6. ELECTRICITY

ELECTRIC CELLS / BATTERIES

A cell is a device which directly changes chemical energy to electrical energy.

Types of electric cells

a) Primary cells, these are cells which cannot be recharged and their chemical reaction which produces electrical energy cannot be reversed e.g the simple cells, dry cells

b) Secondary cells, these are cells that can be recharged and the chemical reaction that produces electricity can be reversed by passing the current thru the opposite direction.

(a) Primary cells

These are cells which produce electricity from an irreversible chemical reaction.

They cannot be recharged by passing a current through them from another source and their chemical reaction which produces electrical energy cannot be reversed

Examples of primary cells;

(i) Simple cells (Voltaic cells)

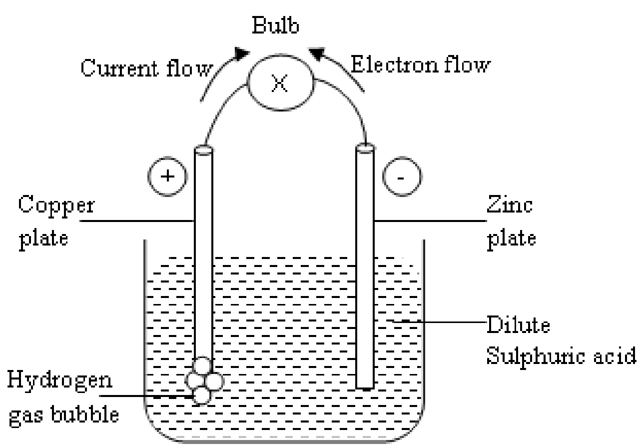
(ii) Leclanche' cell (Dry cell and Wet cell)

(i) Simple cells (Voltaic cells)

A simple cell is made up of two electrodes and an electrolyte. A more reactive metal becomes the cathode while the less reactive metal becomes the anode.

It commonly consists of a copper rod (Positive electrode) and the zinc rod (Negative electrode) dipped into dilute sulphuric acid (Electrolyte). The electrodes are connected by pieces of conducting wires.

In a simple cell, the cathode is Zn, the Anode is copper and the electrolyte is dilute H_2SO_4.



Mechanism of the simple cells

A simple cell gets its energy from the chemical reaction between Zn and H_2SO_4 (aq) i.e.

$$\mathbf{Zn\ (s) + H_2SO_4\ (aq) \longrightarrow ZnSO_4\ (aq) + H_2}$$

Electrons flow the negative plate zinc to the positive plate copper while current flows from the positive to negative plate.

At the cathode

When the circuit is complete, the zinc rod slowly dissolves and goes into electrolyte as zinc ionsZn^{2+}, according to the equation;

$$\mathbf{Zn}\ (s) \rightarrow \mathbf{Zn^{2+}(aq) + 2\bar{e}}$$

At the anode

The electrons travel through the external circuit and arrive at the copper electrode, where they are picked up by the hydrogen ions from the acid to form hydrogen gas according to the equation:

$$\mathbf{2H^+(aq) + 2\bar{e} \rightarrow H_2(g)}$$

- ❖ Thus bubbles of a colorless gas are seen at the copper plate.
- ❖ The reaction generates an electric current.

DEFECTS OF A SIMPLE CELL

Defect	How to minimize
1. Polarization: This is the formation of hydrogen bubbles on the copper plate. The hydrogen given off insulates the anode from the electrolyte. This reduces the voltage of the cell.	-Use of a depolarizing agent like potassium dichromate,(K_2,Cr_2O_7) or manganese dioxide (MnO_4), which oxides hydrogen to form water. -Brushing the copper plate occasionally.
2. Local action: This is due to some reaction between the impurities in Zinc and the acid resulting into the formation of hydrogen bubbles on the zinc plate. The hydrogen bubbles insulate zinc from the electrolyte.	-Rubbing clean Zinc with mercury (amalgamating zinc).This prevents contact of the impurities with the electrolyte) -Cleaning Zinc with conc. H_2SO_4.

NOTE: A simple cell stops working after a short time because of polarization and local action.

(ii) Leclanche' cells

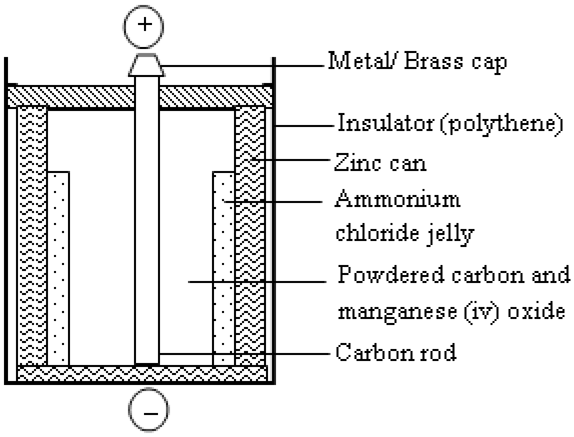
- ❖ Dry Leclanche' cell (Portable, electrolyte cant pour out, faster depolarizing action & can maintain high steady current for some period of time)

- ❖ Wet Leclanche' cell (Bulky and electrolyte can easily pour out, slow depolarizing action & cannot maintain high steady current which lights).

Here polarization and local action are avoided

- Manganese (iv) oxide is in place to act as a depolarizing agent to oxidize hydrogen to water. Thus preventing polarization.
- The carbon powder reduces the internal resistance of the cell and increases the conducting surface area.

❖ **Dry Leclanche' cell**



Carbon is the anode and Zinc is the cathode. The electrolyte is ammonium chloride jelly. The chemical reaction between zinc and ammonium chloride is the source of electrical energy is a dry cell and therefore e.m.f is up.

$Zn (s) + 2NH_4Cl (aq) \longrightarrow ZnCl_2 + 2NH_3 + H_2 (g)$

The e.m.f produced goes on to fall due to polarization and local action. These are the defects of a dry cell.

Polarization
The formation of Hydrogen bubbles at the carbon rod.
Its prevention
The manganese IV oxide around the carbon rod acts as a depolarizing agent which oxides hydrogen to water.

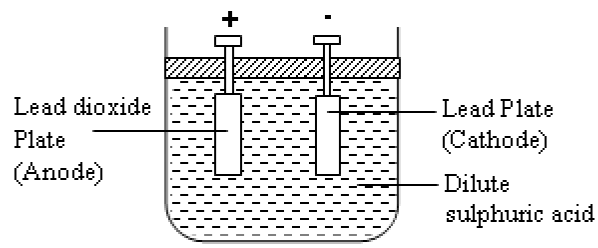
Note: Even if the cell is not working (giving out e.m.f) e.m.f reduces because of local action.

(b) Secondary cells (Accumulators) (or storage cells)
Secondary cells are cells that can't be recharged by passing a current through them from another source once they stop working or reduce on the amount of current being supplied.
Current is produced as a result of a reversible chemical change taking place within the cell.

Use of accumulators
-To start (ignition) of a cars and other locomotives and to provide light to motor cars.
-Used in factories to run machines

Examples of secondary cells (Accumulators)
There are two types of accumulators.
(i) Lead acid accumulator
(ii) Alkaline accumulator (e.g Nickel – cadmium cell; **NiCd** cell, Nickel – iron cell **; NiFe** cell)

(i) Lead acid accumulators
A Lead acid storage battery consists of cells connected in series. Each cell consists of a **lead plate** (negative electrode), **lead dioxide** (or lead (iv) oxide) (positive electrode), and **dilute sulphuric acid** as the electrolyte.
When the accumulator is fully charged, the **relative density of the acid** is about **1.25** and the e.m.f of each pair is **2.2V.**



The cathode is lead, the anode is lead dioxide and the electrolyte is dilute sulphuric acid.
When it is working both electrodes gradually change to lead sulphate while the acid becomes more dilute and its relative density decreases.

Mechanism of an accumulator.
When in use, the negative lead electrode dissociates into free electrons and positive lead (ii) ions.

$$\mathbf{Pb}\ (\boldsymbol{s}) \quad \rightarrow \quad \mathbf{Pb^{2+}(aq)} + \mathbf{2\bar{e}}$$

The electrons travel through the external circuit while the lead (ii) ions combine with the sulphate ions in the electrolyte to form lead (ii) sulphate.

$$\mathbf{Pb^{2+}(aq)} + \mathbf{SO_4{}^{2+}(aq)} \quad \rightarrow \quad \mathbf{PbSO_4(aq)}$$

When the electrons re-enter the cell at the positive lead dioxide electrode, a chemical reaction occurs. The lead dioxide combines with the hydrogen ions in the electrolyte and the electrons to form water, releasing lead (ii) ions into the electrolyte to form additional lead (ii) sulphate.

$$\mathbf{PbO}\ (\boldsymbol{s}) + \mathbf{2\ H^{+}(aq)} + \mathbf{2\bar{e}} \quad \rightarrow \quad \mathbf{H_2O}(\boldsymbol{l}) + \mathbf{Pb^{2+}(aq)}$$

Care and maintenance of lead –acid accumulator

Dos	DONTs
(i) The battery should be charged regularly. (ii) The liquid level should be maintained using distilled water to ensure that electrodes are nor exposed. (iii) Cells should be charged if the R.D. reduces to 1.18 R.D. can be checked using a hydrometer. -	(iv) Cells should not be left uncharged for a long time. (v) When charging, avoid nearby flames because O_2 and H_2 are given off during the process i.e. O_2 is from Anode and H_2 from cathode. (vi) Avoid shortening the terminal i.e. you should not connect the terminals with a low resistance wire or metal because when shortened too much current is taken away from the cell. (vii) Avoid overcharging and over discharging.

(ii) Alkaline cells

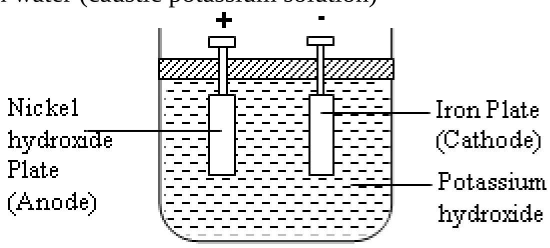
❖ **Nickel – cadmium (NiCd cells)**

Anode is the Nickel –hydroxide and cathode is cadmium

❖ **Nickel – Iron (NiFe Cells)**

Anode is Nickel hydroxide and cathode is iron.

In both cases, the electrolyte is potassium hydroxide dissolved in water (caustic potassium solution)



Uses

- Used in battery driven vehicles
- Used for emergency lighting

Advantages of alkaline cells over Lead-acid cells or accumulators

Alkaline Accumulators	Lead-acid accumulators
(i) Require no special maintenance.	(i) Require special maintenance
(ii) May be left uncharged for a long time without being damaged. They can be out of use for a long time	(ii) They get damaged if left un charged for a long time.
(iii) Are less heavy.	(iii) Are heavy.
(iv) Are long lasting.	(iv) Are not long lasting.
(v) They provide large currents without being damaged.	(v) They provide low currents.
(vi) Are suitable for supplying steady current for a long time.	
(vii) Can with stand over charging.	Can be damaged by over charging.

Disadvantages of the alkaline cells over the lead acid cells.

❖ Alkaline cells are expensive compared to lead acid cells.

❖ Alkaline cells have a low e.m.f and a higher internal resistance.

❖ Cadmium compounds are poisonous

❖ They do not properly store charge.

Capacity of an accumulator

This is the amount of electricity which an accumulator can store. It's measured in ampere hours (Ah)

$\textbf{Capacity} = \textbf{current (A) x time (h)}$

$\textbf{Capacity} = \textbf{It}$

Example:

How long wills a cell marked 80Ah supply a current of 4.5A before it is exhausted.

Solution:

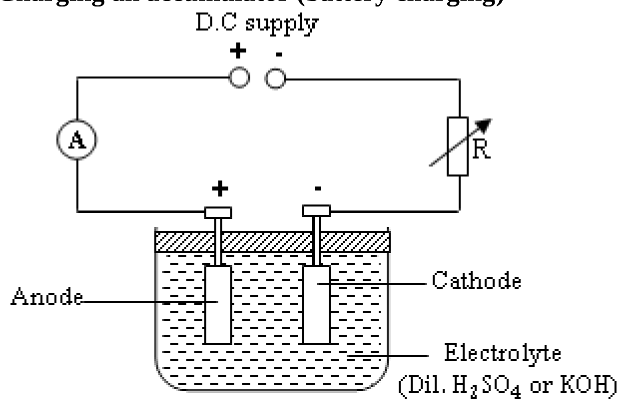
$\text{Capacity} = \text{current (A) x time (h)}$

$\text{Capacity} = \text{It}$

$80 = 4.5 \times t$

$t = 17.8 \text{ Hours}$

Charging an accumulator (battery charging)



An accumulator is recharged by passing a current through it from a D.C supply in the opposite direction to the current it supplies.

Positive of the D.C. supply is connected to the positive of the accumulator while negative terminal of the D.C. supply is connected to the negative of the accumulator.

The acid becomes more concentrated during charging and R.D. of the acid increases.

The Rheostat varies resistance to make the current adjustable.

The ammeter measures the charging current which becomes low as the accumulator is charged and restored to usable condition. This is due to the rise in the e.m.f of the accumulators.

When chemicals have been restored to their original condition, hydrogen gas is given off (gassing process) and the cell is said to be fully charged.

Note;

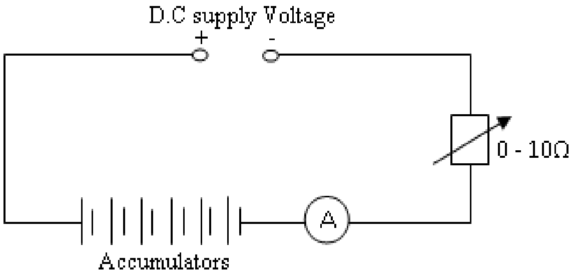
❖ When an accumulator (battery) is being charged, electrical energy charges to chemical energy.

❖ When a battery (an accumulator) is being used (supplying current), chemical energy changes to electrical energy.

❖ Direct current is used during the charging process because alternating current would charge the accumulator in the first half cycle and then discharge it in the next half cycle.

Question:

Six accumulators each of e.m.f 2V and each of internal as shown below;



(i) Explain why its necessary to include a rheostat in the circuit.

(ii) Explain why direct current is used in the charging process.

(iii) What will the ammeter read if the Rheostat is set at 5.4Ω. (I = 2A)

(iv) Find the rate at which electrical energy is converted to chemical energy in (ii) above. (P = 2 4W).

Differences between primary cells and secondary cells.

Primary Cell	Secondary Cell
-Cannot be recharged once it stops working -Current is produced as a result of irreversible chemical change. -Provide a lower e.m.f -Works for a shorter time -Higher internal resistance	-Can be recharged when they stop working. -Current is produced as a result of reversible chemical change. -Provide a higher e.m.f -Works for a longer time. -Lowe internal resistance

Exercise:

1.

1995 Q.28	1998 Q.33	1998 Q.39	2002 Q.15

2. Which of the following statement(s) is or are true?
   (i) Regular charging
   (ii) Maintaining the level of acid by topping it up with distilled water.
   (iii) Avoid over discharging
   (iv) Avoid shorting the terminals.

A: (i), (ii) and (iii) only. B: (i) and (iii) only.
C: (i), (iii) and (iv) only. D: all

3. 1993 Qn.6

(a) (i) Draw a diagram to show the structure of a simple cell.
(ii) Give one defect of a simple cell and state how it is minimized.

(b) Explain how a lead acid accumulator can be recharged when it has run down.

4. 1994 Qn.4

(a) List four different sources of e.m.f

(b) State two advantages of a secondary cell over a primary cell.

5. 1995 Qn.6

(a) Explain why a current does not flow between the electrodes in dilute sulphuric acid until a certain value of p.d is exceeded.

6. 1996 Qn.10

(a) State two advantages of nickel iron accumulator over a lead acid accumulator.

(b) Name the gases evolved during the charging of the lead acid accumulator.

(c) Why a dry cell is called a primary cell?

ELECTRICITY

Electricity is the flow of charged particles such as electrons and ions.
Electricity has various forms which include static electricity and current electricity. Static electricity is discussed in Electrostatics and current electricity will be discussed majorly now.

Electric current is the rate of flow of charge. OR It is the rate of flow of electrically charged particles.

Steady current is the constant rate of flow of charge.
It's measured in **amperes** represented by A. 1 A = 1 CS^{-1}.
An ampere is a current when the rate of flow of charge is one coulomb per second.
Qn. What type of quantity is current?

Source of electric energy
It has various sources which include among others;-

(i) Chemical energy. Its also known as potential or stored energy and releasing. It always requires combustion of burning of coal, natural gas etc.

(ii) Thermal energy. Heat means thermo/ it can produce electrical energy when /after combustion of fossil fuels and biomass.

(iii) Kinetic energy. This is energy in motion e.g. moving water, moving wind etc as they turn the turbines.

(iv) Nuclear energy. Its energy in the bonds inside atoms and molecules during its release it can emit radioactive and thermal energy as well. Its normally produced in nuclear reactors

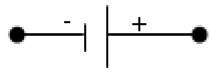
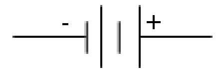
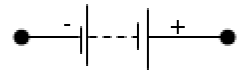
(v) Solar energy. This is energy from the sun which can be captured by photovoltaic cells and then a source of electrical energy.

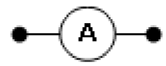
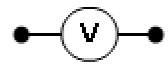
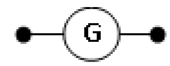
There could be other sources of energy but generally, the above are the major sources.

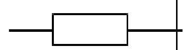
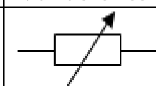
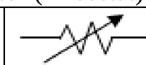
Common electrical /appliances we use in Uganda include.
- Electrical lamps
- Electric kettles
- Electric plates (cookers)
- Electric flat irons

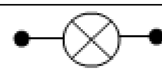
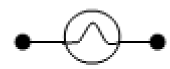
N.B. Electrical appliances can be defined as devices used to simplify worker but use electricity as a form of energy.

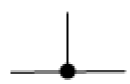
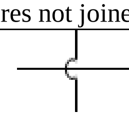
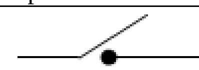
Electric circuits and symbols
Symbols
Electric symbols are symbols used in electricity during the circuits to draw them schematically and represent electrical and electronic components.
They include;

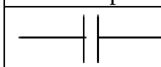
D.C source		**A.C source**
A cell	Battery	Alternating current (a.c)
	 or 	 or 

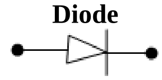
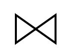
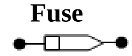
Meters		
Ammeter	Voltmeter	Galvanometer
		

Resistors			
Fixed resistor		Variable resistor (Rheostat)	
			

Bulb or Lamp	
	

Wires		
Connected wires	Wires not joined	Open switch
		

Capacitors			
Fixed capacitor		Variable capacitor	
			

Others	
Diode	**Fuse**
	 or 

There are very many symbols but these are the mostly used electrical symbols.

Terms used;
(i) Charge, Q; Is the quantity of electricity that passes a given point in a conductor at a given time.
The S.I unit of charge is a coulomb. **A coulomb** is the quantity of electric charge that passes a given point in a conductor when a steady current of 1A flows in one second.

(ii) Current, (I); Is the rate of flow of charge. i.e. $I = \frac{Q}{t}$.
The S.I unit of current is an **ampere**. An ampere is a current flowing in a circuit when a charge of one coulomb passes any point in the circuit in one second.
$\mathbf{1A = 1Cs^{-1}}$

Example 1: UNEB 2008 Qn.32
A current of 6A amperes flows for two hours in a circuit. Calculate the quantity of electricity that flows in this time.
Solution:

Given: $I = 6A, t = 2hrs$ $= 2 \times 60 \times 60 = 7200s.$ $Q = ?$	$\mathbf{Q = It}$ $Q = 6 \times 7200$ $Q = 43200\ C$

Example 2: UNEB 2007 Qn.48 (b)
A charge of 180C flows through a lamp for two minutes. Find the electric current flowing through the lamp.
Solution:

Given: $Q = 180\ C, t = 2minutes$ $= 2 \times 60 = 120s.$ $Q = ?$	$\mathbf{Q = It}$ $180 = I \times 120$ $I = 1.5\ C$

(iii) Potential difference (P.d); Is the work done in transferring one coulomb of charge from one point to another in a circuit.
Whenever current flows, it does so because the electric potential at two points are different. If the two points are at the same potential, no current flows between them. $P.d = \frac{W}{Q}$
The S.I unit is a volt. A **volt** is the potential difference between two points in circuit in which, 1J of work is done in transferring 1C of charge from one point to another.
$\mathbf{1V = 1JC^{-1}}$

(iv) Electromotive force, (e.m.f): Is the work done in transferring one coulomb of charge around a complete circuit in which a battery is connected.
It is the p.d across a cell in an open circuit.

Sources of electrical e.m.f.
(i). Electric cell: This converts chemical energy to electrical energy.
(ii). Generators: These convert mechanical energy to electrical energy.
(iii). Thermo couple: This converts thermal energy (or heat energy) to electrical energy.
(iv). Piezo-electric effect (Crystal pick ups)
(v). Photo electric effect (solar cells)

(v) Electrical Resistance, (R): Is the opposition to the flow of current in a conductor. $R = \frac{V}{I}$.
The S.I unit of resistance is an ohm (Ω). **An ohm** is the resistance of a conductor through which a current of one ampere flows when a p.d across it is one volt.

(vi) Internal resistance of a cell, r:
Internal resistance of a cell is the opposition to the flow of current within the cell.

(vii) Open circuit: where current is not being supplied to an external circuit.
(viii) Closed circuit: Where the cell is supplying current to an external circuit.

1. E.m.f:- Is the work done to move a charge of IC through a circuit including a source (cell) i.e. the p.d. when the cell is not supplying current to an external circuit.

2. Terminal p.d. The work done to move a charge of IC through a circuit across the terminals of a battery i.e. it's the p.d when current is being delivered to an external circuit.

NB. The value of the terminal p.d. is always less than e.m.f because of the opposition to the flow of current inside the cell.
Internal resistance: Is the opposition to the flow of current within the cell.

$$E.m.f = Terminal\ pd. + \begin{pmatrix} p.d\ across\ the\ internal \\ resistance, r \end{pmatrix}.$$

$$E = VR + Vr$$
$$\mathbf{E = IR + Ir}$$

Factors affecting resistance of a conductor.
The resistance of a conductor is independent of the P.d, V and the current I through the conductor but it depends on physical factors like; length, cross sectional area and temperature.

Factor	Effect on resistance
(i) Length, l $R \propto l$	Increasing the length increases the resistance of the conductor. This is because increase in length increases the number of collisions electrons have to make with atoms as they travel through the conductor. This reduces the drift velocity of the free electrons and hence increases the resistance of the conductor.
(ii) Cross sectional area, A $R \propto \frac{1}{A}$	When there is an increase in the cross sectional area of the conductor, the number of free electrons that drift along the conductor also increases. This means that there is an increase in the number of electrons passing a given point along the conductor per second, thus an increase in current Consequently, this reduces the resistance of the conductor.
(iii)Temperature, T $R \propto \frac{1}{T}$	When there is an increase in the temperature of the conductor, the atoms vibrate with greater amplitude and frequency about their mean positions. The velocity of the free electrons increases which increases their kinetic energy. Consequently, the number of collisions between the free electrons and the atoms increases. This leads to a decrease in the drift velocity of the electrons. This means that there is a decrease in the number of electrons passing a given point

	along the conductor per second, thus a decrease in current Consequently, this increases the resistance of the conductor.
(iv) Nature of the substance.	Good conductors like metals have low resistance while poor conductors (insulators) have very high resistance.

Note: Supper conductors are materials whose resistance vanishes when they are cooled to a temperature near -273^0C.
Combining the first two factors at constant temperature, we get:

$$R \propto \frac{l}{A} \Leftrightarrow \boldsymbol{R = \rho\frac{l}{A}}$$

Where, ρ is a constant which depends on the nature of the conductor. It is called the Resistivity of the conductor.
Thus thick and short conductors have lower resistances compared to thin and long conductors.

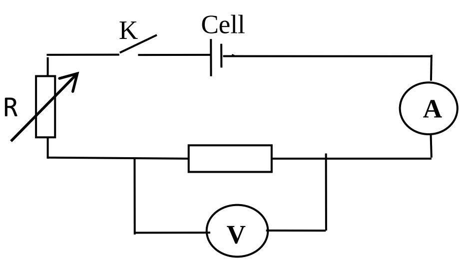
Resistivity, ρ:
Is the electrical resistance across the opposite faces of a cube of 1m length.
The S.I unit of resistivity is an ohm metre,(Ωm).

Conductivity, σ:
Is the reciprocal of electrical resistivity.

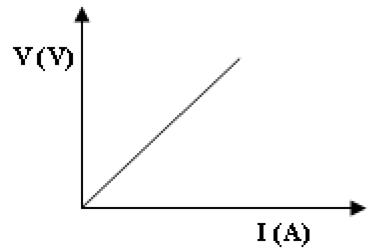
$$\boldsymbol{\sigma = \frac{1}{\rho}}$$

Ohms law:
It states that the current through an ohmic conductor is directly proportional to the P.d across it provided the physical conditions remain constant.

Experiment to verify Ohms law;



-The circuit is connected as shown above.
-Switch, K is closed, and a current, I flows through the circuit.
-Read and record the ammeter reading and the corresponding voltmeter reading.
-The rheostat is adjusted to obtain several values of V and I.
-Plot a graph of V against I



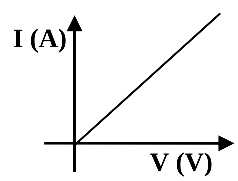
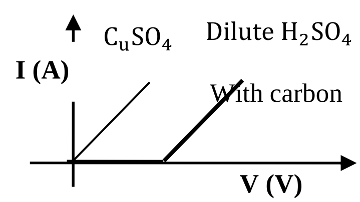
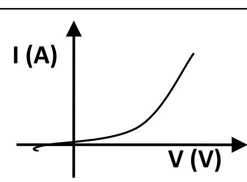
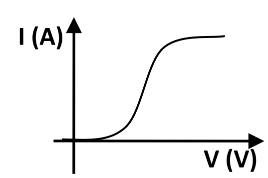
-It is a straight line graph through the origin, implying that V is directly proportional to I which verifies Ohm's law.
.

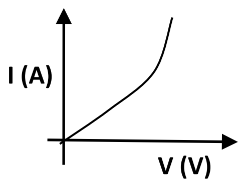
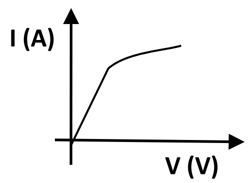
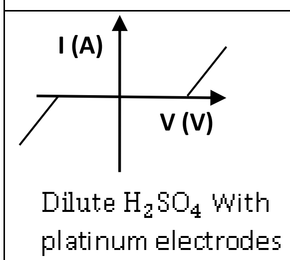
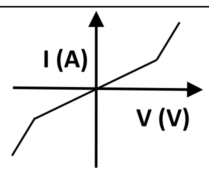
Note: In case the experiment requires resistance, then the slope of the graph is the resistance.
From the graph; **Slope**, $\mathbf{R = \frac{V}{I} = \tan\theta}$.
Where θ is the angle between the line and the horizontal.

Limitations of ohm's law
- ✓ It only applies when the physical conditions of a conductor are constant e.g. temperature, length of a conductor, cross section area etc.
- ✓ It doesn't apply to semi-conductors e.g. diodes and electrolytes

Ohmic and non- ohmic conductors
- Ohmic conductors are conductors which obey ohm's law. E.g. Metals.
- Non Ohmic conductors are conductors which do not obey ohm's law e.g. filament lamps, in diodes, neon gas tubes.

The graphs of current against voltage for different conductors.

(i) **Ohmic conductor** (Pure metal)	**(ii) Electrolytes**
 The straight line passes through the origin. The conductor closely obeys Ohm's law.	 Conductions in electrodes and electrolytes are both ohmic. For some electrodes conduction begins after the voltage has reached a certain value,
(iii) Semi-Conductor diode	**(iv) Thermionic diode (diode valve)**
 There is a slow rise in the current and it is nearly	 The graph is fairly Ohmic. At

Ohmic.	saturation, the current becomes constant.
(v) Thermistor And carbon resistor	**(vi) Filament bulb**
 The resistance of a thermistor decreases as temperature increases. A fall in resistance causes current to increase more rapidly.	 At low currents, the graph is a straight line. As current increases, more heat is produced and temperature increases which increases the resistance of the filament wire.
(v) Acid water	**(vi) Neon gas**
	

ELECTRIC CIRCUITS

An electric circuit can be defined as a combination of electric appliances represented by electric symbols for a particular purpose.
A circuit can be open (incomplete) or closed (completed).
An open circuit is circuit in which electrons are not continuously flowing.
A closed circuit is a circuit which is complete and having electrons continuously flowing.

Parallel and series electric circuits' connection
In connections, we must either connect in series or in parallel.
Some examples

1. A current of 4A flows through an electric kettle when the p.d. across it is 8V. Find the resistance.
2. What voltage is needed to make a current of 0.4A flow through when the appliance has resistance of 20Ω?

Questions

1. Give the unit and its symbol for
   (a) Current
   (b) Charge
2. What instrument is used to measure current.
3. A charge of 4C flows through an ammeter in 1s. What reading will the ammeter show? If the same charge flowed through the ammeter in 2s. What would the current be?
4. (a) Draw a circuit diagram to show two cells connected in series with a switch and two bulbs.
   (b) Draw a 2^{nd} circuit diagram with the same components, but with a switch and two bulbs in Parallel with each other.

Qn. Determine resistance from the information given.

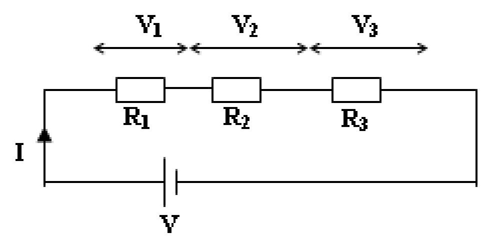
p. d (V)	1.05	1.40	1.80	2.20	2.40
I (A)	0.15	0.20	0.25	0.30	0.34

RESISTANCE
It can be defined as the opposition to the flow of current thru a conductor. A resistor is a conductor which opposes the flow of current thru it.

The unit of resistance is an ohm (Ω)
An **ohm** is the resistance of the conductor when a current of 1 A is flowing and a p.d. of 1 V is across its ends.

Resistor Net works

(i) Series arrangement of resistors
Resistors are said to be in series when they are connected end to end so that the same amount of current is the same.
The positive of one load is connected to the negative of another load.



In series
(i) Same current flows through each resistor.
(ii) P.d across each resistor is different
(iii) Total p.d V = sum of p.d across each resistor.

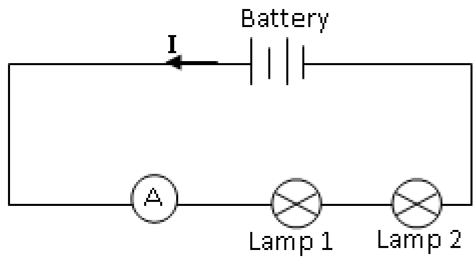
Thus: $V = V_1 + V_2 + V_3$

Using Ohm's law, $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$
$V = IR_1 + IR_2 + IR_3$
$V = I(R_1 + R_2 + R_3)$

If **R** is the resistance of a single resistor representing the three resistors, then V=IR.
$IR = I(R_1 + R_2 + R_3)$

$$\mathbf{R = R_1 + R_2 + R_3}$$

Series circuits
The current is the same at all points around a series circuit connections i.e. from the source (battery/cell) up to all points when its fully connected.

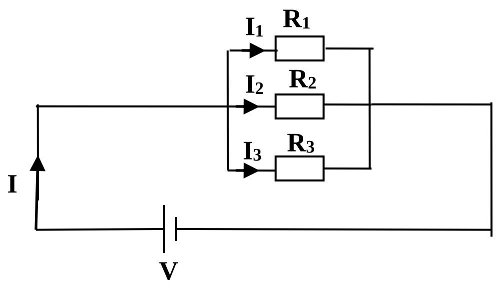


Which is a series connection and current being measured in series.

(ii) **Parallel arrangement of resistors**

Resistors are said to be in parallel if they are connected such that they branch from a single point (known as a **node**) and join up again.

The positive of one load is connected to the positive of another load.



For parallel

- (i) P.d across each resistor is the same.
- (ii) The main current flowing splits and therefore, the current through each resistor is different
- (iii) Total current, I is equal to sum of the current through each resistor.

Thus: $I = I_1 + I_2 + I_3$

Using Ohm's law, $V_1 = \frac{V}{R_1}$; $V_2 = \frac{V}{R_2}$ and $V_3 = \frac{V}{R_3}$

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

If **R** is the resistance of a single resistor representing the three resistors, then: $\mathbf{I} = \frac{\mathbf{V}}{\mathbf{R}}$.

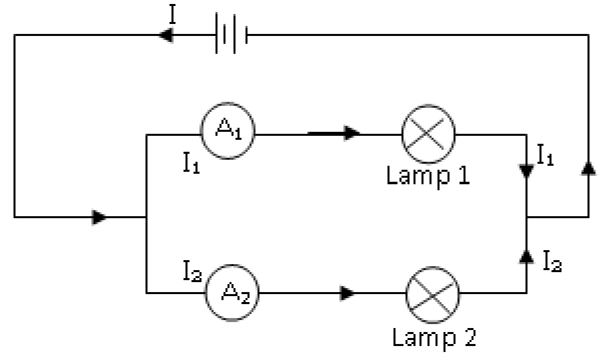
$$\frac{V}{R}. = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{\mathbf{1}}{\mathbf{R}} = \frac{\mathbf{1}}{\mathbf{R_1}} + \frac{\mathbf{1}}{\mathbf{R_2}} + \frac{\mathbf{1}}{\mathbf{R_3}}$$

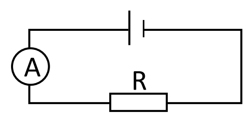
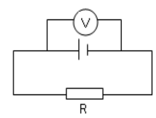
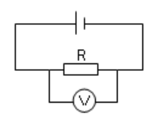
Note: For only two resistors in parallel, the effective resistance can be obtained as follows:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Leftrightarrow \frac{1}{R} = \frac{R_2 + R_1}{R_1R_2} \Leftrightarrow \mathbf{R} = \frac{\mathbf{R_1R_2}}{\mathbf{R_2 + R_1}}$$

Parallel circuits



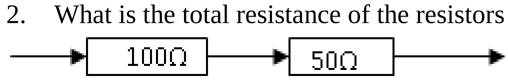
Ammeters are for measuring the current in a parallel circuit. It's characteristic in parallel connections to derive current whenever it reaches the parallel arms of the circuit. But current later recombines to form the original current again before it returns to the cell.

Ammeter	Voltmeter
-A device used to measure current -It has a very low resistance -Always placed in the path of current, i.e in series	-A device used to measure potential different -It has a very high resistance -Connects across the path of the conductor whose p.d. is to be determined, i.e in parallel.
	 

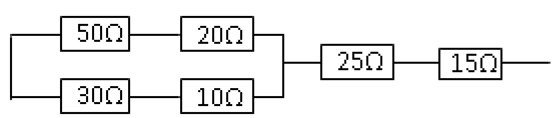
Examples:

1. Show that for two resistors in parallel, the effective resistance $R = \frac{R_1R_2}{R_1 + R_2}$

2. What is the total resistance of the resistors below;

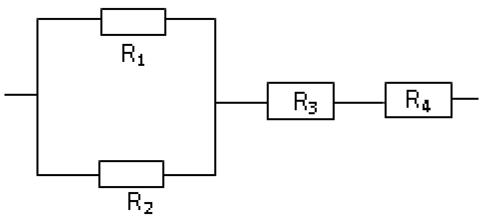


3. What is the effective resistance of the circuit below?



More combinations:

It's very possible to have series and parallel connections combined and in this case, we apply both principles within a given circuit.



If the effective is R

Let the effective of R_1 and R_2 be R_p

$$\frac{1}{R_p}. = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2} \Leftrightarrow R_p = \frac{R_1 R_2}{R_1 + R_2}$$

Let the effective of R_3 and R_4 be R_s

$R_s = R_3 + R_4$

Thus the effective resistance R is given by:

$R = R_p + R_s$

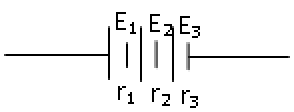
$$R = \frac{R_1 R_2}{R_1 + R_2} + R_3 + R_4$$

Voltage and connections

Voltages or e.m.f's can also be connected in series or parallel.

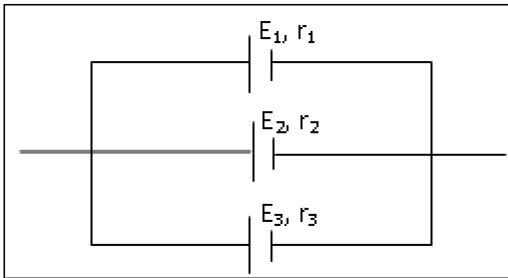
Cells in series

In this case, we sum all the individual e.m.f's to obtain the total e.m.f's:

	
Effective e.m.f, E	Effective resistance, r
$\mathbf{E = E_1 + E_2 + E_3}$	$\mathbf{r = r_1 + r_2 + r_3}$

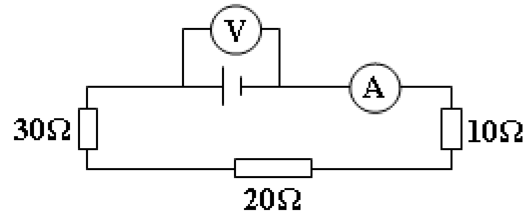
Cells in parallel

For the case of parallel connection of e.m.f. they have the same e.m.f.

	
Effective e.m.f, E	Effective resistance, r
$\mathbf{E = E_1 = E_2 = E_3}$	$\frac{\mathbf{1}}{\mathbf{r}}. = \frac{\mathbf{1}}{\mathbf{r_1}} + \frac{\mathbf{1}}{\mathbf{r_2}} + \frac{\mathbf{1}}{\mathbf{r_3}}$

EXAMPLES

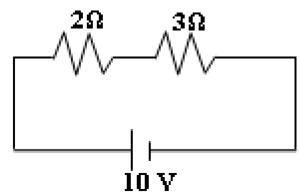
1. (1991 Qn. 35). In the circuit diagram below, the ammeter reading is 0.2 A. Find the voltmeter reading.



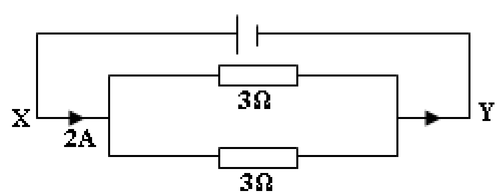
Let R_1=10Ω, R_2=20Ω, R_3=30Ω, I=0.2A, V=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$R = R_1 + R_2 + R_3$ $R = 10 + 20 + 30$ $R = 60\Omega$	$V = IR$ $V = 0.2 \times 60$ $V = 12$ V.

2. **(1997 Qn. 35).** Two coils of wire of resistance 2Ω and 3Ω are connected in series with a 10 V battery of negligible internal resistance. Find the current through the 2Ω resistor. [**Ans: 2A**]

Solution:

Let R_1=10Ω, R_2=20Ω, R_3=30Ω, I=0.2A, V=? 	
First determine the effective resistance, R	Now that we know V and R, let us use Ohms law; **V=IR**
$R = R_1 + R_2$ $R = 2 + 3$ $R = 5\Omega$	$V = IR$ $10 = I \times 5$ $5I = 10$ $I = 2$ A

3. **(1993 Qn. 15).** A current of 2A in flows in a circuit in which two resistors each of resistance 3Ω are connected as shown in the figure below. Calculate the P.d across XY.

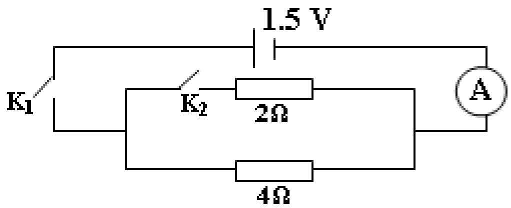


Solution:

Let R_1= 3Ω, R_2= 3Ω, I= 2A, V=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R} = \frac{1}{3} + \frac{1}{3} = \frac{2}{3}$	$V = IR$ $V = 2 \times 1.5$ $V = 3$ V.

$R = \frac{3}{2}\Omega = 1.5\Omega$	

4. **(2007 Qn. 3).** What will be the reading of the ammeter in the figure below if switch $\mathbf{K_2}$ is;

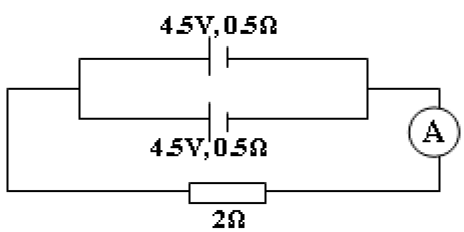


(i) Open and $\mathbf{K_1}$ is closed
(ii) Closed and $\mathbf{K_1}$ is closed.

Solution:

(i) When K_2 is open and K_1 closed, current flows through the 4Ω only. Let R = 4Ω, V=1.5 V, I=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$R = 4\Omega$	$V = IR$ $1.5 = I \times 4$ $I = 0.375\ A$
(ii) When K_2 is closed and K_1 closed, current divides into the 2Ω and 4Ω. Let R_1= 2Ω, R_2= 4Ω, V=1.5 V, I=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R} = \frac{1}{2} + \frac{1}{4} = \frac{3}{4}$ $R = \frac{4}{3}\Omega = 1.33\Omega$	$V = IR$ $1.5 = I \times \frac{4}{3}$ $I = 1.125\ A$

5. **(2008 Qn. 28).** The figure below shows two cells each of e.m.f 4.5 V and internal resistance 0.5Ω, connected to a 2Ω resistor.

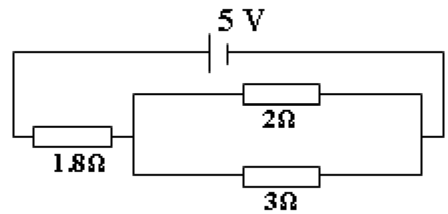


What is the ammeter reading?

Solution:

Let r_1= 0.5Ω, r_2= 0.5Ω, R_3= 2Ω V= 4.5V (Voltages in parallel; E_1=E_2=V), I=?	
First determine the effective resistance, Rp of the resistors in parallel. $\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$ $\frac{1}{R} = \frac{1}{0.5} + \frac{1}{0.5} = \frac{4}{1}$ $R = \frac{1}{4}\Omega = 0.25\Omega$	This resistance Rp is now in series with the 2Ω resistor. Thus the effective resistance, R is; $R = R_P + R_3$ $R = 0.25 + 2$ $R = 2.25\Omega$ Now that we know I and R, let us use Ohms law; $V = IR$ $4.5 = I \times 2.25$ $I = 2\ A.$

6. **(1994 Qn. 4).** The diagram below shows three resistors, 1.8Ω, and 2.0 Ω and 3Ω resistor.



Calculate the; (i) Effective resistance of the circuit
(ii) Current through the circuit.
(iii) P.d across the 2Ω resistor
(iv) Current through the 3Ω resistor.

Solution:

(i) Effective resistance of the circuit The 2Ω and 3Ω are in parallel. Their effective resistance is in series with the 1.8Ω resistor. Thus the effective resistance R is given by: $R = R_p + R_s$ $R = \frac{R_1R_2}{R_1 + R_2} + R_3$ $R = \frac{2 \times 3}{2 + 3} + 1.8 \Leftrightarrow R = \frac{6}{5} + 1.8 \Leftrightarrow R = 1.2 + 1.8$ $R = 3\Omega$
(ii) Current through the circuit. From Ohms law; **V=IR.** $V = IR$ $5 = I \times 3$ $I = \frac{5}{3} = 1.67\ A$
(iii) P.d across the 2Ω resistor P.d across the 2Ω resistor is equal to the P.d across the 3Ω which is equal to the P.d across the parallel combination. Thus from Ohms law; **V=IR.** $V_P = IR_P$ $V_P = \frac{5}{3} \times 1.2$ $V_P = 2\ V$

Thus the P.d across the 2Ω resistor is 2V.

(iv) Current through the 3Ω resistor.

Let the 3Ω resistor = R_1; Then;

$V_1 = I_1R_1$; In this case, $V_1 = V_P = 1.2$ V

$1.2 = I_1 \times 3$

$I_1 = 0.4$ A

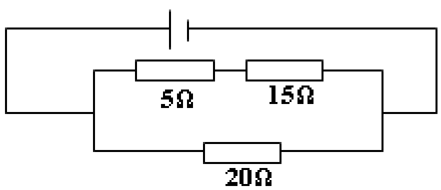
Thus the current through the 3Ω resistor is 0.4A.

7. **(2001 Qn. 31**). Find the effective resistance when two resistors of 5Ω and 15Ω joined in series are placed in parallel with a 20Ω resistor.

Solution:

Let R_1= 5Ω, R_2= 15Ω, R_3= 20Ω,

A sketch diagram showing the network of resistors.



First determine the effective resistance, R_s for the resistors in series.

$R_s = R_1 + R_2$

$R_s = 5 + 15$

$R_s = 20\Omega$

Now R_s is in parallel with the **R_3= 20Ω.**

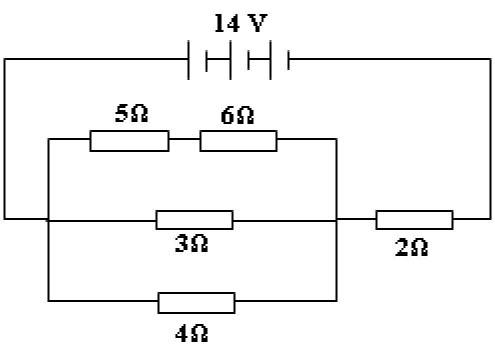
Thus the effective resistance in the circuit is;

$$R = \frac{R_sR_3}{R_s + R_3}$$

$$R = \frac{20 \times 20}{20 + 20} = \frac{400}{40}$$

$R = 10\Omega$

8. In the figure below, find the ;



(i) Effective resistance in the circuit.
(ii) Current through the circuit.
(iii) P.d across the 2Ω resistor.
(iv) P.d across the 6Ω resistor.

Solution:

Let R_1= 5Ω, R_2= 6Ω, R_3= 3Ω, R_4= 4Ω, R_5= 2Ω**,**

(i) Effective resistance in the circuit.

First determine the effective resistance, R_s for the 5Ω and 6Ω resistors in series.

$R_s = R_1 + R_2$

$R_s = 5 + 6$

$R_s = 11\Omega$

Now R_s is in parallel with the **3Ω.** and **4Ω** resistors.

Thus the effective resistance in parallel is;

$$\frac{1}{R_p} = \frac{1}{R_s} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$\frac{1}{R_p} = \frac{1}{11} + \frac{1}{3} + \frac{1}{4}$$

$$\frac{1}{R_p} = \frac{12 + 44 + 33}{132} = \frac{89}{132}$$

$$\frac{1}{R_p} = \frac{12 + 44 + 33}{132} = \frac{89}{132}$$

$$R_p = \frac{132}{89}\Omega = 0.674\Omega$$

Now R_p is in series with the **2Ω** resistor.

Thus the effective resistance in the circuit is;

$R = R_P + R_5$

$R = 0.674 + 2$

$R = 2.674\Omega$

(ii) Current through the circuit.

From Ohms law; **V=IR.**

$V = IR$

$14 = I \times 2.674$

$2.674I = 14$

$I = 5.236$ A

(iii) P.d across the 2Ω resistor.

From Ohms law; **V=IR.**

$V = IR$

$V = 5.236 \times 2$

$V = 10.472$ V

(iv) P.d across the 6Ω resistor.

The P.d across $R_s(5\Omega \text{ and } 6\Omega)$ is equal to the p.d across the 3Ω and is also equal to the p.d across the 4Ω resistor. This is because, R_s, 3Ω and 4Ωare in parallel.

P.d across the parallel combination:

From Ohms law; **V=IR.**

$V_P = I_PR_P$

$V_P = 5.236 \times 0.674$

$V_P = 3.529$

Current through $R_s(5\Omega \text{ and } 6\Omega)$ resistors.

From Ohms law; **V=IR.**

$V_P = I_sR_s$

$3.529 = I_s \times 11$

$11I_s = 3.529$

$I_s = 0.321$ A

Then the P.d across the 6Ω resistor is obtained as follows;

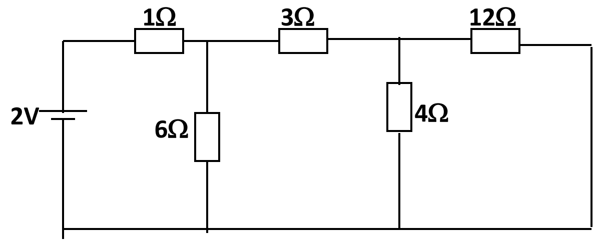
From Ohms law; **V=IR.**

$V = I_sR$

$V = 0.321 \times 6$

$V = 1.925$ V

Example: 8



4 Ωand 12Ω resistors are parallel, their effective resistance is $R_1 = \frac{4 \times 12}{4+12} = 3\Omega$

R_1 and 3Ω resistors are in series, their effective resistance is $R_2 = R_1 + 3 = 3 + 3 = 6\Omega$

R_2 and 6Ω resistors are in parallel, their effective resistance is $R_3 = \frac{6 \times 6}{6+6} = 3\Omega$

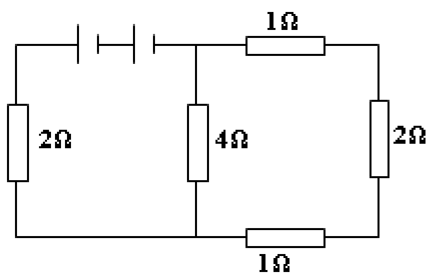
R_3 and 1Ω resistors are in series, their effective resistance is $R = R_3 + 1 = 3 + 1 = 4\Omega$

Hence effective resistance of the whole circuit is R = 4Ω

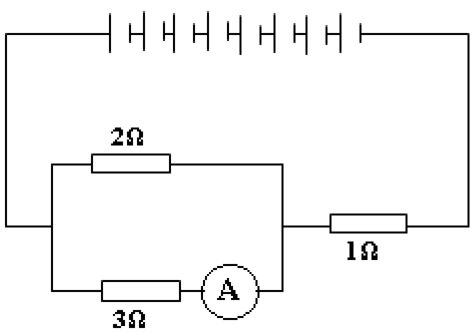
Current flowing $I = \frac{V}{R} = \frac{2}{4} = 0.5A$

Exercise:

1. Calculate the effective resistance of the circuit below. [**Ans: 4Ω**]



2. Eight identical cells each of e.m.f 1.5 and internal resistance 0.1Ω are connected in a circuit as shown bellow.

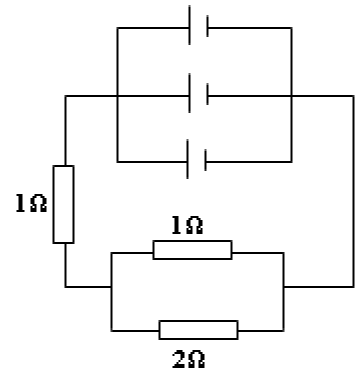


Calculate the;

(i). Current in the circuit.[Ans: 4A]

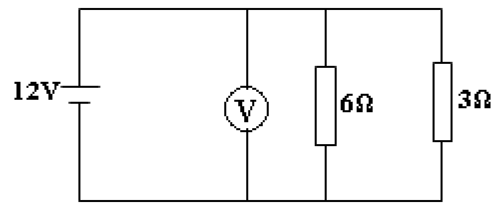
(ii). Ammeter reading, A. [Ans: 1.6 A]

3. Three identical cells each of e.m.f 1.5V and internal resistance 0.1Ω are connected as shown bellow.



Calculate the current in the circuit. [Ans: 0.88A]

4. (1997 Qn. 30). A battery of e.m.f 12V is connected across two resistors of 6Ω and 3Ω as shown below.



Calculate the current through the resistors.

5. See UNEB Paper1

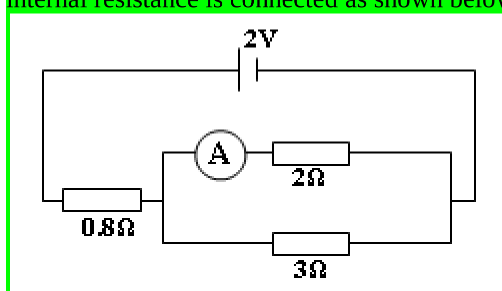
Section A:

1987 Qn.29	1989 Qn.32	1992 Qn.8	1994 Qn.4
1998 Qn.35	2000 Qn.37	2006 Qn.38	2008 Qn.36
1992 Qn.15	1989 Qn.11	1991 Qn.28	1994 Qn.24
1995 Qn.29	1998 Qn.37	2004 Qn.6	2007 Qn.12
1994 Qn.32			

Section B:

2002 Qn.50	1994 Qn.5	1997 Qn.8	1998 Qn.8
2000 Qn.9	2002 Qn.7		

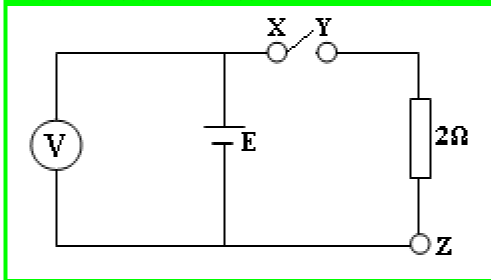
(1989 Qn. 7). (b) A battery of e.m.f 2.0 V and of negligible internal resistance is connected as shown below.



Find the reading of the ammeter, A.

(c) A battery of e.m.f 12 V and internal resistance1Ω is connected for three minutes and two seconds across a heating coil of resistance 11Ω immersed in a liquid of mass 0.2 kg and specific heat capacity of $2.0 \times 10^3 Jkg^{-1}K^{-1}$. Find the rise in temperature of the liquid. Clearly state any assumptions made.

(1989 Qn. 7). (b) A cell of e.m.f, E and internal resistance 1.0 Ω is connected in series with a 2Ω resistor as shown bellow.



The voltmeter reads 1.5V when the switch is open.

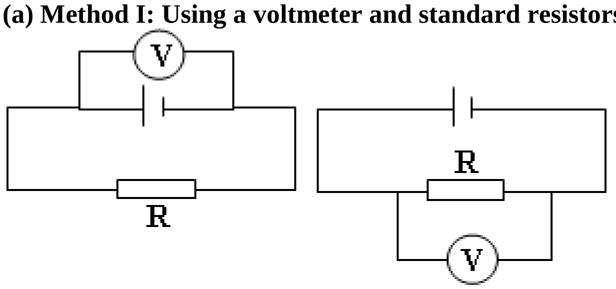
(i). Find the value of E.

(ii). What will be the voltmeter's reading when the switch is closed?

(iii). What will be the voltmeter's reading when X is connected to Z? Give a reason for your answer.

An experiment to obtain internal resistance of a cell.

(a) Method I: Using a voltmeter and standard resistors.



-A high resistance voltmeter is connected across the terminals of the cell, we take the reading which is the E.m.f., **E** of the cell.

-A standard resistor is connected to the cell terminals and the voltmeter reading is taken again which is **V**.

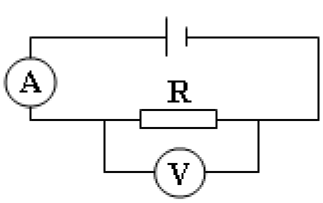
-Calculate the internal resistance of the cell, **r** from;

$$\mathbf{r = \frac{R(E - V)}{V}}$$

-Repeat the procedure using other resistors of different resistances.

-Finally take the mean value of internal resistance.

(b) Method II: Using a voltmeter, Ammeter and standard resistors.



-A high resistance voltmeter is connected across the terminals of the cell, we take the reading which is the E.m.f., **E** of the cell.

-A standard resistor is connected in series with the cell terminals and the voltmeter connected across it as shown above.

-Read and record the voltmeter reading, **V** and the corresponding ammeter reading, **I**.

-Calculate the internal resistance of the cell, **r** from;

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

-Repeat the procedure using other resistors of different resistances.

-Finally take the mean value of internal resistance

Derivation: Find the total resistance using R and r and them apply ohm's law Total resistance $= R + r$ $E = I \times \text{Total restance}$ $E = I(R + r)$ $E = IR + Ir \ldots\ldots\ldots\ldots (i)$	For the resistor alone; $V = IR \ldots\ldots\ldots\ldots\ldots\ldots (ii)$ Subtracting equation (ii) from equation (i) , we get; $E - V = Ir$ Making r the subject of the formula gives; $\mathbf{r = \frac{E - V}{I}}$
Note: The expression $\mathbf{E - V}$ is called **lost volt** and it is defined as the voltage wasted in overcoming the internal resistance of a cell.	
Alternatively: From; $V = IR$, $I = \frac{V}{R}$ Substituting for current, I in the equation for r above, gives;	$r = \frac{E - V}{\left(\frac{V}{R}\right)}$ $\mathbf{r = \frac{R(E - V)}{V}}$

ELECTRICAL ENERGY AND POWER

The advantage of electric energy is the ease with which it may be transferred to light, heat and other forms of energy. Because of this, it can be used in many types of equipment like refrigerators, cookers, lamps, e.t.c.

When electricity passes thru an appliance, it develops and produces some heat which may depend on any of the following;

- Resistance of the conductor
- The amount of current flowing
- The time for which the current has been flowing

Work done by an electric current.

When a charge moves through a resistance wire, the work done becomes the electrical energy which changes to heat energy.

$$\mathbf{\text{Work done} = \text{Voltage} \times \text{Charge}}$$
$$\mathbf{W = V \times Q}$$

From the definition of current, $Q = It$: Thus;

$$W = V \times It$$
$$\mathbf{W = VIt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)}$$

But from Ohm's law, $V = IR$: Thus;

$$W = IR \times It$$
$$\mathbf{W = I^2Rt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)}$$

$$\mathbf{W} = \frac{\mathbf{V^2t}}{\mathbf{R}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{iii})$$

Electrical Power

Power is the rate of doing work or it's the rate of energy transfer.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} = \frac{\text{Energy transfered}}{\text{Time taken}}$$

$$\text{Power, P} = \frac{\text{IVt}}{\text{t}} = \text{IV}$$

$$\mathbf{P = IV = I^2R = \frac{V^2}{R}}$$

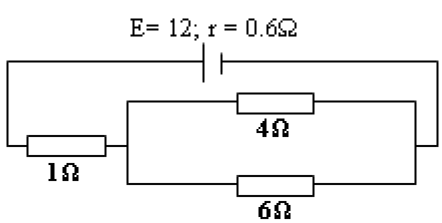
Examples

1. An electrical flat iron of rated 240V, 1500W. calculate the;
   (i) The current through the flat iron.
   (ii) The resistance of the flat iron
   (iii) The energy consumed in $1\frac{1}{2}$ hours.

Solution:

P = 1500W; V = 120V, I = ?	
(i) the current through the flat iron. $\mathbf{P = IV}$ $1500 = I \times 240$ $240I = 1500$ $I = 6.25\ A$	(ii) The resistance of the flat iron $\mathbf{P = \frac{V^2}{R}}$ $1500 = \frac{(240)^2}{R}$ $1500R = 57600$ $R = 38.4\ \Omega$
(iii) The energy consumed in $1\frac{1}{2}$ hours: $\mathbf{E = Pt}$ $E = 1500 \times (1.5 \times 60 \times 60)$ $E = 8{,}100{,}000J$	**One can use;** $\mathbf{E = IVt}$, **or** $\mathbf{E = \frac{V^2}{R}}$

2. In the diagram, below, a 12V battery of internal resistance 0.6Ω is connected to the 3 resistors. A, B, C.



Find the:
(i) Current in each resistor.
(ii) Power dissipated in the 4Ω resistor.

Solution:

R=0.6Ω; E= 12V, I = ?

<u>Effective resistance of the circuit</u> The 2Ω and 3Ω are in parallel. Their effective resistance is in series with the 1.8Ω resistor. Thus the effective resistance R is given by: $R = R_p + R_s$ $R = \frac{R_1R_2}{R_1 + R_2} + R_3 + r$ $R = \frac{4 \times 6}{4 + 6} + 1 + 0.6$ $R = \frac{24}{10} + 1 + 0.6$ $R = 2.4 + 1 + 0.6$ $R = 4\Omega$	**(i) Current through the circuit.** From Ohms law; **V=IR.** $V = IR$ $12 = I \times 4$ $I = \frac{12}{4} = 3\ A$ Thus current through the 1Ω resistor is 3 A. P.d across the parallel combination, 4Ω and 6Ω resistors. From Ohms law; **V=IR.** $V_P = IR_P$ $V_P = 3 \times 2.4$ $V_P = 7.2\ V$ Thus the P.d across the 4Ω and 6Ω resistors is 7.2V.
Current through the Ω resistor. From Ohms law; **V=IR.** $V_1 = I_1R_1$ $7.2 = I_1 \times 4$ $4\ I_1 = 7.2$ $I_1 = 1.8\ A$	**Current through the 6Ω resistor.** From Ohms law; **V=IR.** $V_2 = I_2R_2$ $7.2 = I_2 \times 6$ $6\ I_2 = 7.2$ $I_2 = 1.2\ A$ Alternatively: $I_2 = I - I_1$ $I_2 = 3 - 1.8$ $I_2 = 1.2\ A$
(ii) Power dissipated in the 4Ω resistor. $P = I^2R$ $P = (1.8)^2 \times 4$ $P = 3{,}24 \times 4$ $P = 12.96\ W$	**One can use;** $\mathbf{P = IV}$, **or** $\mathbf{P = \frac{V^2}{R}}$

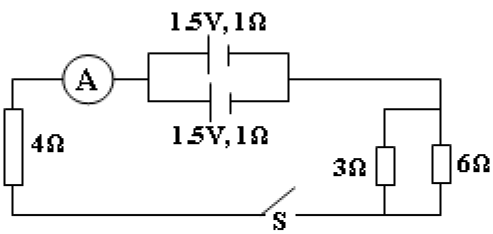
3. **(1992 Qn. 6).** An electrical appliance is rated 240V, 60W.
   (a) What do you understand by this statement?
   (b) Calculate the current flowing through and the resistance of the appliance when operated at the rated values above. [0.25A, 960Ω respectively]

Solution:

(a) 240V, 60W means that the appliance supplies or consumes 60 joules of electrical energy in one second when connected to a 240V mains supply.	
(b) V=240V, P=60W, I=?	
(i) From: $P = IV$ $60 = I \times 240$ $240I = 60$ $I = 0.25A$	**(ii)** From: $P = \frac{V^2}{R}$ $P = \frac{V^2}{R}$ $60 = \frac{(240)^2}{R}$ $60R = 57600$

	$R = 960\Omega$

4. **(1990 Qn. 3).** (c) In the diagram below, two batteries of e.m.f 1.5V and internal resistance of 1Ω each are connected to a network of resistors in a circuit which includes a switch, S.



(i). What will be the reading on the ammeter when switch S is closed? [Ans: 0.23A]

(ii). What is the power developed in the 4Ω resistor when S is closed? [Ans: 0.21 W]

Solution:

<table>
<tr><td colspan="2">$R_1 = 4\Omega$; $R_2 = 3\Omega$; $R_3 = 6\Omega$; $V_1 = 1.5V$; $V_2 = 1.5V$;
$r_1 = 1\Omega$; $r_2 = 1\Omega$;</td></tr>
<tr><td rowspan="2">Effective resistance of the circuit
For the two cells in parallel.
$r = \frac{r_1 r_2}{r_1 + r_2} = \frac{1 \times 1}{1 + 1} = 0.5\Omega$

For the two standard resistors in parallel.
$R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{3 \times 6}{3 + 6} = 2\Omega$

Thus effective resistance is;
$R = R_p + R_s + r$
$R = 0.5 + 2 + 4$
$R = 6.5\ \Omega$</td><td>(i) Current through the ammeter.
From Ohms law; V=IR.
$V = IR$
$1.5 = I \times 6.5$
$6.5I = 1.5$
$I = 0.23\ A$</td></tr>
<tr><td>(ii) power developed in the 4Ω resistor when S is closed?
From Ohms law; V=IR.
$P = I^2R$
$P = (0.23)^2 \times 4$
$P = 0.0529 \times 4$
$P = 0.21\ W$</td></tr>
</table>

Exercise:

1. An electric appliance is rated 200V, 0.05kW. Calculate the;

(i) Current through the appliance.[0.25A]
(ii) Resistance of the appliance.
(iii) Time it will take to transfer energy of 10,000J. [200 seconds]

2. Appliance A allows 3A of current to go through it when connected to a 200 V supply while appliance B has a resistance of 40Ω when connected to the same supply. Which of the two appliances heats up first and why?

3. see UNEB

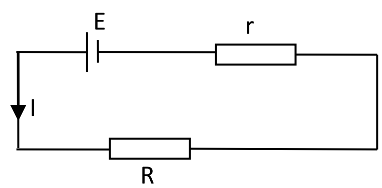
Section A			
1997 Qn. 37	1989 Qn. 8	2007 Qn. 4	2003 Qn. 38
1988 Qn. 10	1991 Qn. 15	1998 Qn. 35	1999 Qn. 36
2006 Qn. 36			

Example: 5

A battery of un known e.m.f and internal resistance is connected in series with a load of resistance, R ohms. If a very high resistance voltmeter is connected across the load reads 3.2V and the power is dissipated in the battery is 0.032W and efficiency of the circuit is 80%. Find the:

(i) Current flowing
(ii) Internal resistance of the battery.
(iii) Load resistance, R
(iv) E.m.f of the battery.

Solution:



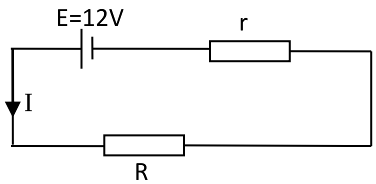
Total resistance, $= R + r$ From the circuit formula; $I = \frac{E}{R + r} \ldots\ldots\ldots\ldots\ldots\ldots.(i)$ Power dissipated in the battery; $P = I^2r = 0.032 \ldots\ldots\ldots (ii)$ From Ohm's law; the terminal p.d is; $V = IR = 3.2 \ldots\ldots\ldots\ldots (iii)$ $\text{Efficiency}, = \frac{P.out}{P.in} \times 100$ $\frac{80}{100} = \frac{I^2R}{ER}$ $0.8 = \frac{I^2R}{I^2(R + r)}$ $R = 0.8(R + r)$ $R = 4r$	From equation (iii) $I(4r) = 3.2 \ldots\ldots\ldots\ldots (iv)$ Equation (ii) ÷ (iv) $\frac{I^2r}{4Ir} = \frac{0.032}{3.2}$ $\underline{I = 0.04\ A}$ From equation (ii) $(0.04)^2r = 0.032$ $\underline{r = 20\Omega}$ $R = 4r$ $\underline{R = 4(20) = 80\Omega}$ From equation (ii) $E = I(R + r)$ $E = 0.04(40 + 20)$ $\underline{E = 4\ V}$

Example:6

A battery of e.m.f 12V and un known internal resistance is connected in series with a load resistance, R reads 11.4V and the power dissipated in the battery is 0.653W. Find the:

(i) Current flowing.
(ii) Internal resistance of the battery.
(iii) Load resistance, R.
(v) Efficiency of the circuit.

Solution:



From Ohm's law; the terminal p.d is;
$V = IR = 11.4 \ldots\ldots\ldots\ldots (i)$

P.d across the internal resistance is lost volts (Ir). From;
$E = I(R + r) \Leftrightarrow Ir = E - IR$
$Ir = 12 - 11.4$
$Ir = 0.6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$

Power dissipated in the battery;
$P = I^2r = 0.653 \ldots\ldots (iii)$
Equation (iii) ÷ (ii)
$\frac{I^2r}{Ir} = \frac{0.653}{0.6}$
$I = 1.088\ A$

From equation (iii)
$(1.088)^2 r = 0.653$
$r = 0.55\Omega$

From equation (i)
$IR = 11.4$
$(1.088)R = 11.4$
$R = 10.48\Omega$

$\text{Efficiency}, = \frac{\text{Power output}}{\text{Power input}} \times 100\%$

$= \frac{I^2R}{ER} \times 100\%$

$= \frac{(1.088)^2(10.48)}{12(1.088)} \times 100\%$
$= 95\%$

Commercial Electric Energy

All electric appliances are connected in parallel so that each is at the same voltage.
All electric appliances are marked showing the power rating in watts (W) and the voltage in volts (V).
The power of an appliance indicates the amount of electrical energy it supplies or the amount of work it does per second.

For example: A heater marked 240V, 1000W, means that the heat consumes 1000J of electrical energy every second when connected to 240V.

Commercial Unit of electric energy.
There are always charges for electricity consumed that the electricity board gives for us for payment and they use our meters to estimate the energy consumed.
The energy consumed is measured in **kWh** which is an abbreviation for **kilowatt hour**.
The commercial unit of electrical energy is a kilowatt-hour, (kWh) since a watt second is very small.

A kilowatt hour is the electrical energy used by a rate of working of 1000 watts for 1 hour.
It is the quantity of electrical energy converted into other forms of energy by a device of power 1000watts in one hour.
1 watt = 1 joule per second
1 kWh = 1000x1hr
= 1000 x 60 x 60 x 60 joules.
1 kWh = 3,600,000J = 3.6 MJ

Cost of electric energy calculation

$$\begin{bmatrix}\textbf{Number of units used} \\ \text{(Energy consumed)}\end{bmatrix} = \begin{bmatrix}\textbf{Power} \\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\textbf{Time} \\ \text{(in hours)}\end{bmatrix}$$

$$\textbf{Total cost} = \begin{bmatrix}\textbf{Number of units used} \\ \text{(Energy consumed in kWh)}\end{bmatrix} \times \begin{bmatrix}\textbf{Rate per} \\ \textbf{unit}\end{bmatrix}$$

The **rate per unit** is the **cost per unit** of electrical energy consumed. Thus the cost of using an appliance is given by;

$$\textbf{Total Cost} = \begin{bmatrix}\textbf{Power} \\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\textbf{Time} \\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\textbf{Cost per} \\ \textbf{unit}\end{bmatrix}$$

Examples;

1. **(1995 Qn. 33).** Four bulbs each rated at 75W operate for 120 hours. If the cost of electricity is sh.100 per unit, find the total cost of electricity used.

Solution:

Number of bulbs = 4;
Power rating for each bulb = 75W
Total Power rating for 4 bulb = $4 \times 75W = 300W$
$= \frac{300}{1000}\ kW$
$= \mathbf{0.3\ kW}$

Total Time = 120 Hours
Cost per unit = sh. 100

$$\text{Total Cost} = \begin{bmatrix}\text{Power} \\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time} \\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per} \\ \text{unit}\end{bmatrix}$$

Total Cost = [0.3 kW] × [120 hrs] × [sh. 100]

Total Cost = sh. 3600

2. An electric immersion heater is rated at 3000W, 240V. Calculate the;
(i) Current and resistance of the heating element.
(ii) Total number of electric units it consumes in $1\frac{1}{2}$ hours.
(iii) Cost per unit if sh. 9000 is paid after using it for 3hours everyday for ten days.

Solution:

(i) V= 240V, P =3000W, I=?, R = ?

From: $P = IV$
$3000 = I \times 240$
$240I = 3000$
$I = 12.5A$

From: $P = \frac{V^2}{R}$
$P = \frac{V^2}{R}$
$3000 = \frac{(240)^2}{R}$
$3000R = 57600$
$R = 19.2\Omega$

(ii)

Total Power $= 3000\text{W}$ $= \frac{3000}{1000}$ kW $= \mathbf{3\ kW}$	Total Time $= 1\frac{1}{2}$ hours $= \frac{3}{2}$ hours $= \mathbf{1.5\ hours}$

$$\begin{bmatrix}\text{Number of units used}\\ \text{(Energy consumed)}\end{bmatrix} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix}$$

Number of units used (Energy consumed) $= 3 \times 1.5$

Number of units used (Energy consumed) $= 4.5\text{ kWh} = 4.5\text{ Units}$

(iii)

Total Power $= 3000\text{W}$ $= \frac{3000}{1000}$ kW $= 3$ kW	Total Time $= 3 \times 10$ hours $= 30$ hours

Let the cost per unit be y

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

$9000 = 3 \times 30 \times y$

$9000 = 90y$

$y = \text{sh.}100$

3. Mr. Lutaaya uses 3 kettles of 800W each, a flat iron of 1000W, 3 bulbs of 60W each and 4 bulbs of 75W each. If they are used for 3 hours every day for 30 days and that one unit of electricity costs sh. 200, find the total cost of running the appliances.

Solution:

Kettles	Flat irons	60W Bulbs	75W Bulbs
$P = 3 \times 800$ $P = 2400$ W $= \frac{2400}{1000}$ kW $= 2.4$ kW	$P = 1 \times 1000$ $P = 1000$ W $= \frac{1000}{1000}$ kW $= 1$ kW	$P = 3 \times 60$ $P = 180$ W $= \frac{180}{1000}$ kW $= 0.18$ kW	$P = 4 \times 750$ $P = 300$ W $= \frac{300}{1000}$ kW $= 0.3$ kW

Total power $= (2.4 + 1 + 0.18 + 0.3)\text{ kWh} = 3.88\text{ kWh}$

Total time $= (3 \times 30)$ hours $= 90$ hours.

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

Total Cost $= [3.88\text{ kW}] \times [90\text{ hrs}] \times [\text{sh.}200]$

Total Cost $= \text{sh.}69840$

4. Find the cost of running five 60 W lamps and 4 100 W lamps for 8 hours if the electric energy costs shs. 5.0 per unit.**[Shs.28**]

5. A house has one 100 W bulb, two 75 W bulbs and 5 40 W bulbs. Find the cost of having all lamps switched on for 2 hours every day for 30 days at a cost of shs. 30 per unit. [**Shs. 810**].

6. See UNEB

Section A			
2002 Qn. 36	1999 Qn. 40	2003 Qn. 37	2006 Qn. 28
2007 Qn. 14			
Section B			
1992 Qn. 2	1997 Qn. 8	2008 Qn. 4	

Generation and Transmission of electricity

(a) Generation of electricity

Electricity is generated at power stations by using one of the following;

- Coal, Nuclear reactions, Falling water, e.t.c.

(b) Transmission of electricity

- The electricity generated at the power station is then stepped up to higher voltage using step up transformers for transmission.
- Electricity is transmitted at high voltages to reduce power loss through heating effect in the transmission cables. Transmission cables are made thick to reduce its resistance hence minimizing power loss through the $\mathbf{I^2R}$ − mechanism.
- The electricity is then stepped down using step down transformers in phases. That is, it is first stepped down to heavy factories, industries, cities, towns, and finally to homes.
- The transmission can either be over head or underground. In some developed countries, the grid system is used
  The grid system is a system where different power stations are inter connected or networked so that in cases there is power failure in one power station or when one station is stopped for maintenance work, the other stations continue to supply the power.

(c) House wiring.

Domestic electric installation

Power is connected in a house by thick cables from the pole called mains to the fuse box {meter box}, then main switch and to the distribution box. Here, power is directed to electrical equipments. Each circuit has its own fuse which is connected to a live wire.

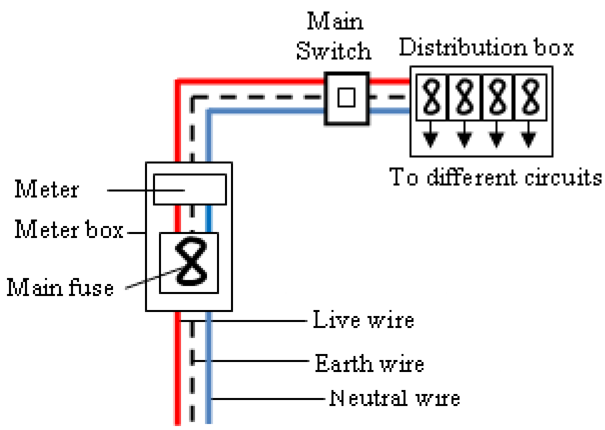
The main switch board (distribution box) breaks both wires when in OFF position and is therefore called a **double pole switch.**

It completely cuts off the supply in the house.

In supply cable:
Power enters the house thru the supply cable from the electric pole from which two insulated wires, the live and the neutral come from. They are distinguished by colour i.e;

Type of wire	Colour
(i) Live wire	Red or Brown
(ii) Neutral wire	Blue or Black
(iii) Earth wire	Yellow or Green or Yellow with green stripes

The earth wire is usually earthed and is therefore at zero potential while the live wire is at a potential of 240V for the case of Uganda.
The electricity being supplied is alternating and it therefore alternates from positive to negative in a single cycle.



Switches, Sockets and Plugs

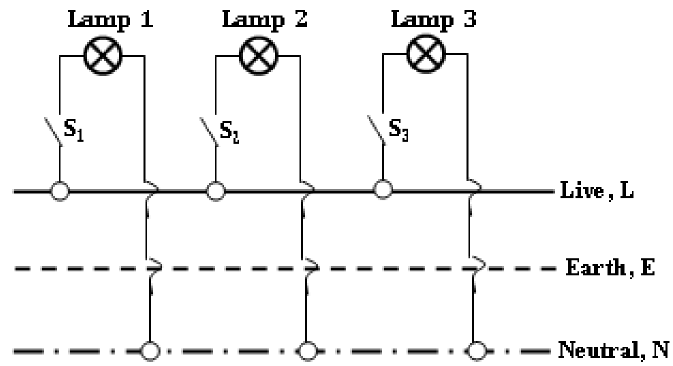
Electric system	Connection
(i) Switches	❖ Control the flow of current ❖ Connected to the live wire to prevent the appliance from being live when switched off. Thus they are called single pole switches.
(ii) Fuses	❖ It is a thin wire of low melting point which melts when the current exceeds a required value so as to break the circuit. ❖ It must be connected to the live wire.
(iii) Sockets	❖ These are power points usually put on the walls. ❖ They have 3 holes leading to the live wire L, neutral wire N and earth wire E.
(iv) Plugs	❖ These are points which connect or tap power from the socket to the appliance. ❖ It has 3 pins that fit into the 3 holes in the socket. The pins are marked with L, N and E for live, neutral and earth wires respectively.

Connection of appliances
Electrical appliances are usually connected in parallel with the mains so that;

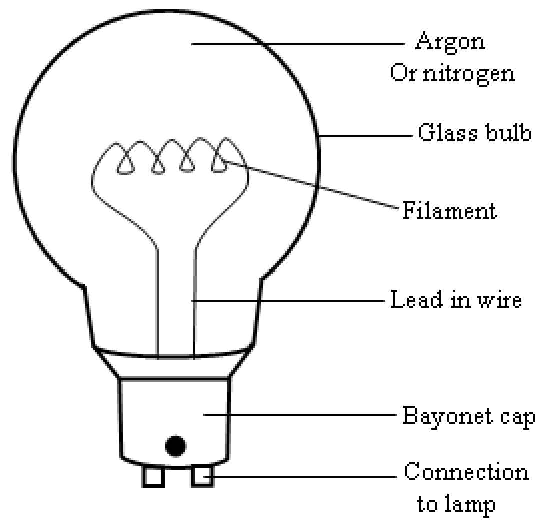
(i) They receive full main potential difference.

(ii) When one circuit is faulty or switched off, the other circuits remain working.

(a) Light circuits
All lamps in house wiring are connected in parallel with the switch on the live wire to the lamp.



(i) Filament Lamp / Incandescent lamp:

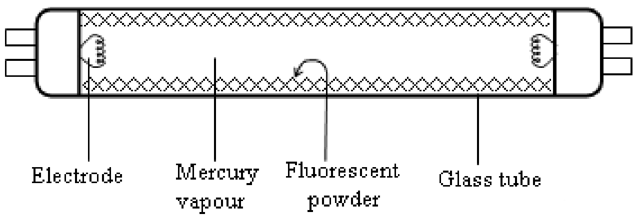


-When switched on, the coiled tungsten filament is heated, it becomes white hot and emits light.
-The higher the temperature of the filament, the greater the electrical energy changed to light.

Note:

- ❖ The filament is made out of tungsten, because tungsten has a higher melting point. Hence it can't easily melt when white hot.
- ❖ The filament is coiled in order to reduce space occupied and hence reduce the rate of heat loss by convection currents in the gas.
- ❖ The glass bulb is filled with an inert gas at low pressure, to prevent evaporation of tungsten and increase the operating temperature. Otherwise it would condense on the bulb and blacken it.

(ii) Fluorescent lamps/ Tubes/ Discharge lamp.



-When switched on, the mercury vapor emits ultra-violet radiations.
-The radiations strike the fluorescent powder (e.g Zinc sulphide, **ZnS**) and the tube glows emitting light.

Differences between a filament lamp and a fluorescent lamp

Filament lamp	Fluorescent lamp
-Not long lasting	-Long lasting
-Cheaper	-Expensive
-Emit light by heating the filament in the bulb.	-Emit light by sending an electrical discharge through an ionized gas.
-Have high operating temperatures.	-Have low operating temperatures.
-Can easily be disposed off since the inert gasses are not poisonous.	-Care should be taken when disposing them off, since mercury vapor is poisonous.
-High energy/ power consumption, hence high energy costs.	-Low energy/ power consumption, hence low energy costs.

Qn. With the aid of diagrams, describe how a filament lamp and a fluorescent/discharge lamp work.

(b) Socket ring mains.
The sockets on the ring main circuit are connected in parallel so that they receive full main potential difference.
The use of a **ring** of wire reduces the thickness of wire which has to be used.
Both ends of the loop are connected to the fuse box.
The current, I flowing is normally 12 amperes. Thus the fuse used should be just above 12 A.

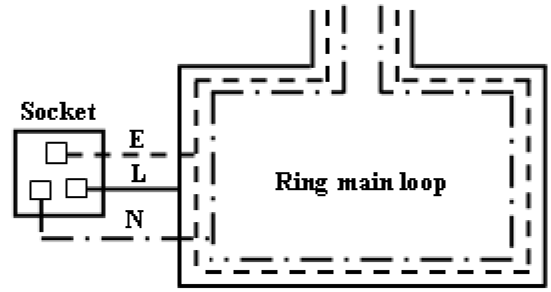
Choosing an ideal fuse for the appliance
The ideal fuse to be used should have a maximum rating which is a little higher than the normal current expected.

Example:
Suggest an appropriate fuse value to be used for a 3kW appliance when used on a 240V main supply.

P = 3kW=3000 W; V = 240 V

$$P = IV$$
$$3000 = I \times 240$$
$$240I = 3000$$
$$I = 12.5A$$

Thus the appropriate fuse should be slightly higher than 12.5A



Safety precautions in a house

- Electric cables must be properly insulated
- Keep hands dry whenever dealing with electric supply
- In case of an electric shock, switch off the main switch immediately
- Before a fuse is replaced check the fault in the circuit which caused the problem and make sure it's rectified.

Sources of e.m.f
They are;
- Cells. These change energy to electric energy
- Batteries/accumulators. Also convert chemical energy to electrical energy
- D.C and A.C. generators
- Photo cells, they convert light energy to electrical
- Thermocouples. They convert heat energy to electrical energy.

Exercise:

1. (1989 Qn. 17). How many lamps marked 75W, 240V could light normally when connected in parallel having a 5A fuse.
A: 1 B: 3 C: 16 D: 26

2. (1990 Qn.39). Very high voltages are used when distributing electric power from the power station because;
A: Some electric equipment require very high voltages
B: Currents are lower, so energy losses are smaller
C: Very high voltages are generated at the power stations
D: There is less likely hood of the transmission lines being struck by lightning.

3. (1991 Qn.7). An electric toaster plate rating is 220-240V, 750W. The fuse is:
A: 1 A B: 3 A C: 5 A D: 13 A

4. (2000 Qn. 31). For safety in a house, a fuse and a switch are connected to:

	Fuse	Switch
A	Live wire	Neutral wire
B	Neutral wire	Earth wire
C	Live wire	Live wire
D	Earth wire	Neutral wire

5. (1999 Qn. 39). Which of the following statements are true about electric wiring?

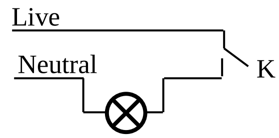
(i) The fuse is always connected into the live wire leading to the circuit.
(ii) The fuse is always connected into the Neutral wire leading to the circuit.
(iii) When a fault develops in a circuit, it is the neutral which has to be disconnected.

A: (i) only B: (iii) only
C: (i) and (iii) only D: (i), (ii) and (ii).

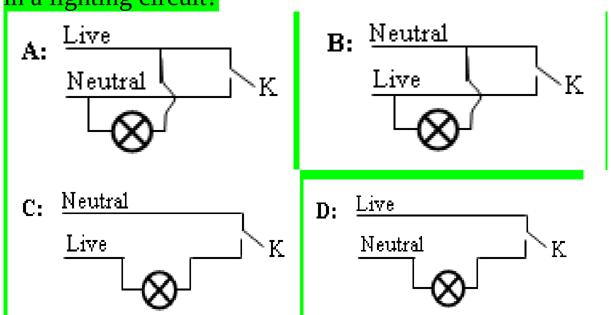
6. (2002 Qn. 18). The device which disconnects the mains when there is a sudden increase in voltage is;
A: Fuse B: Switch C: Earth wire D: Circuit breaker

7. (1992 Qn. 2). In a house wiring system, all connections to the power points are in parallel so as to:
A: Supply the same current.
B: Operate at the same voltage.
C: Minimize the cost of electricity
B: Consume the same amount of energy.

8. (2008 Qn. 17). The possible energy transfer in an electric bulb is;
A: Light energy to heat energy.
B: Heat energy to electrical energy.
C: Electrical energy to light energy.
D: Light energy to electrical energy.



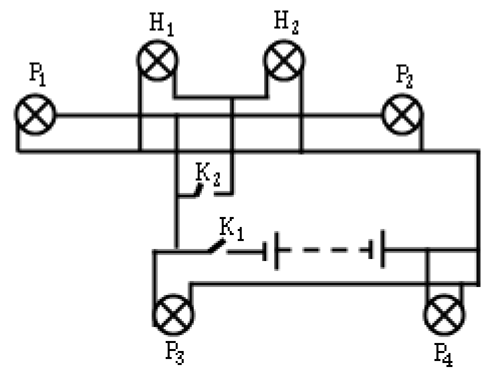
9. (1993 Qn. 33). Which of the following circuit diagrams shows the correct positions for the lamp and the switch K in a lighting circuit?



10. (1991 Qn. 7).

SECTION B

11. (1991 Qn.3). The figure below shows a circuit diagram of a part of a wiring system of a car. H_1 and H_2 are headlamps and P_1, P_2, P_3 and P_4 are parking lamps.



(a) How can;
(i) All the lamps be switched on?
(ii) Both headlamps be switched off without affecting the parking lamps.

(b) State what happens to the lamps if P1 is broken when all the lamps are on. Give a reason for your answer.

12. (2000 Qn.8). (a) Describe the structure and action of a fluorescent tube.
(b) Give **one** advantage of a fluorescent tube over a filament lamp.
(c) Describe the functions of;
(i) A fuse.
(ii) An earth wire
(d) Describe briefly how power is transmitted from a power station to a home.
(e) Find the cost of running two 60W lamps for 20 hours if the cost of each unit is sh.40.