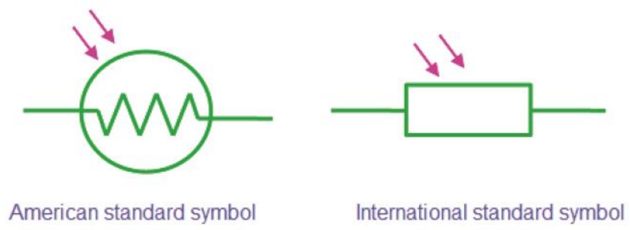
Uses of diodes

- Diodes convert alternating current (AC) to direct current (DC), which is essential for powering most electronic devices such as power adapters, battery chargers, DC power suppliers.
- Zener diodes are used to maintain a constant voltage level, protecting sensitive components from voltage spikes.
- In digital circuits, diodes help build logic gates and control signal flow.
- They're also used in Relay protection and Logic level shifting
- In radios and TVs, diodes help extract audio or video signals from modulated carrier waves — basically turning radio waves into sound or images.

Light dependent Resistors (LGR) or Photo-resistors

It is an electronic component whose resistance depends on the intensity of incident light on it.

Symbol of photo-resistor



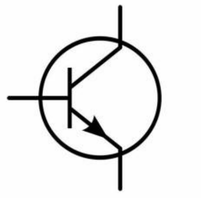
Uses of photo-resistors

- Used in **automatic Lighting** such as streetlights that turn on at dusk and off at dawn
- Used in **cameras** to measure light levels and adjust exposure
- Used in **security Systems** to detect changes in light when someone passes by, triggering alarms or cameras
- **Smartphones and tablets** use them to adjust screen brightness automatically

- In **Solar Trackers** help solar panels follow the sun by detecting its position throughout the day.

Transistors

A transistor is a semi-conductor device with three terminals, capable of amplification and rectification. Amplification is the process of transforming weak currents (signals) into strong ones while rectification is the process of converting an alternating current or voltage into the direct current or voltage.



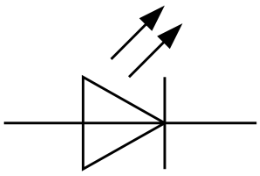
Uses of thermistors

- **Digital Thermometers and Thermostats:** They're the core sensing element in devices that measure or regulate temperature — from medical thermometers to smart home thermostats.
- **Automotive Systems:** Thermistors monitor engine coolant and oil temperatures, helping optimize performance and prevent overheating in cars and trucks.
- **Microwaves** to prevent overheating
- **Refrigerators** for defrost control
- **Ovens and washing machines** to regulate internal temperatures
- They ensure rechargeable batteries (like in laptops or EVs) don't overheat during charging or discharging — crucial for safety and longevity.

Light Emitting diode (LED)

It is an electronic component that emits light when an electric current flows through it.

Symbol for LED

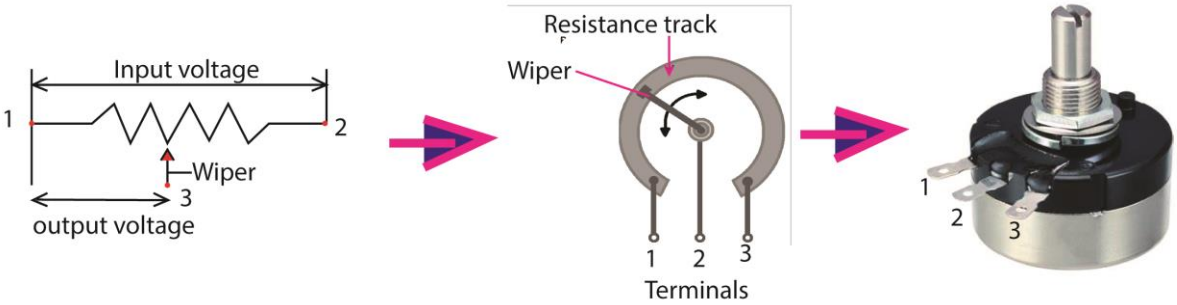


Uses of LED

- They are durable source of light
- They are used in displays and Screens such as TV, Monitors and smartphones
- **Power indicators** on electronics (like your laptop or charger).
- **Traffic lights and pedestrian signals**: Quick response and high visibility.
- **Automotive lighting**: Brake lights, turn signals, and interior lighting.

Potentiometer

A potentiometer is a **three-terminal variable resistor** that lets you adjust voltage or resistance in a circuit — kind of like a volume knob for electricity.



How It Works

Inside, it has a resistive track and a movable contact called a *wiper*. When you turn or slide the knob, the wiper moves along the track, changing the resistance between the terminals.

Types of Potentiometers

- **Rotary**: You twist a knob to adjust (like on a stereo).
- **Linear (slider)**: You slide a lever up or down.
- **Digital**: Controlled electronically, often used in modern devices.

Common Uses

- **Volume controls** in audio equipment
- **Brightness or contrast** adjustments in displays
- **Position sensors** in joysticks or servos
- **Tuning circuits** in radios
- **Calibration tools** in lab instruments

Revision Questions

1. A 240 V, 600W water heater is used to boil water for 5 min.
   (a) By what means does heat spread through the water?

   (b) Calculate

      (i) The current that flows in the heater.

      Current = $\frac{P}{V} = \frac{600}{240}$ = 2.5A

      (ii) The electrical energy converted into heat.

      Energy = power x time = 600 x 5 x 60 = 180kJ

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Thanks

Dr. Bbosa Science