7.1 ANALYSING ELECTRIC FIELDS AND CHARGE FLOW

<table>
<tr>
<td>State the relationship between electron and electric current

Where does charge come from?</td>
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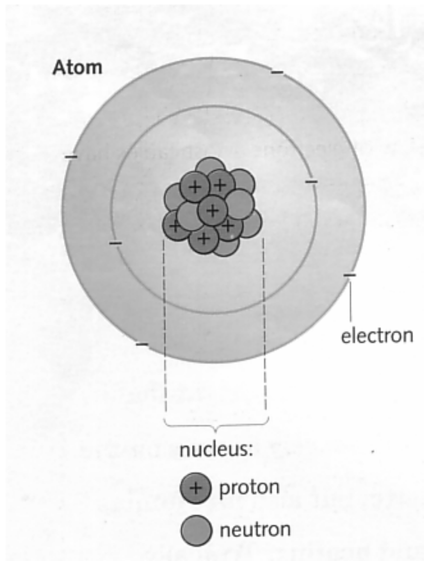
- Matter is made up of tiny particles called atoms.



- At the center of the atom is the nucleus which is made up of protons and neutrons.
- Surrounding the nucleus are particles called electrons.
- A proton has a positive charge.
- An electron has an equal negative charge while a neutron is uncharged / neutral.

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<tr>
<td>Unit of electric charge</td>
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- Electric charge is denoted by the symbol Q.
- The unit of electric charge is the coulomb , C.
- Charge on one electron = -1.6×10^{-19} C
- Charge on one proton = 1.6×10^{-19} C

A body is:

(a) neutral, if it has equal numbers of positive and negative charges.

(b) charged negative, if it has more negative than positive charges. (atom gains electron)

(c) charged positive, if it has more positive than negative charges. (atom losses electron)

- The force acting on two bodies of the same net charges will repel each other.
- The force acting on two bodies of different net charges will attract each other.
- The force causes movement of electrons or flow of charges.

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<tr>
<td>Electric</td>
<td>

- The rate of flow of electric charge

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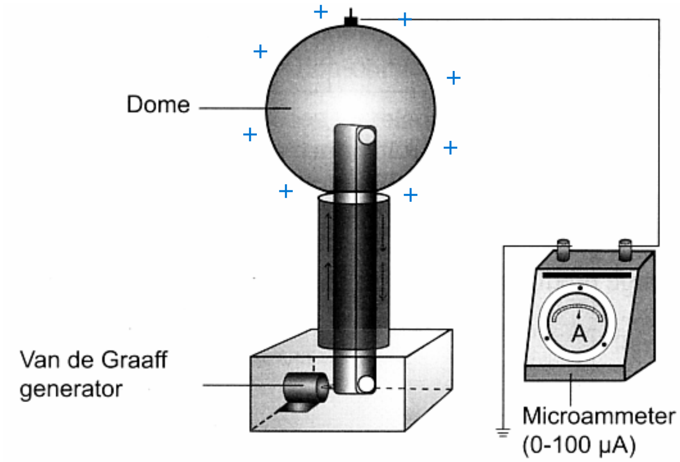
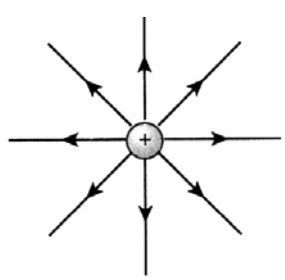
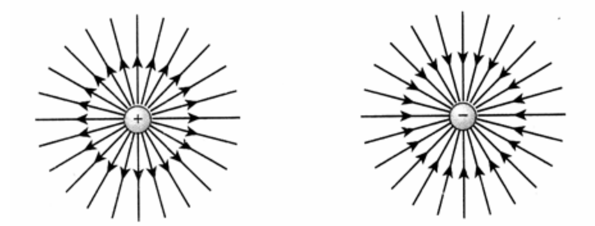
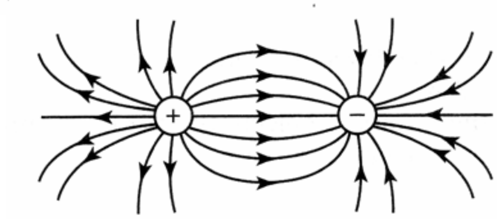
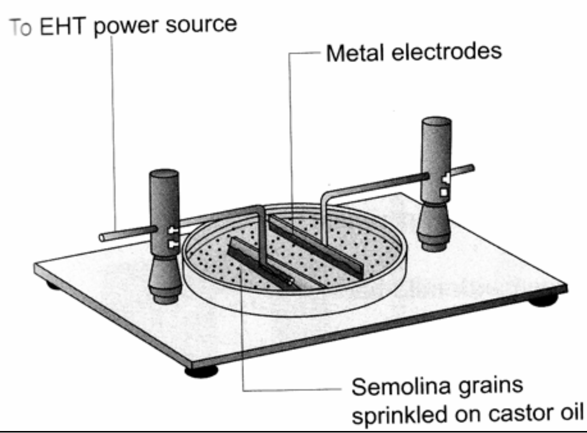
Current	• **Current, I = charge, Q / Time, t** = $I = \frac{Q}{t}$ • **The SI unit = ampere, A**

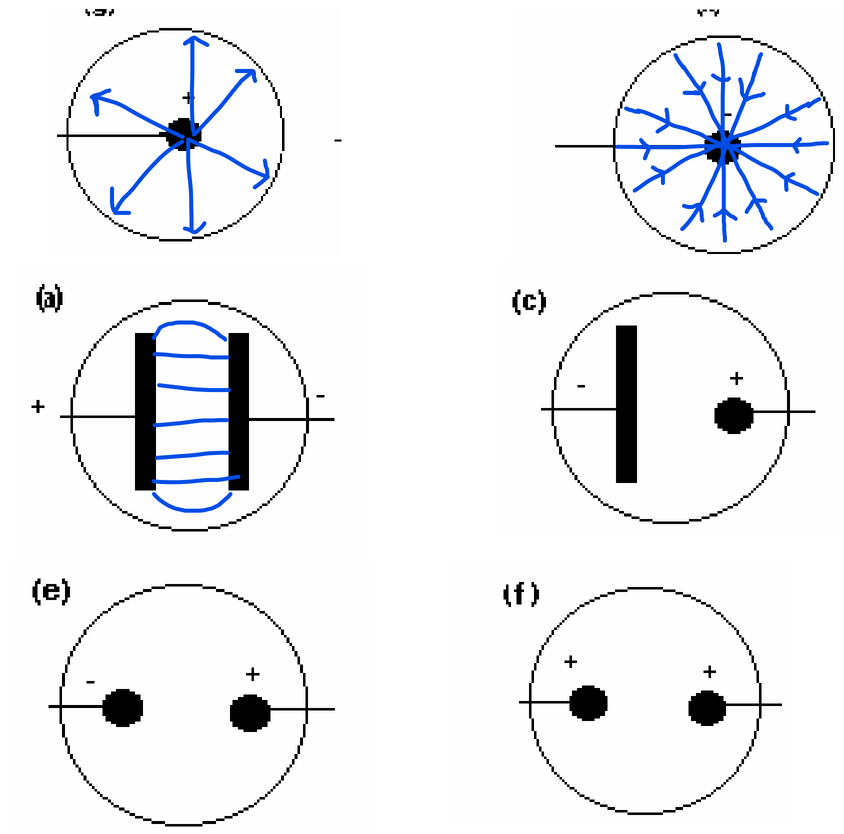
Activity 1

Aim	**To investigate the relationship between electric charges and electric current.**
Apparatus	**Van de Graaff generator, connection wires, microammeter** 
Procedure	• **Start the motor of a Van de Graaff generator for a few minutes to produce positive charges on the metal dome of the generator.** • **Bring your finger close to the dome of the generator. Observe what happens.** • **Touch the dome of the generator with the free end of the wire that is connected to the microammeter. Observe the microammeter needle closely.** • **Switch off the motor of the Van de Graaff generator.**
Observation	**1. You will feel a brief electric shock when your finger is brought close to the dome of the generator.** **2. The microammeter needle is deflected when a wire is connected to the dome of the generator.** **3. You can safely touch the metal dome with your finger.** **4. The microammeter needle is returned to its zero position when the Van de Graaff is switched off.**

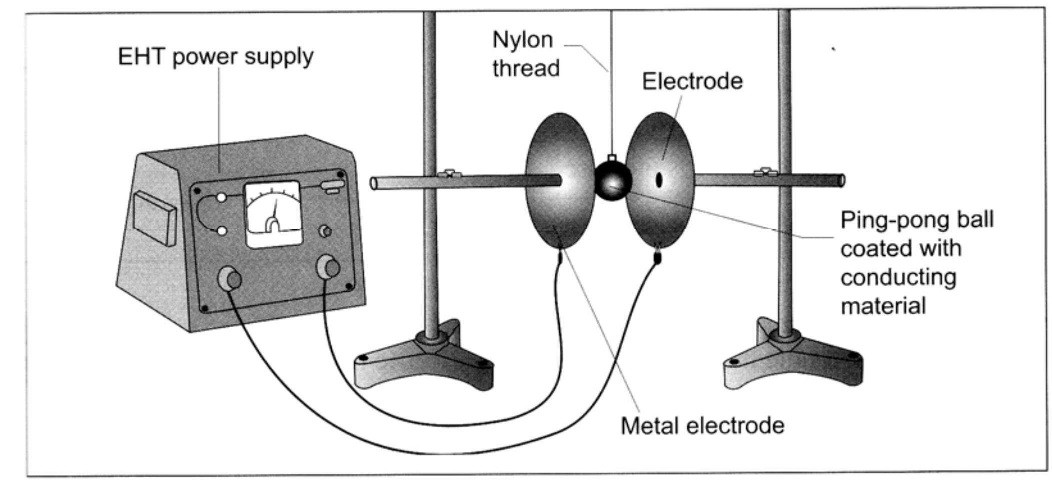
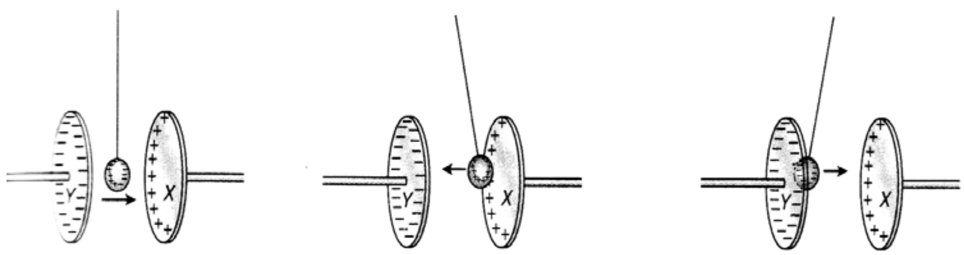
Explanation	1. **When the motor of the Van de Graaff generator is switched on, it drives the rubber belt. This cause the rubber belt to rub against the roller and hence becomes positively charged. The charge is then carried by the moving belt up to the metal dome where it is collected. A large amount of positive charge is built up on the dome.** 2. **The electric field around the metal dome of the generator can produced a strong force of attraction between the opposite charges. Electrons will suddenly accelerate from the finger to the dome of the generator and causes a spark.** 3. **When the wire touches the dome, the microammeter needle is deflected. This shows that a current is flowing through the galvanometer.** 4. **The electric current is produced by the flow of electrons from earth through the galvanometer to the metal dome to neutralize the positive charges on its surface.** 5. **The metal dome can be safely touched with the finger as all the positive charges on it have been neutralized.**
Conclusion	**A flow of electric charge (electrons) through a conductor produces an electric current.**
Describe an electric filed.	**<u>An electric field is a region in which an electric charge experiences an electric force (attraction or repulsion).</u>**  • **An electric field is created from a positively charged sphere in the spaces surrounding it.** • **A negative charged body when placed at any point in this region is pulled towards the charged sphere – attractive force** • **A positively charged body that is placed in the same region is pushed away – repulsive force.**

	• An electric field is represented by a series of arrowed lines called <u>electric field lines.</u> • The lines indicate both the <u>magnitude</u> and <u>direction</u> of the field. • The direction of an electric field at any point is taken as the <u>direction</u> of the <u>force</u> acting on a charged body placed at that point. • Electric field lines never <u>cross</u> each other. • Electric field lines are most <u>dense</u> around objects with the <u>greatest amount of charge</u>.  (a) Positive charge (b) Negative charge 
To map the electric field around metal electrodes	

Method	• **Two plane electrodes connected to the terminals of an EHT power supply are dipped into a dish of castor oil.** • **The EHT is switched on and some semolina grains is sprinkled on the surface of the oil.** • **The electric field pattern formed by the semolina particles is observed and noted.**

	• The experiment is repeated using a plane electrode and a cylindrical electrode followed by two cylindrical electrodes.
Result	

Describe the effect of an electric field on a charge **Method**	**A charged ball in an electric field**

Observation	
Discussion	• **Switch on the EHT power supply and charge the ping-pong ball by contact with one of the electrodes. Observe what happen to the movement of the ping pong ball.**  • **When the EHT power supply is switched on, plate X is positively charged and plate Y is negatively charged. Since the ping-pong ball is neutral it remains at the centre as the electric forces acting on it are balanced.** • **When the ping-pong ball touches the positively charged plate X, the ball receives positive charges from the plate and experiences a repulsive force. The ball will then pushed to the negatively charged plate Y.** • **When the ball touches plate Y, the positive charges are neutral by the negative charges. The ball then negatively charged and repels toward plate X. The process is repeated and the ball oscillate to and fro between the two metal plates X and Y.** • **The rate of oscillation of the ping-pong ball can be increased by increasing the voltage of the EHT power supply and decrease the distance between the two plates X and Y.**
Method	**The effect of an Electric field on a Candle Flame**

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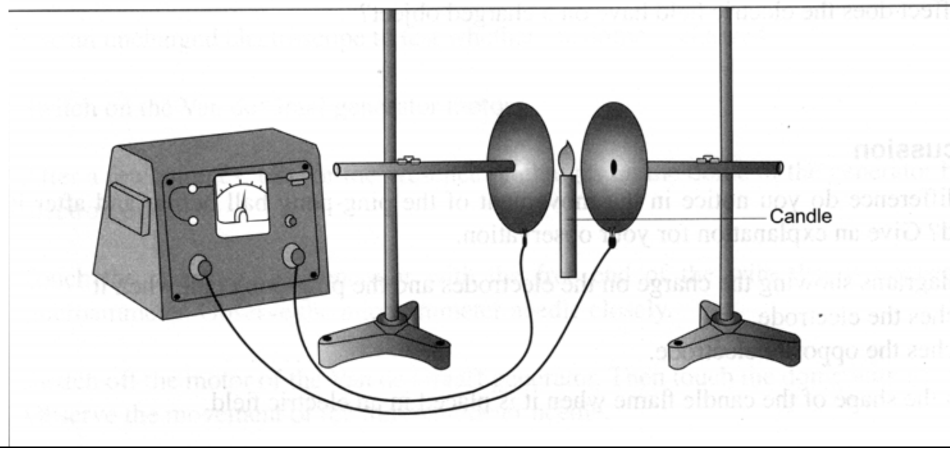
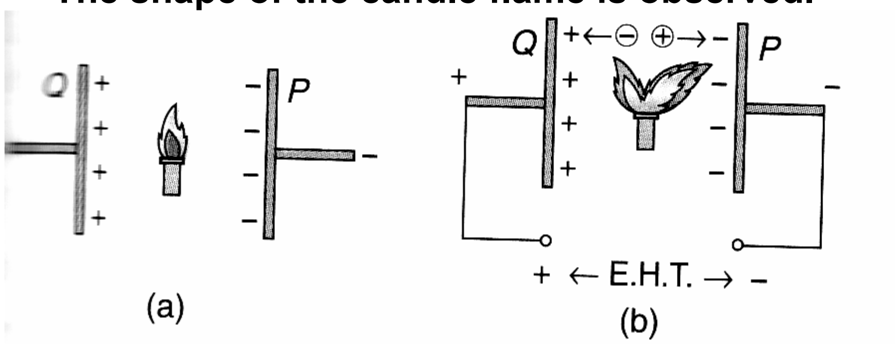
<tr><td></td><td>
</td></tr>
<tr><td>Discussion</td><td>

- The ping-pong ball is replaced with a candle.
- The shape of the candle flame is observed.



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<tr><td>Explain the observation.</td><td>

- When the EHT power supply is switched on, the candle flame divided into two portions in opposite directions.
- The portion that is attracted to the negative plate P is very much larger than the portion that is attracted to the positive plate Q.

- The hot flame of the candle ionized the air molecules in its surrounding into positive and negative ions.
- The positive ions are attracted towards the negative plate P. At the same time, the negative ions are attracted to the positive plate Q.
- The movement of the ions towards the plated P and Q caused the candle flame to spread out.

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<tr><td>Explain why the flame is not symmetrical</td><td>

- The bigger portion of the flame is attracted towards the negative plate as the mass of the positive ions is larger than of the negative ions.

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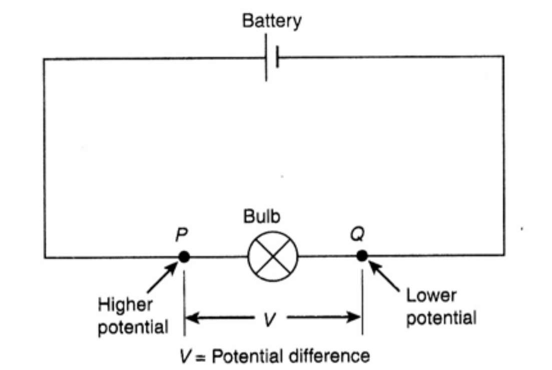
Solving problems involving electric charge and current	
<u>Example 1</u> **The current flows in a light bulb is 0.5 A.** **(b) Calculate the amount of electric charge that flows through the bulb in 2 hours.** **(c) If one electron carries a charge of 1.6×10^{-19} C, find the number of electrons transferred through the bulb in 2 hours.** Q = It Q = 0.5(2X60X60) Q = 3600C Q = Ne 3600 = N(1.6 x 10^-19) N = 2.25 x 10^22	**<u>Example 2</u>** **Electric charges flow through a light bulb at the rate of 20 C every 50 seconds. What is the electric current shown on the ammeter?** I = Q/t I = 20/50 I = 0.4A **<u>Example 3</u>** **When lightning strikes between two charged clouds, an electric current of 400 A flows for 0.05 s. What is the quantity of charge transferred?** Q = It Q = 400(0.05) Q = 20C

7.2 RELATIONSHIP BETWEEN ELECTRIC CURRENT AND POTENTIAL DIFFERENCE

Define Potential Difference



- **When a battery is connected to a bulb in a circuit, it creates electric field along the wires.**
- **The positive terminal P is at a higher potential and the negative terminal Q is at a lower potential.**
- **The potential difference between the two terminals causes the charges to flow across the bulb in the circuit and lights up the bulb.**
- **Work is done when electrical energy carried by the charges is dissipated as heat and light energy after crossing the bulb.**

Potential difference

The <u>potential difference</u>, V, is defined as the work done when 1 C of charge moves between two points in an electric field.

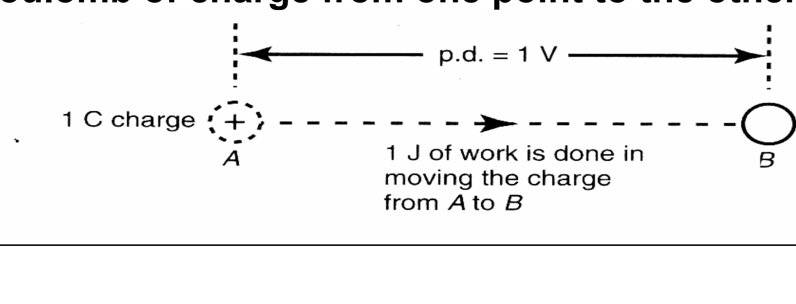
Equation

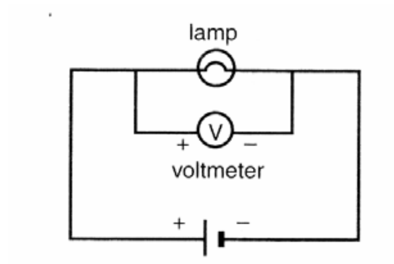
Potential difference, $V = \dfrac{\text{Work done, } W}{\text{Charge, } Q}$ **or** $V = \dfrac{\text{Energy, } E}{\text{Charge, } Q}$

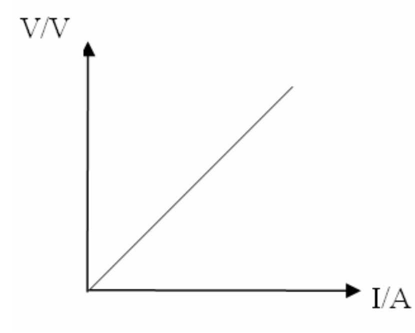
$V = \dfrac{W}{Q} = \dfrac{E}{Q}$ **SI unit is Volt (V)**

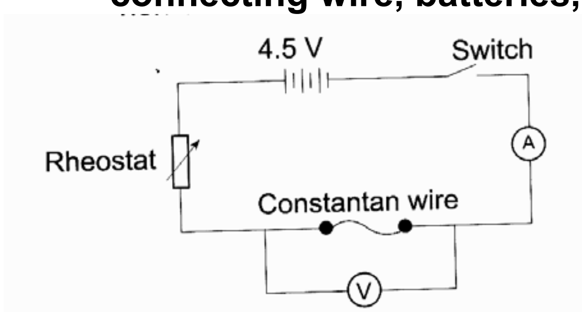
What is 1 Volt?

- **1 Volt = 1 joule per coulomb.**
- **The potential difference across two points in a circuit is 1 Volt if 1 Joule of work is done in moving 1 Coulomb of charge from one point to the other.**

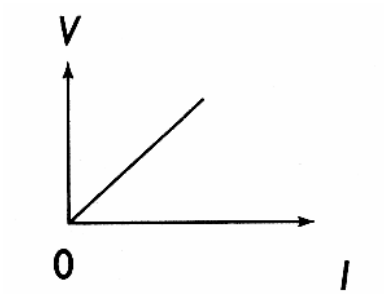
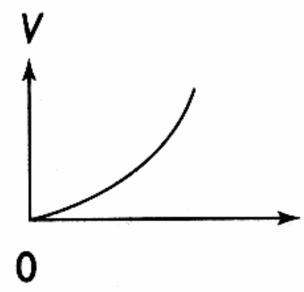


How to measure potential difference? **How to measure current?**	• **The potential difference across two points in a circuit can be measured using a voltmeter. Voltmeters must always be connected in <u>parallel</u> between the points concerned.**  • **Ammeter measures current in amperes.** • **Connected in series with a resistor or a device** • **Ammeter has a low resistance so that its existence has little effect on the magnitude of current flowing.**
Solve problems involving W = QV	**1. In a closed circuit, a 6 V battery is used to drive 40 C of electric charge through a light bulb. How much work is done to drive the electric charge through the bulb?** W = QV W = 40(6) W = 240J
	2. If 72 J of work has to be done to carry 6 C of charge across two parallel metal plates, what is the potential difference across the metal plates? V = W/Q V = 72/6 V = 12V
Describe the relationship between current and potential difference	• **The greater the potential difference or voltage, the greater the current flow.** • **When the potential difference between two points in a circuit increases, the current flowing through it increases.** • **When the potential difference (V) between the points decreases, the current (I) decreases.** • **The potential difference is directly proportional to the current flowing through it.**

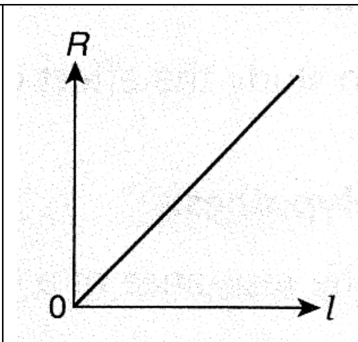
State Ohm's Law	**The electric current, I flowing through a conductor is directly proportional to the potential difference across it if the temperature and other physical conditions are constant.** can affect R
Sketch a Graph of V against I	**From Ohm's Law,** **V $\propto$ *I* or** $\frac{V}{I}$ **= constant = gradient** **The graph of V against *I* is straight line through the origin.** **The gradient of the graph is constant.** 
What is ohmic conductor and non-ohmic conductor?	• **Conductors that obey Ohm's Law are called <u>ohmic conductors.</u>** • **Conductors that do not obey Ohm's Law are called <u>non-ohmic conductors.</u>**
Define resistance	• **A measure of how much a conductor resists the flow of electricity. A good conductor has a low resistance and a poor conductor has a high resistance.** • **<u>The resistance (R) of a conductor is defined as the ratio of the potential difference (V) across the conductor to the current (I) flowing through it.</u>** $R = \frac{V}{I}$ **unit = VA^{-1} = ohm, Ω**
Disadvantage of resistance **Advantage of resistance**	• **Resistance causes some of the electrical energy to turn into <u>heat</u> , so some electrical energy is lost along the way if we are trying to transmit electricity from one place to another through conductor.** • **It is resistance that allows us to use electricity for heat and light. The heat is generated from electric heaters or the light that we get from light bulbs is due to the resistance of the wire. In a light bulb, the current flowing through a resistance filament causes it to become hot and then glow.**

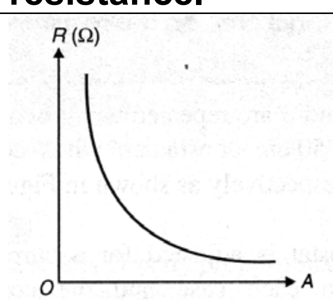
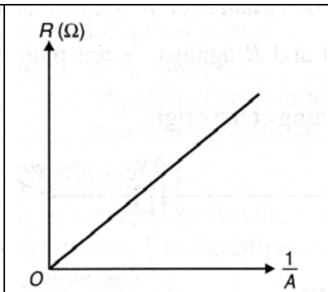
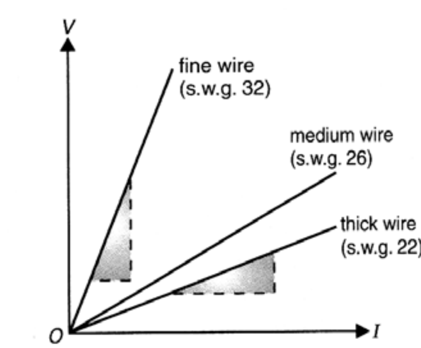
Ohm's Law equation	**V = IR where V = potential difference , I = current R = resistance**
Plan & conduct an experiment to find the relationship between current and potential difference.	**Aim: To determine the relationship between the potential difference and the electric current flowing through an ohmic and non ohmic conductor.** **Hypothesis:** The larger the potential difference, the larger the electric current.
Variables	**Manipulated variable:** Current **Responding variable:** Potential difference **Controlled variables:** thickness / cross sectional area / resistivity / temperature of constantan wire
Procedure	**Apparatus: Rheostat, constantan wire, switch, connecting wire, batteries, ammeter, voltmeter** 
Control MV **Measure RV** **Repeat** **Tabulate** **Analyze**	**Turn on the switch and adjust the rheostat until the ammeter reads the current, I = 0.2 A.** **Read the value of the potential difference, V, from the voltmeter. Record the readings.** **Repeat the experiment for I = 0.3 A, 0.4 A, 0.5 A, 0.6 A** **Tabulate the data.** **Plot a graph of V against I.** **Repeat the experiment by replacing the constantan wire, which is ohmic conductor with an electric bulb which is a non-ohmic conductor.** nichrome

Sketch the graph V vs I and describe the shape of each graph.

ohmic conductor	non ohmic conductor
	

<table>
<tr><td colspan="4"><u>Explain factors that affect resistance</u></td></tr>
<tr><td>Length, l</td><td colspan="2">For conductors of the same material and cross-sectional area, the resistance R is directly proportional to its length, l
$R \propto l$

This means that doubling the length doubles the resistance.</td><td></td></tr>
<tr><td>Cross-sectional area, A
$R \propto \frac{1}{A}$</td><td colspan="3">For conductors of the same material and length, the resistance R is inversely proportional to its cross-sectional area, A.

This means that doubling the cross-sectional area halves the resistance.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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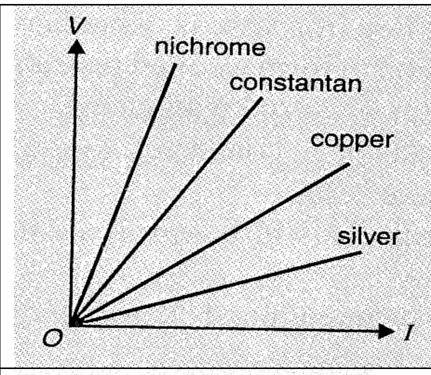
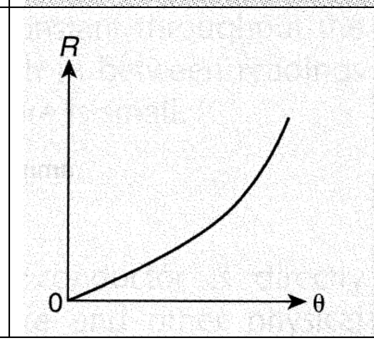
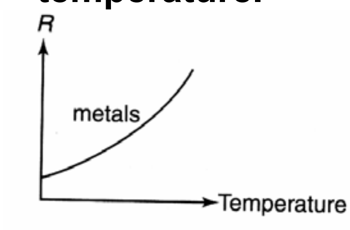
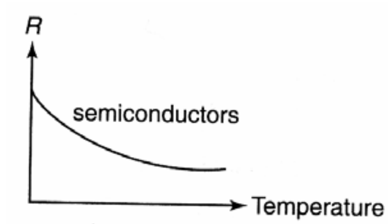
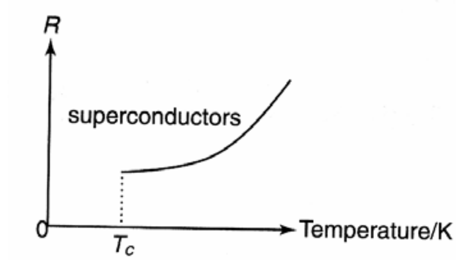
Type of material	**The resistance of a wire depends on the material it is made from.**	
Tempera-ture	**For conductors of the same material, length and cross-sectional area, the resistance R generally increases with temperature.**	

Solve problems involving potential difference, current and resistance.

1. A current of 0.5 A flows through a length of resistance wire when a potential difference of 12 V is applied between the ends of the wire. **(a) what is the resistance of the wire?** **(b) What is the current flowing through the wire if the potential difference is increased to 15 V.**	R = V/I R = 12/0.5 R = 24 ohm I = V/R I = 15/24 I = 0.625A

Describe super-conductor	• **The resistance of a metal increases with temperature** • **The resistance of a semiconductor decreases with temperature.**   • **A superconductor is a material whose resistance becomes zero when its temperature drops to a certain value called the <u>critical temperature.</u>** 
Advantages	• **This enables superconductors to maintain a current with no applied voltage at that temperature.** • **Able to sustain large currents** • **Smaller power loss during transmission** • **Less heat energy is wasted** • **Small-sized motors and generators can be used.**
MAGLEV trains	• **Magnetic-levitation is an application where superconductors perform extremely well. Transport vehicles such as trains can be made to 'float' on strong superconducting magnets, virtually eliminating friction between the train and its tracks.**
MRI scanner	• **Magnetic resonance imaging (MRI) is to determine what is going on inside the human body. By exposing the body to a strong superconductor-derived magnetic field, hydrogen atoms that exist in the body's water and fat molecules are forced to accept energy from the magnetic field. They then release this energy at a frequency that can be detected and displayed graphically by a computer.**
Electrical power line	• **Electric cable made of superconductors will increase the efficiency of electrical power transmission as the loss of energy in the form of heat is greatly reduced.**

7.3 SERIES AND PARALLEL CIRCUITS

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<td>Identify series circuits</td>
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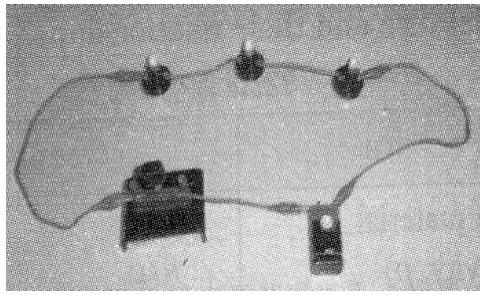
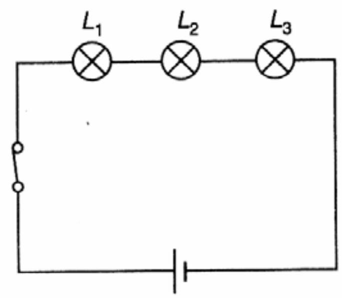
- **In a series circuit, two or more resistors are connected one end after another to form a single path for current flow.**

- **The bulbs share the potential difference from the battery, so each glows dimly.**
- **The brightness of each bulb is equally the same since the same current flows through each bulb.**
- **If one bulb is removed, the other goes out because the circuit is broken.**

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<td>Identify parallel circuits</td>
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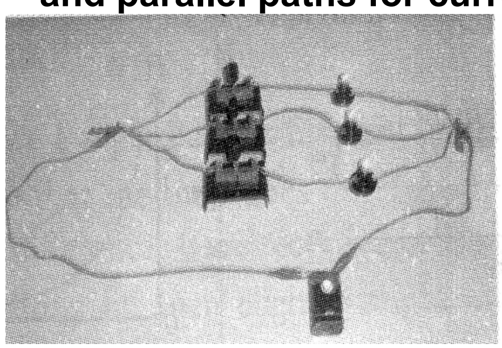
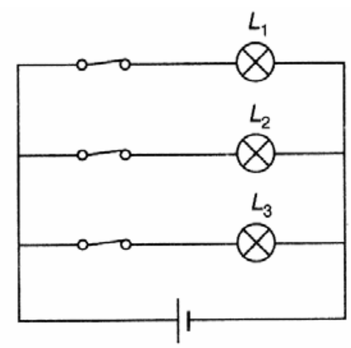
- **All the components are connected with their corresponding ends joined together to form separate and parallel paths for current flow.**

- **Each bulb gets the full potential difference from the battery because each is connected directly to it. So each bulb glows brightly.**
- **The brightness of each bulb in a parallel circuit is brighter than those in a series circuit with the same number of bulbs.**
- **If one bulb is removed, the other keeps working because it is still part of an unbroken circuit.**

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Compare the current and potential difference of series circuits and parallel circuits.

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<tr><th>Series circuit</th><th>Parallel circuit</th></tr>
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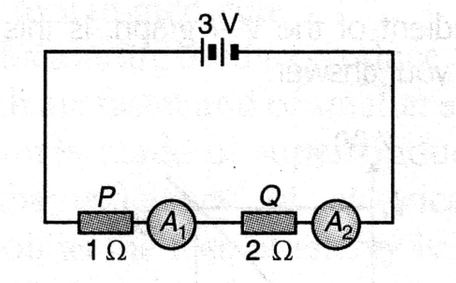

The current has only one path to flow.
Readings on ammeter A_1 and A_2 are the same. $I_1 = I_2$

<u>Current</u> flows through each <u>resistor</u> in <u>series</u> is the <u>same</u>.

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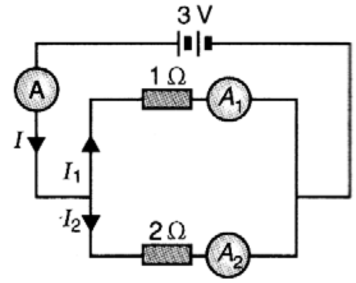

The current has more than one path to flow. The current from the battery splits into separate branches.
Reading on ammeter A is the sum of readings on A_1 and A_2.
$I = I_1 + I_2$
The two resistors <u>share</u> the <u>main current.</u>

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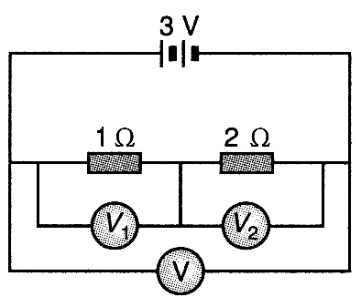

Reading on voltmeter V is the sum of readings on V_1 and V_2
$V = V_1 + V_2$

The two resistors <u>share</u> the applied <u>potential difference</u>.

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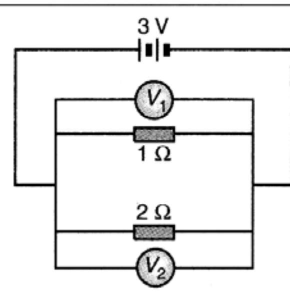
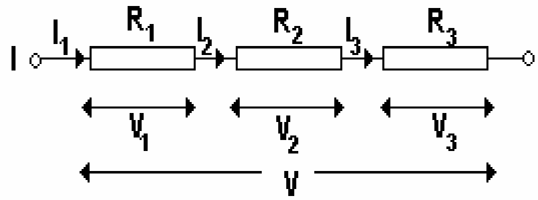
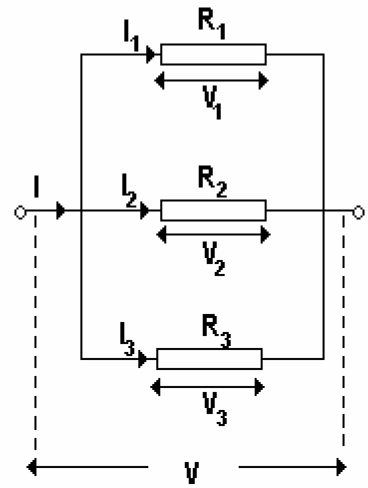


Readings on voltmeters V_1 and V_2 are the same.
$V_1 = V_2$
<u>Potential difference</u> across each <u>resistor</u> in <u>parallel</u> is the <u>same</u>.

</td></tr>
<tr><td>When a bulb in a series circuit has blown up, the other bulb would not be able to light up</td><td>When a bulb in a parallel circuit has blown up the other bulb would still be able to light up.</td></tr>
<tr><td colspan="2">The bulbs in parallel circuit light up brighter as compared to the bulbs in series circuit. In parallel circuit, the voltage across each bulb is higher as compared to the voltage of each bulb in series circuit. The bulb lights up brighter indicates that the current that passes through it is larger.</td></tr>
</table>

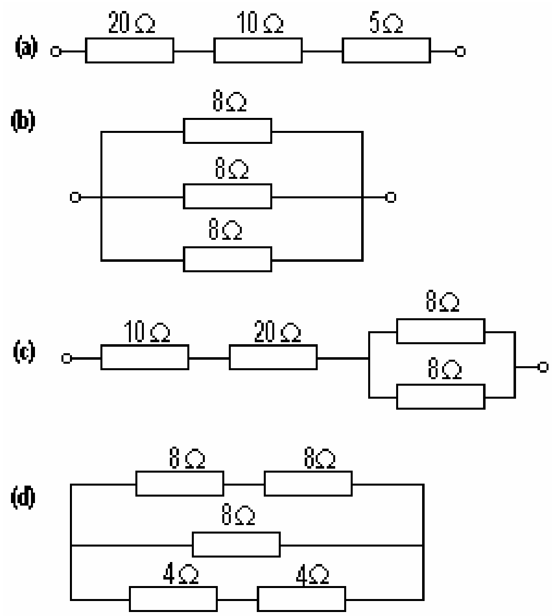
Determine the effective resistance of resistors connected in series and parallel.

	Series circuit	Parallel circuit
		
Current	$I = I_1 = I_2 = I_3$	$I = I_1 + I_2 + I_3$
Potential Difference	$V = V_1 + V_2 + V_3$	$V = V_1 = V_2 = V_3$
Resistance	$R_1 + R_2 + R_3 = R$	$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{R}$
Brightness of light bulb	**Each bulb has the same brightness. Dimmer**	**Each bulb has the same brightness. Brighter.**

Solve problems involving current, potential difference and resistance in series circuits, parallel circuits and their combinations.

<table>
<tr>
<td>

1. Calculate the effective resistance of the resistors.



</td>
<td>

a) R = 20+10+5

b) 1/R = 3/8
R = 8/3
R = 2.667

R = R/n if all are the same

c) R3 = 8/2
= 4
R = 10+20+4 = 34

d) R1 = 16
R3 = 8

1/R = 1/16+1/8 +1/8
R = 3.2

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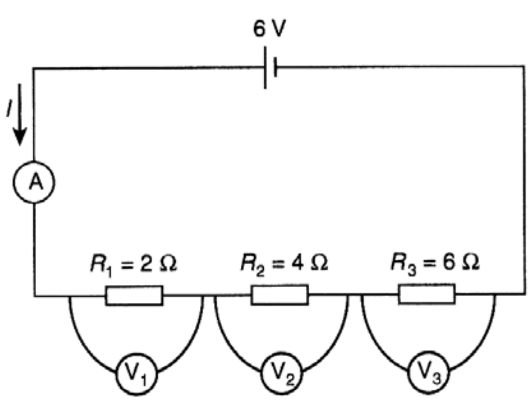
2. Three resistors R_1, R_2 and R_3 are connected in series to a 6 V battery.



Calculate

(a) the effective resistance, R of the circuit,
(b) the current, I in the circuit
(c) the potential difference across each resistor, V_1, V_2 and V_3.

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<td>

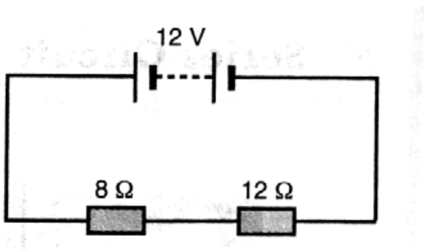
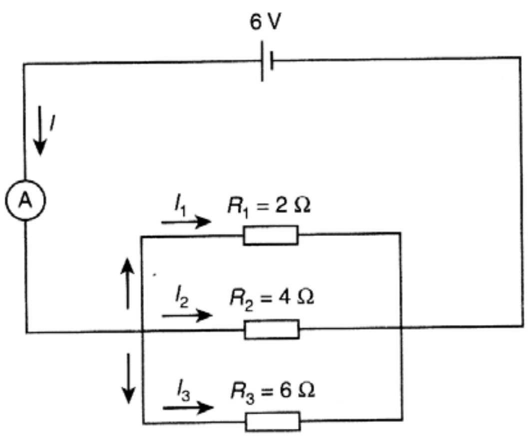
R = 12

I = V/R
= 6/12
= 0.5A

V1= IR1 = 0.5(2) = 1
V2= IR2 = 0.5(4) = 2
V3= IR3 = 0.5(6) = 3

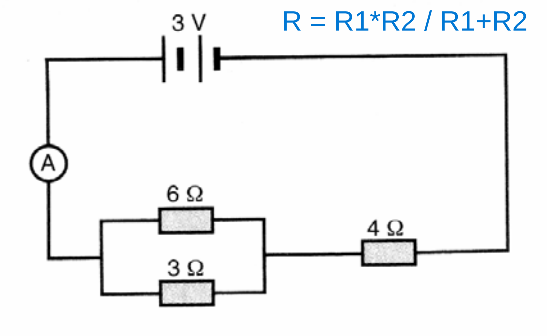
V1 = (R1/ total R) V total

</td>
</tr>
</table>

3. An 8 Ω resistor and a 12 Ω resistor are connected with a 12 V battery. What is the potential difference across the **(a) 8 Ω resistor** **(b) 12 Ω resistor**  	V1 = (8/20)12 V1 = 4.8V V2 = 12-4.8 = 7.2V
4. The three resistors R_1, R_2 and R_3 are connected in parallel to the battery.  **Calculate** **(a) the potential difference across each resistor,** **(b) the effective resistance, R of the circuit** **(c) the current, I in the circuit** **(d) the current I_1, I_2 and I_3 passing through each resistor.**	a) V = V1 = V2 = V3 = 6 b) 1/R = 1/R1 + 1/R1 + 1/R3 1/R = 1/2 + 1/4 + 1/6 = 11/12 R = 1.091 c) I = V/R I = 6/1.091 = 5.5A d) I1 = V/R1 = 6/2 = 3A I2 = V/R2 = 6/4 = 1.5A I3 = V/R3 = 6/6 = 1A

5. A potential difference of 3 V is applied to a network of resistors.

R = R1*R2 / R1+R2



(a) What is the reading of the ammeter A?
(b) What is the p.d across the parallel network?
(c) What is the current flowing through the 6 Ω resistor?

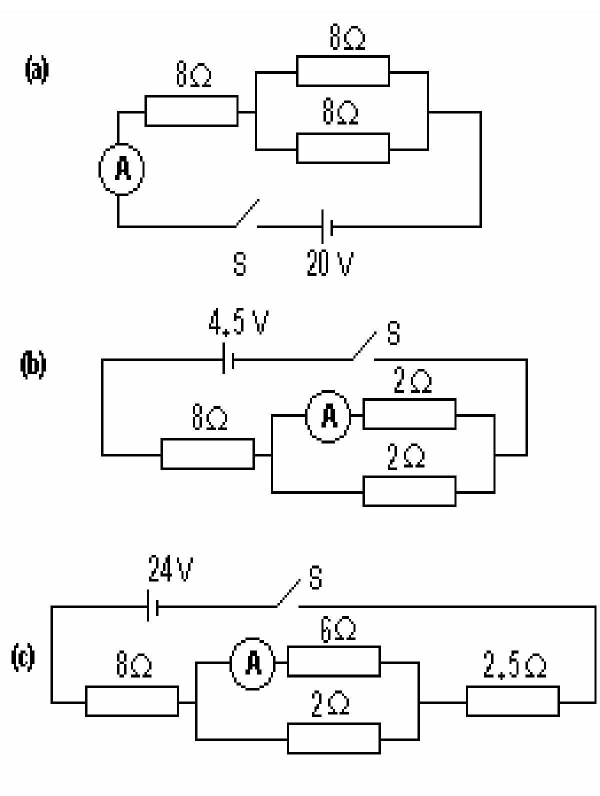
1/R = 1/6 + 1/3 = 1/2
R1 = 2
R = 2+4 = 6

I = V/R = 3/6 = 0.5A

V1 = IR1 = 0.5(2) = 1V

I1 = V/R1
= 1/6
= 0.167A

6. What is the reading of the ammeter?



R2 = 8/2 = 4
R = 8+4 = 12

I = 20/12 = 1.75A

R = 2 / 2 = 1
I = V/R = 4.5

I1 = (R2 / total R) total I
I1 = (2/4) 4.5
I1 = 2.25

1/R2 = 1/6 + 1/2 = 2/3
R2 = 1.5
R = 8 + 1.5 + 2.5
R = 12
I = 24/12 = 2A

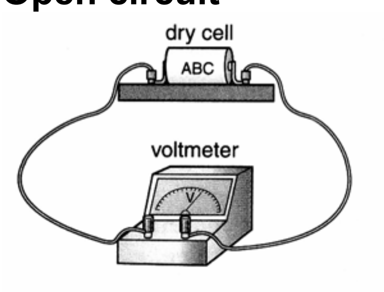
I1 = (2 / 8) 2
I1 = 0.5A

7.4 ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE

<table>
<tr><td>Define electro-motive force (e.m.f), E</td><td colspan="2">The electromotive force, E (e.m.f.) is defined as the work done by a source in driving one coulomb of charge around a complete circuit.

Unit of e.m.f. is the volt, V = J C^{-1}</td></tr>
<tr><td>What does the label 1.5 V on the battery mean?</td><td colspan="2">The voltage label on a battery or cell indicates its e.m.f
The label 1.5 V on a dry cell indicates the e.m.f. of the cell is 1.5 V.
A cell has an e.m.f. of 1.5 V if a flow of 1 C of charge produces 1.5 J of electrical energy to the whole circuit.</td></tr>
<tr><td>Compare e.m.f. and potential difference</td><td>

• **Open circuit**



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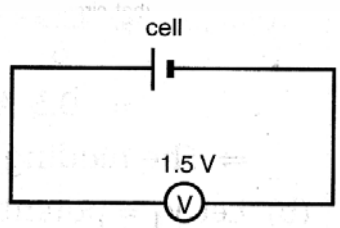
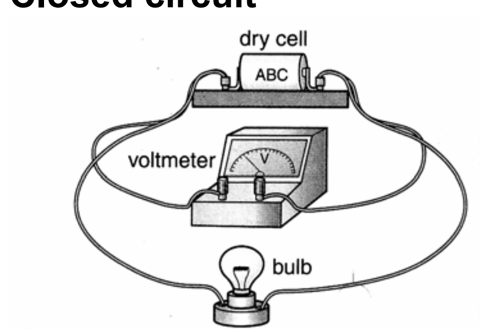


• **No current flows through the circuit**
• **The voltmeter reading is 1.5 V.**
• **The e.m.f. = the reading of the voltmeter which is connected directly across the terminals of the cells.**
• **e.m.f. = 1.5 V**

</td><td>

• **Closed circuit**



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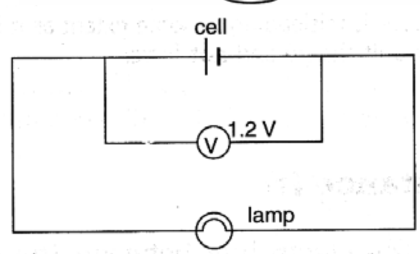
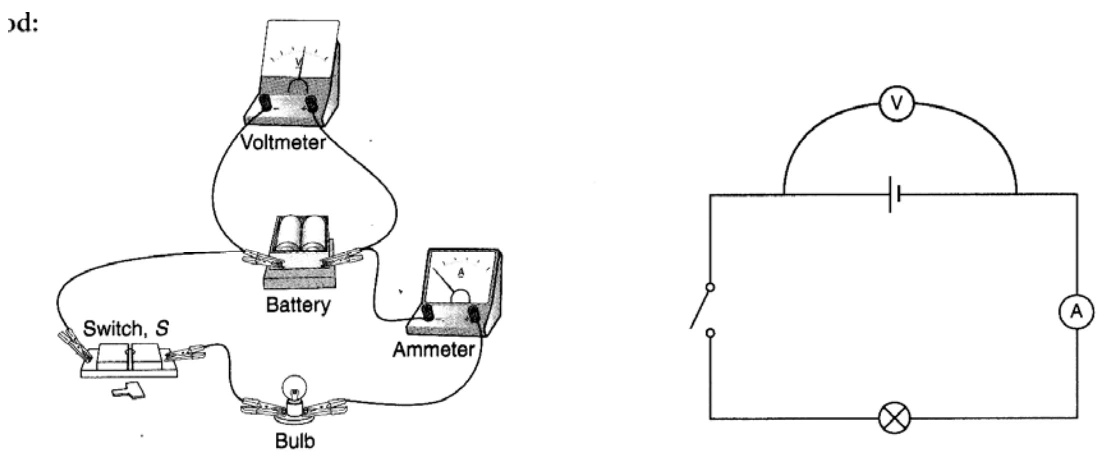


• **Current flows through the circuit**
• **The reading of the voltmeter will drop a little if a lamp is connected in series to the cell.**
• **If the voltmeter reading is 1.2 V, then the potential difference across the lamp = 1.2 V.**
•

</td></tr>
</table>

Electromotive Force, E	Potential Difference, V
Indicates the electrical energy given to 1 C of charge flowing through the cell or source.	Indicates the electrical energy that is transformed to other forms of energy when 1 C of charge passes through a component in a closed circuit.
Used in reference to source of electrical energy	Used in reference to electrical component in a circuit.
Represented by the voltmeter reading in an open circuit (when switch is opened)	Represented by the voltmeter reading in a closed circuit (when switch is closed)
Measured in JC^{-1} or Volts,V	Measured in JC^{-1} or Volts,V

To distinguish between e.m.f. and potential difference

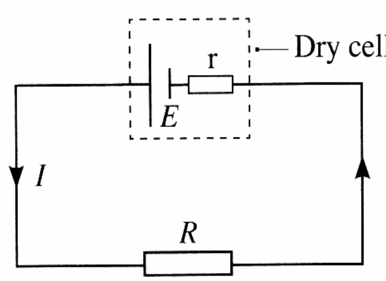


(a) Electrical circuit (b) Circuit diagram

- **Switch S is let in the open position. What happens to the bulb is observed. The readings of the ammeter and the voltmeter are recorded.**
- **Switch S is closed and what happens to the bulb is observed. The readings of the ammeter and the voltmeter are recorded.**

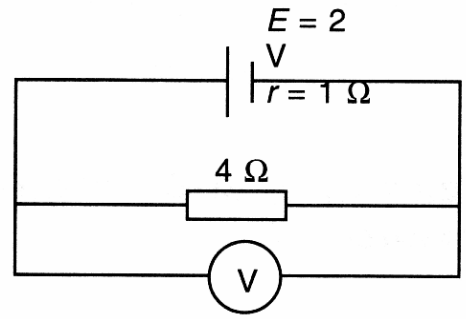
Position of switch	Open	Closed
State of the bulb	Light off	Light up
Ammeter reading/A	0 A	0.2 A
Voltmeter reading/V	3.0 V	2.6 V

Discussion 1. Why does the ammeter reading is zero when switch S is open and have a reading when switch S is closed.	The reading of the ammeter when switch S is open is zero because there is no flow of charge in an open circuit, Current flow is zero. When switch S is closed, there is an ammeter reading due to the flow of charge in the closed circuit produce flow of current.
2. Compare the difference in the two voltmeter readings measured.	The reading of the voltmeter when switch S is open is higher than when switch S is closed.
3. What is the work done in moving 1 C of charge around the complete circuit?	The reading of the voltmeter when the circuit is open is the e.m.f. value of the cell. The voltmeter reading = 3.0 V 3.0 J of electrical energy is required to move 1 C of charge around the complete circuit.
4. What is the work done in moving 1 C of charge across the light bulb?	The reading of the voltmeter when the circuit is closed is the potential difference across the bulb. The voltmeter reading = 2.6 V Therefore, 2.6 V of electrical energy is dissipated by 1 C of charge across the light bulb. The electrical energy is transformed to light and heat energy.
5. Why there is a difference in the two voltmeter readings measured?	There is a drop in potential difference across the cell. Drop in potential Difference = e.m.f - potential difference (bulb) 0.4 V = 3.0 V – 2.6 V This is caused by the internal resistance of the cell.

Why there is drop in potential difference?	• **In an open circuit when there is no current flow, the potential difference, V across the cell is the electromotive force, *E* of the cell.** • **In a closed circuit when there is a current flow, the potential difference, V across the cell is smaller than the e.m.f. of the cell.** • **This drop in potential difference across the cell is caused by the internal resistance of the cell.** • **e.m.f. = 1.5 V means the cell gives 1.5 J of electrical energy to each coulomb that passes through it. The energy dissipated in the resistor or bulb is less than 1.5 J per coulomb. The current that flows through the circuit also flows through the battery.** • **Internal resistance in the battery causes this loss of energy or drop in potential difference across the battery.** • **Some of the energy per charge the battery provides will be used to overcome the internal resistance of the battery and change to heat energy.** • **In practice, the potential difference a battery provides to an external circuit will always be less than its e.m.f.**
Explain Internal Resistance, r	**The internal resistance, r of a source or battery is the resistance against the moving charge due to the electrolyte in the source or cell.** **Work is needed to drive a charge against the internal resistance.** **This causes a drop in potential difference across the cell as the charge flows through it and loss of heat energy in the cell.**
Explain equation relates, *E, V, I,* and r	**E.m.f of the cell = *E*** **P.d to the external circuit = V** **Drop in P.d. inside the cell = *Ir*** $Ir = E - V$ *Or* $E = V + Ir$ *Or* $E = IR + Ir$ 

Solve problems involving e.m.f and internal resistance

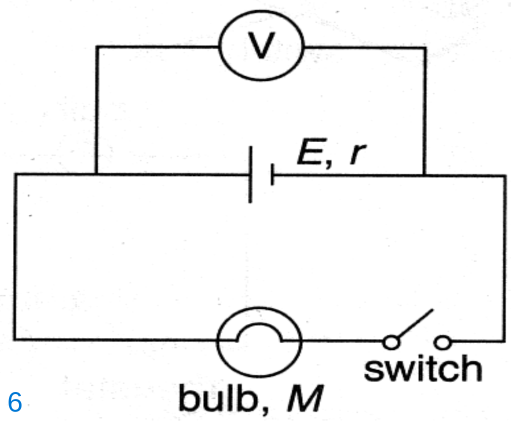
Example 1
A cell with e.m.f. 2 V and internal resistance 1 Ω is connected to a resistor of 4 Ω. What is the reading on the voltmeter when it is connected across the 4 Ω resistor?



emf = I(R+r)
2 = I(5)
I = 2/5

V = E - Ir
V = 2 - 0.4
V = 1.6V

Example 2
A bulb M is connected to a battery by means of a switch. A voltmeter is also connected across the battery. When the switch is open, the voltmeter reads 6.0 V. When the switch is closed, the voltmeter reads 4.8 V.
(a) What is the e.m.f. of the battery?
(b) If the resistance of the bulb M is 8 Ω, what is the current passing through M when the switch is closed?
(c) Find the value of the internal resistance, r, of the battery.

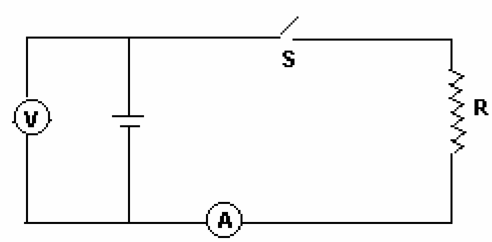


a) emf = 6

b) I = V/R = 4.8/8 = 0.6

c) Ir = emf - V
0.6r = 1.2
r = 2

1. When switch S is opened, the voltmeter reading is 1.5 V. When the switch is closed, the voltmeter reading is 1.35 V and the ammeter reading is 0.3 A.



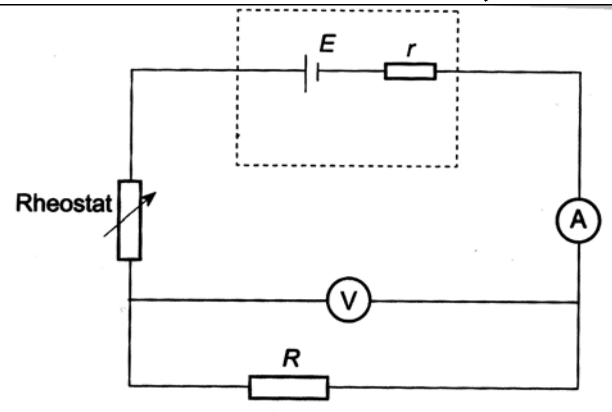
Calculate:
(a) e.m.f 1.5V
(b) internal resistance
(c) resistance of R

Ir = emf - V
0.3r = 1.5 - 1.35
r = 0.15/0.3
r = 0.5

R = V/I
R = 1.35/0.3
R = 4.5

Determine e.m.f. and internal resistance, r

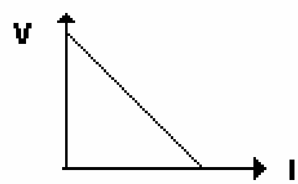
Diagram



Procedure

- Turn on the switch, adjust the rheostat until the ammeter reading is I = 0.2 A
- Record the voltmeter reading as V
- Repeat the experiment with current, I = 0.3 A, 0.4 A, 0.5 A and 0.6 A.

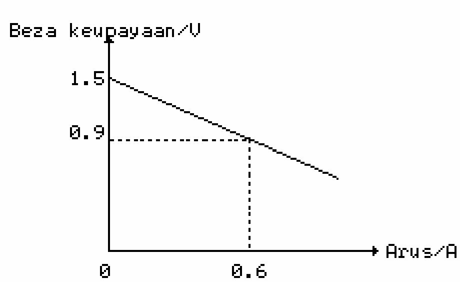
Plot graph of V against I on a graph paper.



$E = V + Ir$
$V = -Ir + V$
Compare $y = mx + c$
$\therefore$ E = y intercept
r = gradient

1. Why the potential difference across the cell decreases when the current increases?

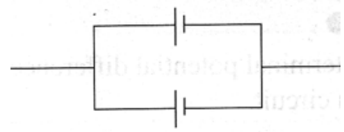
- When the switch is opened, the voltmeter = e.m.f , I = 0 A
- When the switch is closed, current flows through the circuit and there is a drop in potential difference due to the internal resistance in the cell ($V = Ir$)
- The readings of the voltmeter decreases as V = e.m.f. - Ir
- The bigger the current, the bigger the drop in potential difference (Ir) and the lesser the reading of the voltmeter, V.



Determine:

(a) the e.m.f of the cell

(b) the internal resistance of the cell

Comparison between total e.m.f and total internal resistance in a series and parallel circuit . each cell has E = 1.5 V and r = 0.5 Ω	
	
Total e.m.f = 2 x 1.5 = 3.0 V	**Total e.m.f = 1.5 V**
Total r = 2 x 0.5 = 1.0 Ω	**Total r = ½ x 0.5 = 0.25 Ω**

7.5 ELECTRICAL ENERGY AND POWER

Define electrical energy	• **Electrical energy is defined as the ability of the electric current to do work.** • **It is supplied by a source of electricity such as cell or battery when current flows in a closed circuit.** • **It can be converted by an electrical appliance into other forms of energy such as heat, light, mechanical when current flows in it.**
Relation-ship between electrical energy, voltage, current and time.	• **The potential difference, V across two points is defined as the energy, E dissipated or transferred by 1 C of charge, Q that moves through the two points.** $V = \frac{E}{Q}$ • **Current is the rate of charge flow.** $Q = It$ • $E = VQ = VIt$ • **From ohm's law,** $V = IR$ **:** $E = I^2Rt$ **or** $I = \frac{V}{R} \Rightarrow E = \frac{V^2t}{R}$ • **The unit of electrical energy is Joule, J**
Define electric power	• **Power is the rate of electrical energy dissipated or transferred.** • **Power = Energy / Time** $P = \frac{E}{t}$ $\therefore P = \frac{VIt}{t} = VI$ **unit = J s^{-1} = Watt = W**

<table>
<tr><td></td><td>

- For resistors and lamps, combine P = VI with V = IR

$$P = VI \qquad P = I^2 R \qquad P = \frac{V^2}{R}$$

</td></tr>
<tr><td>Power rating</td><td>

- An electrical kettle which is marked 240 V 1500 W means that the electric kettle will consume 1500 J of electrical energy every 1 second if it is connected to the 240 V.

</td></tr>
<tr><td>Formula for energy consumed</td><td>

- The amount of electrical energy consumed in a given time:
Energy consumed = Power rating x time
E = Pt

</td></tr>
<tr><td>Compare power rating and energy consumption of various electrical appliances</td><td>

- The larger the power rating in the electrical appliance, the more energy is used every second.
- The longer the usage time, the more electrical energy is consumed.

<table>
<tr><th>Appliance</th><th>Power rating / W</th><th>Time / hr</th><th>Energy consumption / J</th></tr>
<tr><td>Fan</td><td>50</td><td>1</td><td></td></tr>
<tr><td>Television</td><td>100</td><td>1</td><td></td></tr>
<tr><td>Computer</td><td>200</td><td>1</td><td></td></tr>
<tr><td>Air condition</td><td>1 000</td><td>1</td><td></td></tr>
<tr><td>Washing machine</td><td>1 800</td><td>½</td><td></td></tr>
<tr><td>Water heater</td><td>3 600</td><td>½</td><td></td></tr>
</table>

</td></tr>
<tr><td>What is kWh?</td><td>

- 1 kilowatt-hour represents the amount of energy consumed in 1 hour by an electrical appliance at the rate of 1 kilowatt.
- 1 kWh = 1 unit energy
- E = Pt
1 kWh = 1 kW x 1 hr = 1000 W x 3600 s = 3.6 x 10^6 J

</td></tr>
<tr><td>How to calculate the cost of electrical energy</td><td>

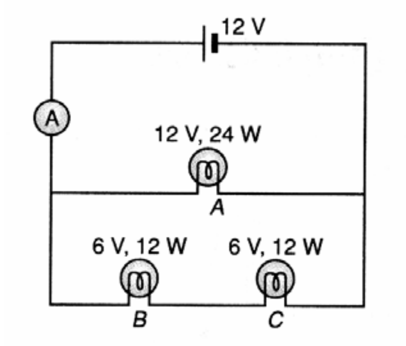
- Cost = number of units x cost per unit
- If one unit of electricity cost 21.8 cents, calculate the cost of using five 36 W fluorescent lamps if they are switched on five hours a day for the month of January.
E = Pt = 5 x 0.036 kW x 5 hr x 31 = 27.9 unit
Cost = 27.9 x 21.8 = RM 6.10

</td></tr>
</table>

Compare various electrical appliances in terms of efficient use of energy	• **Efficiency is a percentage of the output power to the input power.** **Efficiency** $= \frac{\text{Energy output}}{\text{Energy input}} \times 100\% = \frac{\text{Output power}}{\text{Input power}} \times 100\%$ • **The efficiency of an electrical appliance is always less than 100% as some energy is lost in the form of heat and sound.**

Solve problem involving electrical energy and power

1. An electric kettle is connected across a 240 V power supply. If the resistance of the heating element is 40 Ω, calculate **(b) the current flowing through the element** **(c) the quantity of heat produced in 10 minutes**	**2. An immersion heater has a power rating of 240 V, 750 W.** **(a) What is the meaning of its power rating?** **(b) What is the resistance of the immersion heater?** **(c) What is the electrical energy consumed in 15 minutes?**
3. The lamp of a motorcycle is labeled “12 V, 15 W”. **(a) Explain the meaning of “12 V, 15 W”.** **(b) What is the value of the current flowing through the lamp when it is connected to a 12 V supply?** **(c) How much is the resistance of the filament of the lamp?**	

4. **The diagram shows three light bulbs A, B and C connected to a power supply of 12 V.**  **Calculate the ammeter reading.**	
5. **A lamp is marked '240 V, 100 W' What is the efficiency of the lamp if it produces a light output of 12 W?**	
6. **An appliance with a power of 2 kW is used for 10 minutes, three times a day. If the cost of electricity is 25 cents per unit, what is the cost of operating the appliance in the month of April?**	
Describe ways of increasing energy efficiency	• **The term energy efficiency refers to gaining a higher level of useful outputs using less input. This can be achieved using efficient devices.** • **By increasing energy efficiency, not only are we reducing our cost but also we assist the industry in energy conservation.** • **Several ways to increase energy efficiency includes:** **1. Use more energy efficient lightings** • **Replace regular incandescent (filament) light bulbs with compact fluorescent light bulbs.** **2. Proper utilization of all electrical appliances** • **Run your washing machine only when it is fully loaded & Iron your clothes only when you have at least a few pieces to iron.**

	3. **Limit excessive usage of air-conditioning and lighting by switching them off upon leaving the room, thus reducing energy loss.** 4. **Regular cleaning of air filters in air-condition units and clothes dryers.** 5. **defrost refrigerators regularly, check the seal on refrigerator doors and vacuum the grille behind refrigerators.** 6. **Improve ventilation and air flow.**
What are fuses?	• **A fuse is a short piece of thin wire which overheats and melts if current of more than a certain value flows through it.** • **If a short circuit develops in the appliance, a current which is too high will flow. The fuse will melt and prevents overheating of the wire that can cause a fire.** • **If an electrical appliance is rated 960 W and 240 V then current in normal use is 4.0 A. The fuse suitable for use must slightly higher than the normal current flowing through the appliance .ie 5 A fuse.**
Three-pin plug	• **Live wire, L (brown). A current flows through the circuit** • **Neutral wire, N (blue). It is a zero potential difference.** • **Earth wire, E (green). Safety wire which connects the metal body of the appliance to earth. If a live wire touches the metal body of appliance, a large current would immediately flow to the earth and breaks the fuse. This will prevent a person from electrocution.**