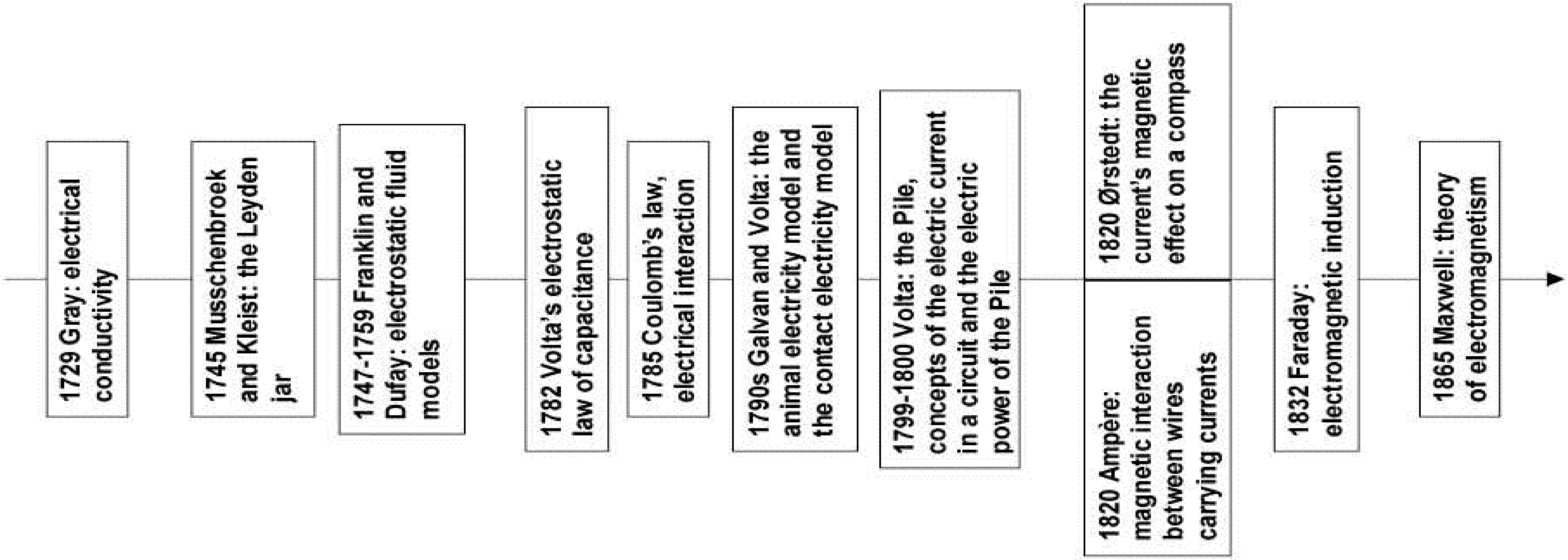
University of Venda - South Africa Institute of Physics
Vhembe Physical Science Teacher Training, 07- 09 February 2022

Electric Circuits (Circuits, Conservation of Electrical Charge, Kirchoff's Rule and Ohm's Law**)**

teaching electric circuits [Teaching Electric Circuits: Teachers' Ideas And Understanding Of Misconceptions]

David Tinarwo

The chronology of the main turning points of electricity in 1700's and 1800's



Electric circuit in history

Static electricity:

- is a transfer of electrons produced by friction, like when you rub a balloon across a sweater.
- A spark or very brief flow of current can occur when charged objects come into contact, but there is no continuous flow of current. In the absence of a continuous current, there is no useful application of electricity

The invention of the battery

- which could produce a continuous flow of current -- made possible the development of the first electric circuits
- **Alessandro Volta** invented the first battery, the voltaic pile, in 1800.
- The very first circuits used a battery and electrodes immersed in a container of water
- The flow of current through the water produced hydrogen and oxygen.
- **Thomas Edison** invented his incandescent light bulb, he sought practical applications for it by developing an entire power generation and distribution system.
- The first such system in the United States was the Pearl Street Station in downtown Manhattan. It provided a few square blocks of the city with electric power, primarily for illumination.
- One classification of circuits has to do with the nature of the current flow. The earliest circuits were battery-powered, which made in a steady, constant current that always flowed in the same direction. This is **direct current**, or DC. The use of DC continued through the time of the first electric power systems. A major problem with the DC system was that power stations could serve an area of only about a square mile because of power loss in the wires.
- In 1883, engineers proposed harnessing the tremendous hydroelectric power potential of Niagara Falls to supply the needs of Buffalo, N.Y. Although this power would ultimately go beyond Buffalo to New York City and even farther, there was an initial problem with distance. [https://science.howstuffworks.com/environmental/energy/circuit3.htm]

Importance of classroom experiments in physics teaching:

Experiment is an integral component in giving the starting point of knowledge formation and conceptualization so can be used to introduce new ideas or to clarify puzzling aspects of topics with which students typical struggle.

- ✓ If the result of an experiment is surprising and yet convincing, students are in a position to build ownership of the new idea and use it to scaffold learning
- ✓ If the **result of an experiment is surprising** yet convincing, students are in position to build ownership of the new idea and use it to scaffold learning.
- ✓ In addition to checking that the **conceptual focus** of the experiment has been understood correctly, post-experiment assignments can push students to describe a follow-up experiment or to extend the concept to another application.

Classroom Experiments keep learners active in a number of ways depending on the nature of the particular experiment. Students are active in generating data or behavioral observations

- ✓ Students analyze data, examples or models
- ✓ Students work together in groups to solve problems, devise strategies or understand class concepts
- ✓ Students predict how changing the experiment will change the outcomes
- ✓ Students compare experimental results to classroom theories and use them to confirm or critique the theories

Charles-Augustin de Coulomb

- **Born:** 14 June 1736 Angoulême, Angoumois, France
- **Died:** 23 August 1806 (aged 70) Paris, France
- **Nationality:** French
- Alma mater: École royale du génie de Mézières
- **Known for:** Torsion balance, Coulomb's law, Coulomb friction, Coulomb damping, Mohr-Coulomb theory

André-Marie Ampère

- **Born:** 20 January 1775 Lyon, Kingdom of France
- **Died:** 10 June 1836 (aged 61) Marseille, Kingdom of France
- **Nationality:** French
- **Known for:** Ampère's circuital law Ampère's force law Ampère's right hand grip rule
  Avogadro-Ampère hypothesis
  Monge–Ampère equation

Alessandro Volta

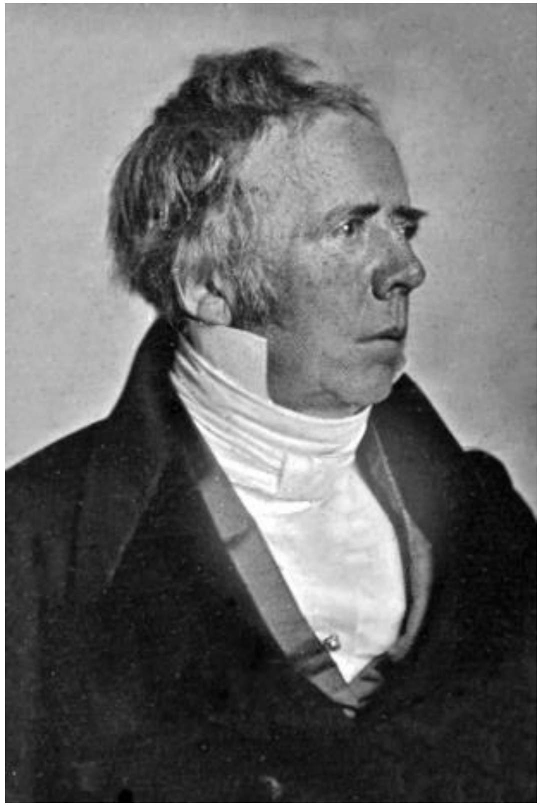
- **Who was he?:** in full Conte Alessandro Giuseppe Antonio Anastasio Volta was a physicist whose invention of the electric battery provided the first source of continuous current.
- **Born:** February 18, 1745 Como Italy
- **Died:** March 5, 1827 (aged 82) Como Italy
- **Inventions:** battery voltaic pile

Hans Christian Ørsted

- **Born:** 14 August 1777 Rudkøbing, Denmark-Norway
- **Died:** 9 March 1851 (aged 73) Copenhagen, Denmark
- **Nationality:** Danish
- **Alma mater:** University of Copenhagen (PhD, 1799)
- **Known for:** Discovery of electromagnetism and Aluminium
- **Awards:** Copley Medal (1820)

Scientific career

- **Fields:** Physics, chemistry, aesthetics
- **Institutions:** University of Copenhagen, Technical University of Denmark (Founder and Principal)
- **Influences:** Immanuel Kant



Talk briefly about important contributing scientists to the topic

Georg Simon Ohm

- **Who was her?**: was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell, invented by Italian scientist Alessandro Volta.
- **Born:** 16 March 1789, Erlangen, Germany
- **Died:** 6 July 1854, Munich, Germany
- **Education:** University of Erlangen-Nuremberg
- **Awards:** Copley Medal

PAPER 1 (PHYSICS): TOPICS AND CONTENT

	Content (items involving GRAPHS are underlined)	
Topic	Grade	Content
Electricity & Magnetism	Grade 10	Magnetism (magnetic field of permanent magnets, poles of permanent magnets, attraction and repulsion, magnetic field lines, earth's magnetic field, compass), Electrostatics (two kinds of charge, force exerted by charges on each other (descriptive), attraction between charged and uncharged objects (polarization), charge conservation, charge quantization),**Electric circuits (emf, potential difference (pd), current, measurement of voltage (pd) and current, resistance, resistors in parallel)14 h Prescribed experiment: PD and current in series and parallel circuits (X)**
	Grade 11	Electrostatics (Coulomb's Law, Electric field), Electromagnetism (Magnetic field associated with current-carrying wires, Faraday's Law), Electric circuits (Energy, Power) 20 hours Recommended experiment: Ohm's law: PD and current for resistor and bulb
	Grade 12	Electric circuits (<u>internal resistance</u> and series-parallel networks), Electrodynamics (electrical machines (generators, motors), <u>alternating current</u>) 12h Prescribed experiment: Internal Resistance of a battery. Current and PD Experiment: Compare PD graphs for alternating and direct current

QUESTION 7: ELECTROSTATICS (COULOMB'S LAW and ELECTRIC FIELDS)

Common Errors and Misconceptions

a) Candidates failed to recall that 'like charges repel', hence the repelled sphere should have been positive.

b) Many candidates omitted the force of gravity in their free body diagram.

c) Candidates also confused Coulomb's Law with Newton's Law of Universal Gravitation.

d) Candidates swopped/mixed-up on the formulae **for E and F; F = $k\frac{Q}{r^2}$ and $E = k\frac{Q_1Q_2}{r^2}$.**

e) Many candidates failed to realize that the forces acting on the sphere are in equilibrium and a closed vector diagram would have assisted them in calculating the tension in the string.

f) Candidates did not use the absolute value of the charges when substituting in the formula of Coulomb's Law or the electric field at a point.

So what can we do to improve the understanding of our students of field and force?

Suggestions for Improvement

(a) Teachers need to emphasize to learners that calculations of net electrostatic force and electric field are similar in terms of their vector considerations.

(b) Teachers need to clarify the distinction between the two equations i.e. $E = \frac{F}{q}$ and $E = k\frac{Q}{r^2}$. It is important that learners understand which charge 'q' and 'Q' refer to in each of these formulae.

(c) Expose learners to vector diagrams (1D and 2D) and vector triangles when determining the resultant of forces (e.g. electrostatic, gravitational and tension) acting on a body and net electric fields.

Tribo-electric series determines whether one material is likely to become charged from another material. Materials from the more positive end of the series are more likely to lose electrons than those from the more negative end.

Material	Tribo-electric series	Series continues	
Glass	Very positive	Material	Tribo-electric series
Human hair	↓	Wood	↓
Nylon		Amber	
Wool		Hard rubber	
Fur		Nickel, Copper	
Lead		Gold, Platinum	
Silk		Polyester	
Aluminium		Polyurethane	
Paper		Polypropylene	
Cotton		Silicon	
Steel		Teflon	Very negative

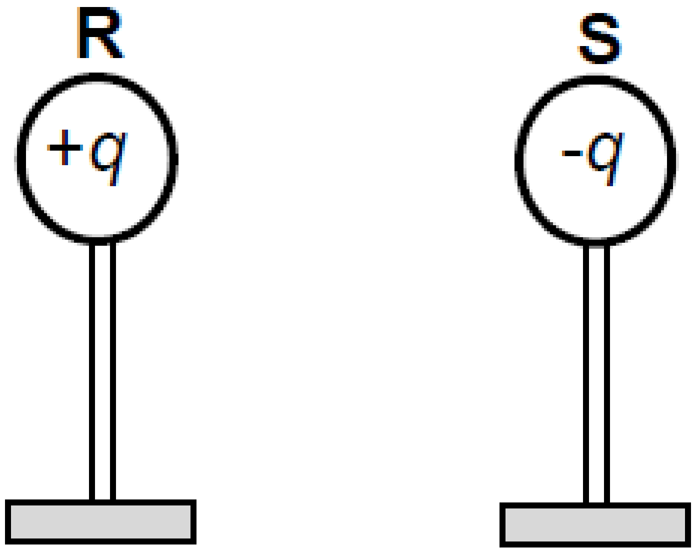
DEFINITION: Electric field

A region of space in which an electric charge will experience a force. The direction of the field at a point in space is the direction in which a **positive test charge** would moved if placed at that point.

In physical theories, a test particle, or test charge, is an idealized model of an object whose physical properties (usually mass, charge, or size) **are assumed to be negligible except** for the property being studied, which is considered to be insufficient to alter the behavior of the rest of the system.

Physical Sciences (2019) P1: Multiple Choice

1.7 Two identical spheres, R and S, on insulated stands, carrying charges of +*q* and -*q* respectively, are placed a distance apart. Sphere R exerts an electrostatic force of magnitude *F* on sphere S. The two spheres are now brought into contact and returned to their original positions. The magnitude of the electrostatic force that sphere R exerts on sphere S is now …



A zero

B F/2

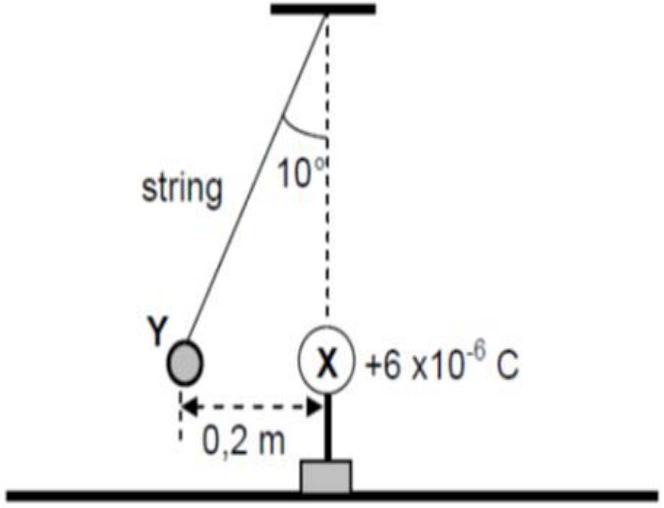
C F

D 2F

QUESTION 7 (Physical Sciences P1 of 2019)

7.1 A small sphere, Y, carrying an unknown charge, is suspended at the end of a light inextensible string which is attached to a fixed point. Another sphere, X, carrying a charge of $+6 \times 10^{-6}\ C$, on an insulated stand is brought close to sphere Y.

Sphere Y experiences an electrostatic force and comes to rest 0,2 m away from sphere X, with the string at an angle of 10° with the vertical, as shown in the diagram.



QUESTION 7 (Physical Sciences P1 of 2019) cont..

7.1.1 What is the nature of the charge on sphere Y? Choose from POSITIVE or NEGATIVE. (1)

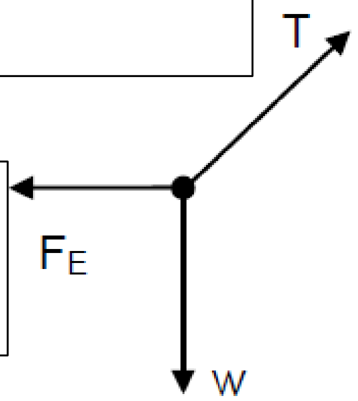
How is the electrostatic force here? Attractive or repulsive? So which charges attract or repel? Then conclude

7.1.2 Calculate the magnitude of the charge on sphere Y if the magnitude of the electrostatic force acting on it is 3,05 N. (3)

What is given/known? F=3,05 N, $q_X = +6 \times 10^{-5}\ C$, constant k, then what is wanted? $\boldsymbol{q_Y}$. Which principle is applied? Coulomb law: $F = k\frac{q_X q_Y}{r^2}$, then make the wanted the subject of the formula: $q_Y = \frac{Fr^2}{kq_X}$, substitute the SI values

7.1.3 Draw a labelled free-body diagram for sphere Y. (3)

Identify the forces acting on sphere Y, **electrostatic** pushing away, **gravity vertically** downward and **tension** in the string pulling along the string



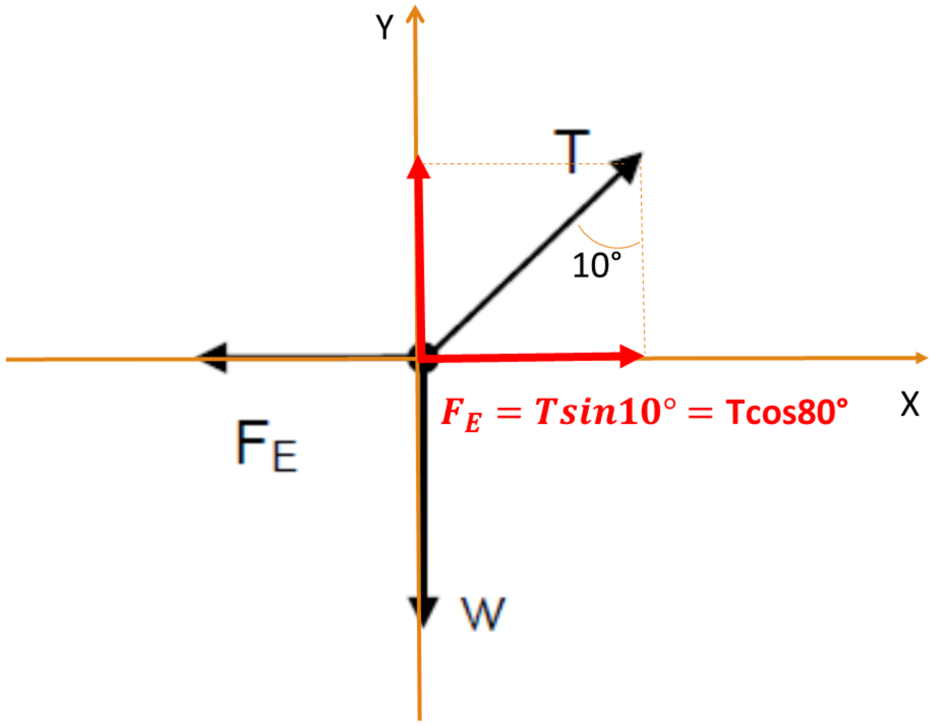
7.1.4 Calculate the magnitude of the tension in the string. (3)

Important: the forces are at equilibrium, So net force is zero and thus components along each axes are independently at equilibrium, or balanced, or equal. Note that the known here

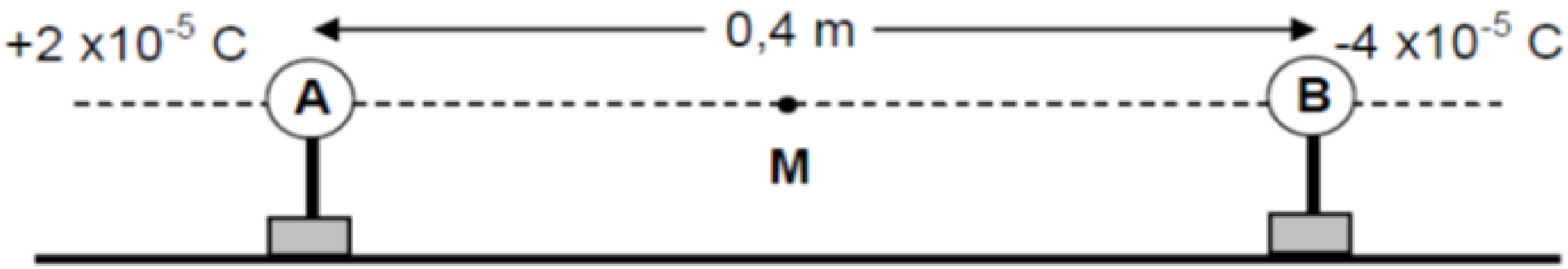
is only the electrostatic force $\boldsymbol{F_E}$ and the x-component of tension T is at equilibrium with $\boldsymbol{F_E}$

$\boldsymbol{F_E = Tsin10° = Tcos80°}$.

$\boldsymbol{T = \frac{F_E}{sin10°}}$, **or** $\boldsymbol{T = \frac{F_E}{Cos80°}}$

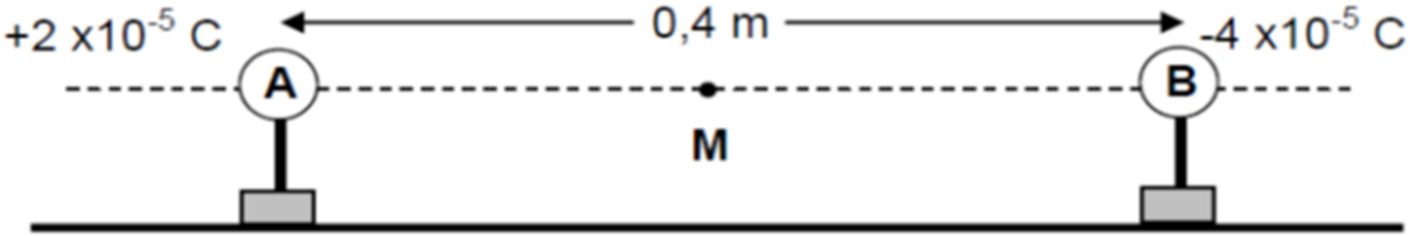


7.2 Two small charged spheres, A and B, on insulated stands, with charges $+2\times10^{-5}\ C$ and $-4\times10^{-5}\ C$ respectively, are placed 0,4 m apart, as shown in the diagram below. M is the midpoint between spheres A and B.



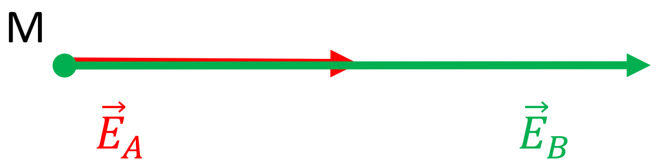
7.2.1 Define the term electric field at a point. Recalling, important are the key words: The electric field at a point is the **(electrostatic) force** experienced **by/per unit positive charge** placed at that point. (2)

7.2.2 Calculate the net electric field at point M.



Given data: distances of charged spheres A and B to the point M: $r_A = r_B = \frac{0,4}{2}\ m = 0,2\ m$, charge of spheres A and B: $q_A = +2 \times 10^{-5}C$, $q_B = -4 \times 10^{-5}C$. Wanted is the net electric field E_{net} at point M:

Sketch: the electric fields due to charge on spheres A and B at point M.
Concept of test **charge and its use in determining the direction of the E field**



The fields are in the same direction, so they vectorially add.

$$E_{net} = E_A + E_B = k\frac{q_A}{{r_A}^2} + k\frac{q_B}{{r_B}^2} = (9\times10^9 N\cdot m^2\cdot C^{-2})\frac{(+2\times10^{-5}C)}{(0{,}2\;m)^2} + (9\times10^9 N\cdot m^2\cdot C^{-2})\left|\frac{(-4\times10^{-5}C)}{(0{,}2\;m)^2}\right|,$$

$$E_{net} = (9\times10^9 N\cdot m^2\cdot C^{-2})\frac{(+2\times10^{-5}C)}{(0{,}2\;m)^2} + (9\times10^9 N\cdot m^2\cdot C^{-2})\frac{(4\times10^{-5}C)}{(0{,}2\;m)^2} = 1{,}35\times10^7\;N/C$$


the sign of the charge is used to determine the direction of the field and the subsequent addition is vectorially!

Units need to be emphasized to be N/C

Electric Circuits

Circuits, Conservation of Electrical Charge, Kirchoff's Rule and Ohm's Law)

QUESTION 8: ELECTRIC CIRCUITS

Common Errors and Misconceptions

(a) Many candidates were not scientifically correct in defining the emf of a battery as key words were omitted in their definitions.

(b) Many candidates omit the units in the final answer.

(c) Candidates have no clear understanding of the relationship between potential difference V, current I, resistance in the circuit when using the equation

$$\varepsilon = Ir + IR = V_{internal} + V_{external}\,.$$

(d) The influence on $V_{external}$ in the presence of r_i when there is a change in the total resistance in the circuit is still a problem for many candidates.

(e) Learners are unable to substitute the correct values of R, V and I when applying the formula $R = \frac{V}{I}$ for the whole circuit, or parts of the circuit

So what can we do to improve the understanding of our students of the application of Ohm's law?

Suggestions for Improvement

(a) Although the principles of series and parallel circuits are taught from Grade 9, the basic principles have to be revised and practiced constantly. The critical features of series and parallel circuits should be reinforced.

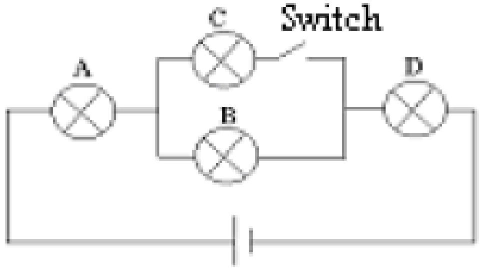
(b) Use PhET simulations to demonstrate the relationship between $\boldsymbol{V_{external}}$ **and** $\boldsymbol{V_{internal}}$ as well as the effect of adding resistors in series and parallel.

(c) Teachers need to get learners to conduct practical work involving series and parallel circuits and to make observations and calculations regarding resistance, current, emf and potential difference regarding these circuits. These informal practical activities can be used as teaching tools for electric circuits.

(e) Learners need to understand the formula $R = \frac{V}{I}$ and be able to substitute the correct values of R, V and I when applying the formula to the whole circuit or to parts of a circuit.

I

All the bulbs are identical in the circuit shown below.



I) Put in correct order the brightness of bulbs when the switch is closed. Explain your response briefly.

II) Explain how the brightness of each bulb changes compared o situation I when the switch is open.

II

All the bulbs are identical in the circuit shown below.

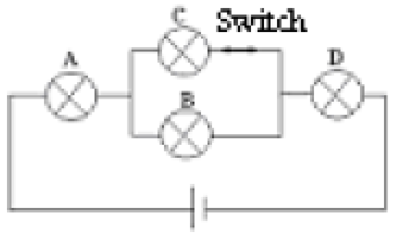


Figure 1

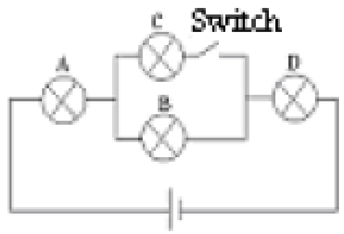


Figure 2

I) Switch is closed in Figure 1. Put a cross (x) in a box of which you think the brightness of the bulbs are given in correct order. Explain your choice briefly.

❑ A=D>B=C ❑ A>B=C>D ❑ C>A=D>B ❑ A=B=C=D

❑ None of the bulbs are lit when the switch is closed ❑ ……………………

Your response:

II) Switch is open in Figure 2. Put a cross (x) in a box of which you think the brightness of the bulbs are given in correct order explain your choice briefly.

❑ A>B=C>D ❑ A>B=D, C isn't lit ❑ A=D>B=C

❑ A=B= C=D ❑ A>B>D, C isn't lit

❑ None of the bulbs are lit when the switch is closed ❑ …………………

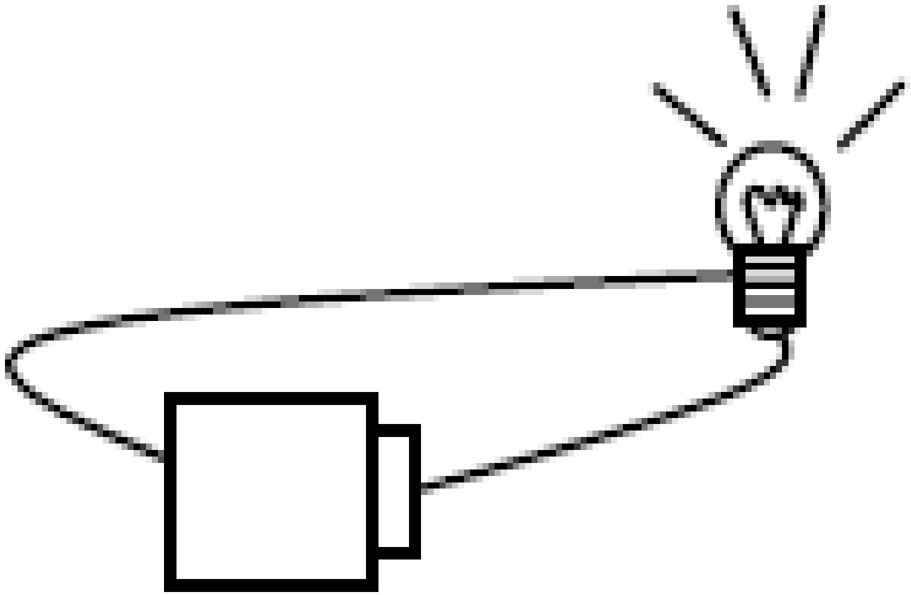
Your response:

Test your conceptual understanding for simple electric circuits (KÜÇÜKÖZER & KOCAKÜLAH, 2007)

Educators may check for Conceptual understanding on simple electric circuits using some open-ended questions designed to clear misconceptions, (KÜÇÜKÖZER & KOCAKÜLAH, 2007).

Check-up quizzes

Q1. A bulb is connected to a battery and gives light as shown in the figure.

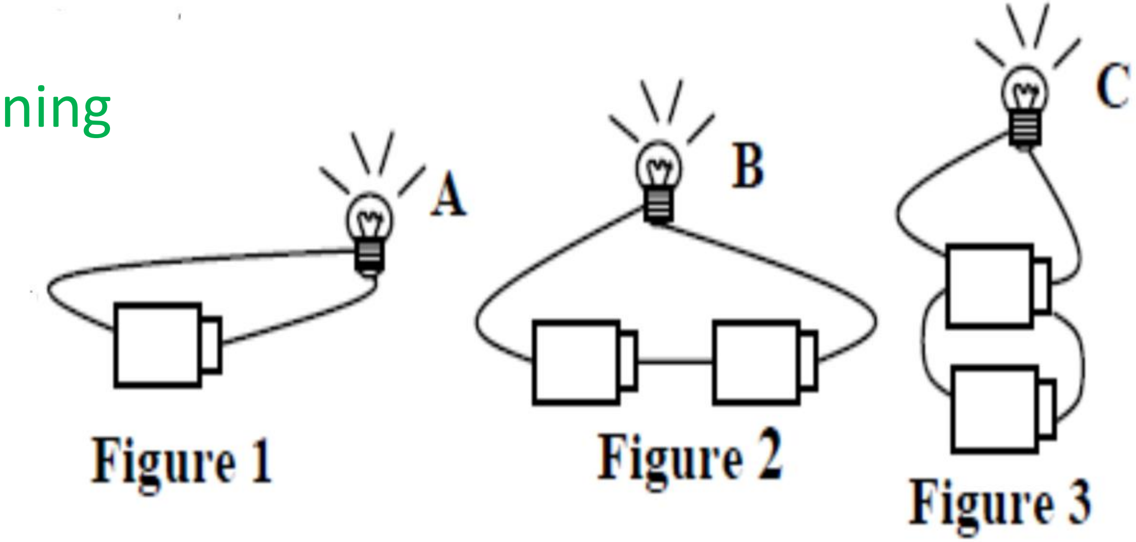


Explain why the bulb gives light.

Bulb and sources

Q2. Batteries and bulbs are identical in three figures. Choose the alternative which you think is the correct answer about the brightness of bulbs. Explain your reasoning briefly.

I. A>B>C
II. B>A>C
III. B>A=C
IV. A=B=C
V. B=C>A



Q3. This question involves the changes made in a sample electric circuit. Please choose the correct option for each situation and explain why you choose that alternative.

3.1 If R1 decreased, brightness of bulb;

A. INCREASES B. DECREASES C. STAYS THE SAME

Your explanation:

3.2 If R2 decreased, brightness of bulb;

A. INCREASES B. DECREASES C. STAYS THE SAME

Your explanation:

3.3 If R1 increased, brightness of bulb;

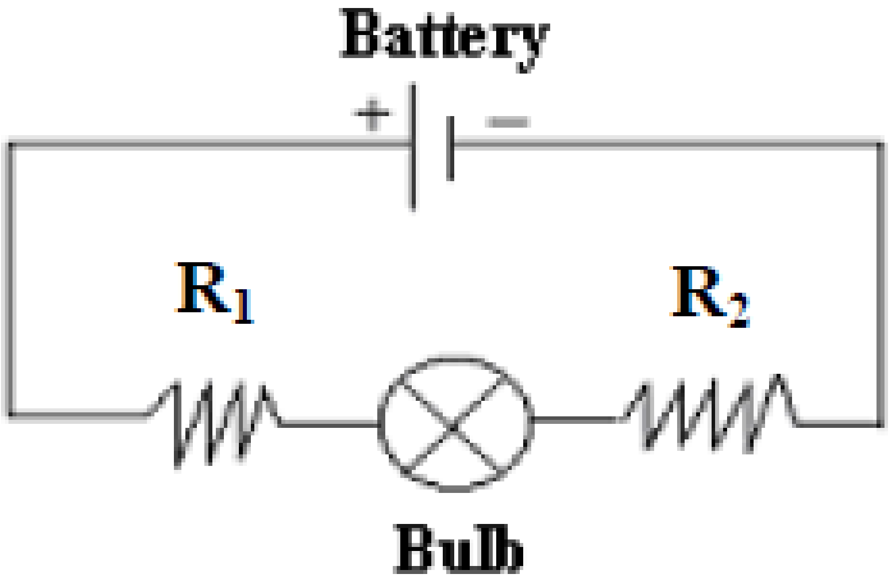
A. INCREASES B. DECREASES C. STAYS THE SAME

Your explanation:

3.4 If R2 increased, brightness of bulb;

A. INCREASES B. DECREASES C. STAYS THE SAME

Your explanation:



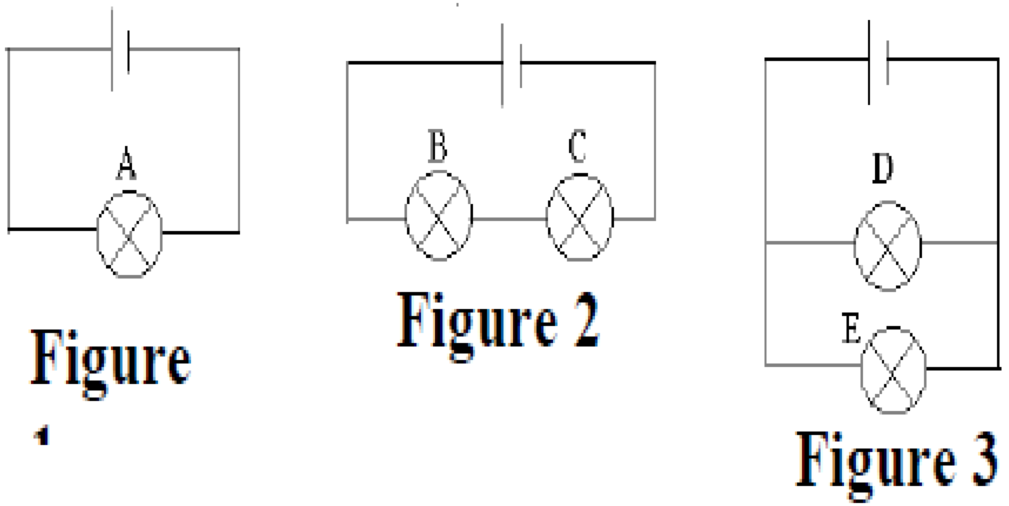
Q4. If bulbs and batteries are identical in the figures given below.

Choose the alternative which you think is the correct answer about the brightness of bulbs. Explain your reasoning briefly.

I: A>B=C=D=E   II: A=B=C>D=E

III: A>B=C>D=E   IV: A=D=E>B=C

V: A=B>C>D>E



Q5. All bulbs are identical in the circuit shown in Figure 1. Use this information answers the questions below.

Switch is closed in Figure 1. Choose the alternative which you think is the correct answer about the brightness of bulbs. Explain your reasoning briefly.

1. A=D>B=C

2. A>B=C>D C>A=D>B

3. A=B=C=D

4. None of bulbs are lit when the switch is closed.

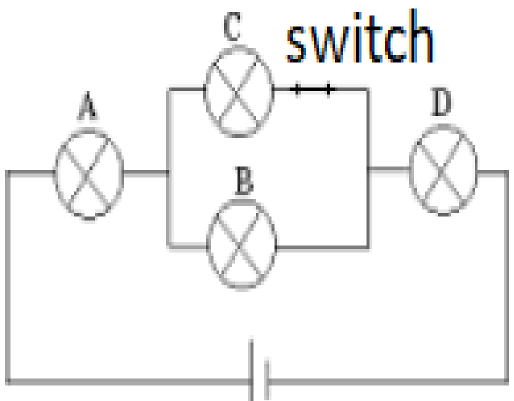


Figure 1

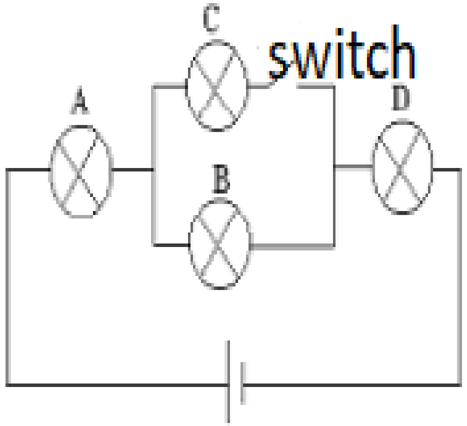


Figure 2

Bulbs are identical in two circuits in Q6.1 and Q6.2. Choose the alternative which you think is the correct answer about the potential difference between two specified points of each circuit.

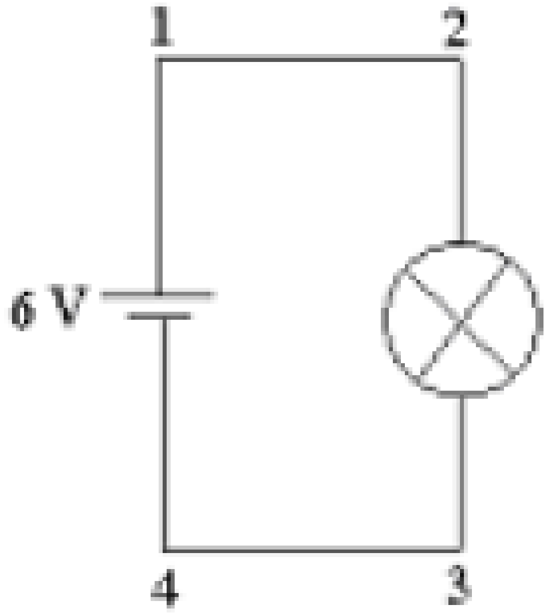
Q6.1

A. Between 1 and 2 = 6 Volt, 2 and 3 = 6 Volt, 3 and 4 = 6 Volt

B. Between 1 and 2 = 6 Volt, 2 and 3 = 3 Volt, 3 and 4 = 3 Volt

C. Between 1 and 2 = 0 Volt, 2 and 3 = 6 Volt, 3 and 4 = 0 Volt

D. Between 1 and 2 = 2 Volt, 2 and 3 = 2 Volt, 3 and 4 = 2 Volt



Give your explanation

Q6.2

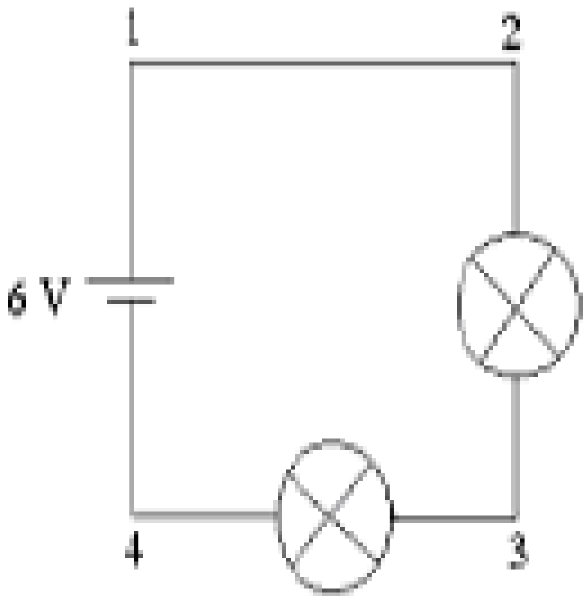
A. Between 1 and 2 = 6 Volt, 2 and 3 = 6 Volt, 3 and 4 = 6 Volt

B. Between 1 and 2 = 6 Volt, 2 and 3 = 3 Volt, 3 and 4 = 0 Volt

C. Between 1 and 2 = 0 Volt, 2 and 3 = 3 Volt, 3 and 4 = 0 Volt

D. Between 1 and 2 = 2 Volt, 2 and 3 = 2 Volt, 3 and 4 = 2 Volt

E. Between 1 and 2 = 0 Volt, 2 and 3 = 3 Volt, 3 and 4 = 3 Volt



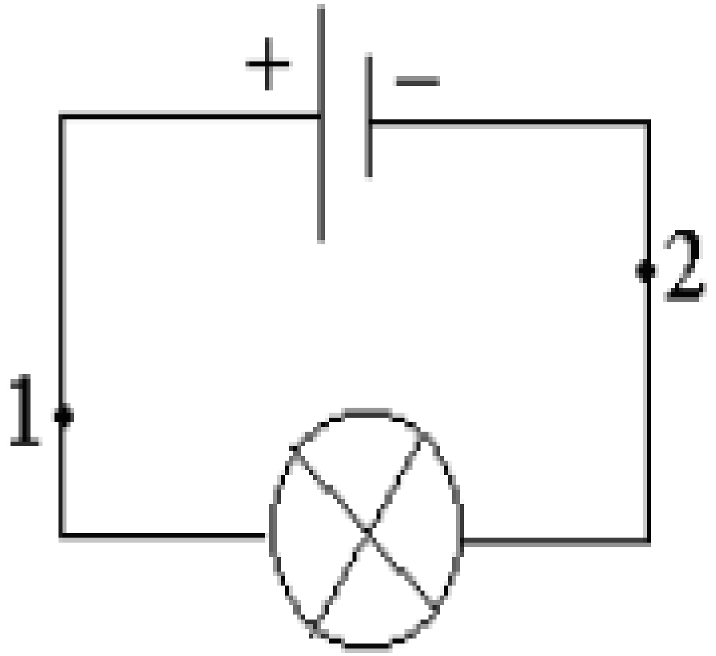
Q7

Choose the alternative which you think is the correct answer about the magnitude of currents in points 1 and 2 in the circuit besides. Explain your reasoning briefly.

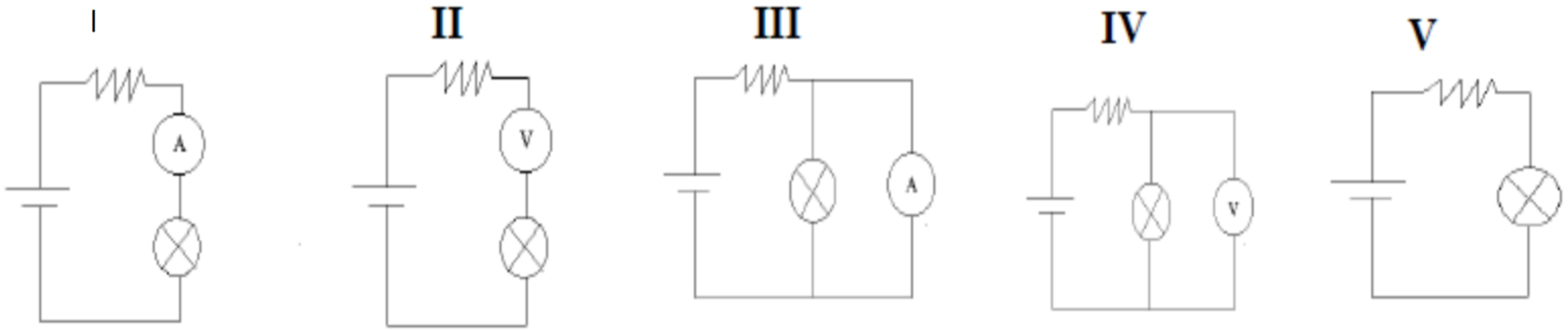
A. 1>2

B. 1=2

C. 1<2



Q8



Resistors, bulbs and batteries are identical in all five circuits.

Choose the alternative which you think is the correct answer about the brightness of bulbs in each circuits. Explain your reasoning briefly (A: Ammeter, V: Voltmeter).

A. I=II=V>III=IV

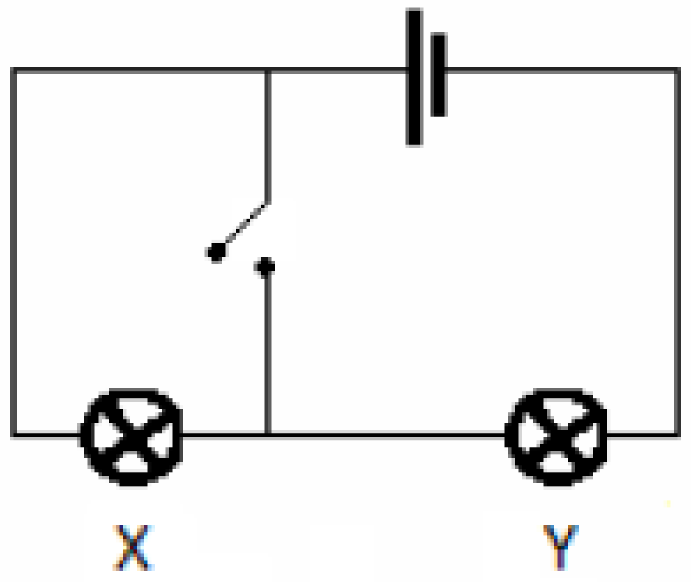
B. I=II=V>III=IV

C. V>I=II>III=IV

Q9

How does the brightness of the light bulbs change if the switch is closed?

(A) y brighter, x=0
(B) both brighter
(C) y=0, x=0
(D) x brighter, y=0
(E) no difference

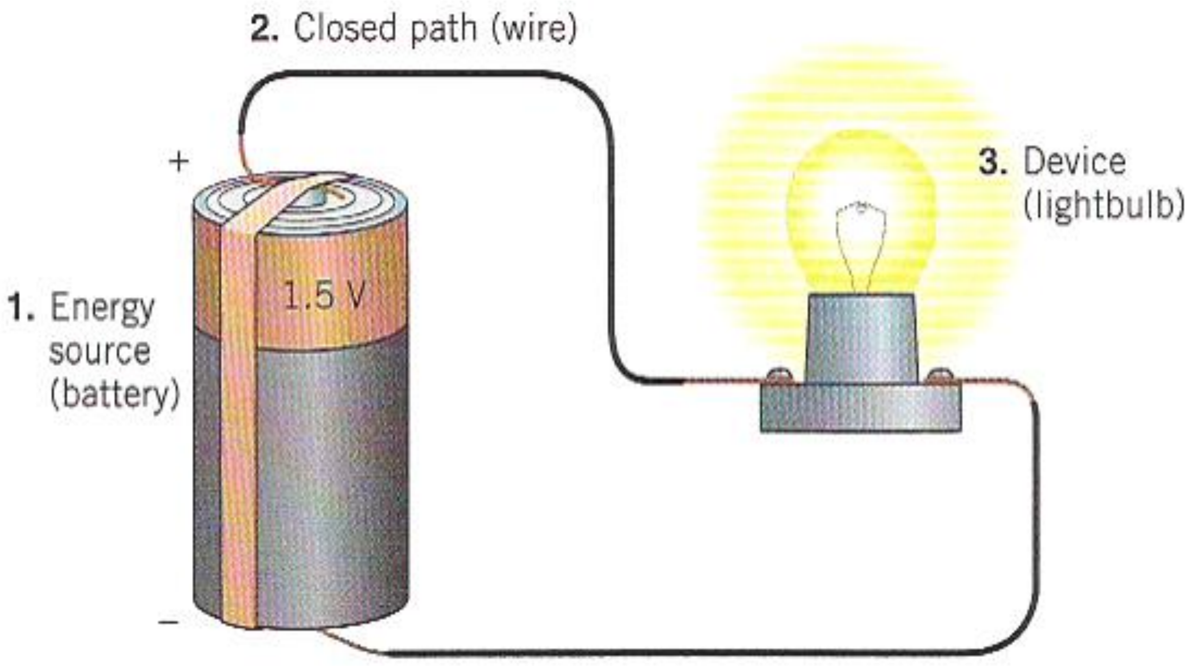


6.1. Which wrong option do you expect your learners to choose?
6.2. Why do you think they will choose this option?
6.3. How would you explain to learners why the chosen option is incorrect?

A Basic Circuit

All electric circuits have three main parts

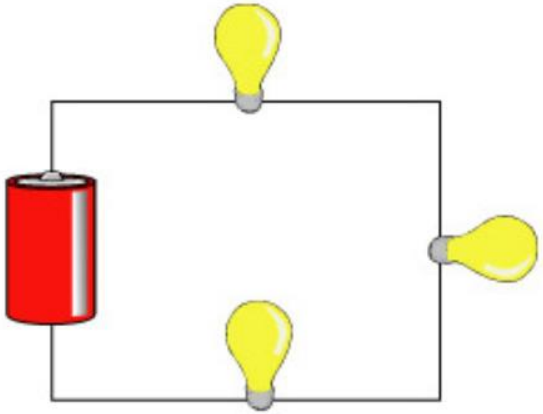
1. A source of energy
2. A closed path
3. A device which uses the energy

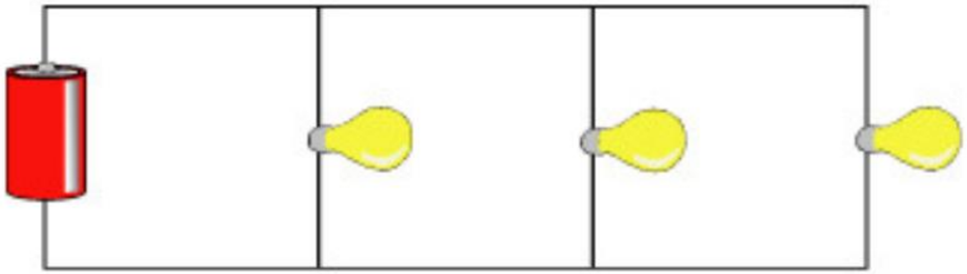


If ANY part of the circuit is open the device will not work!

Ways to Wire Circuits (Physics 1)

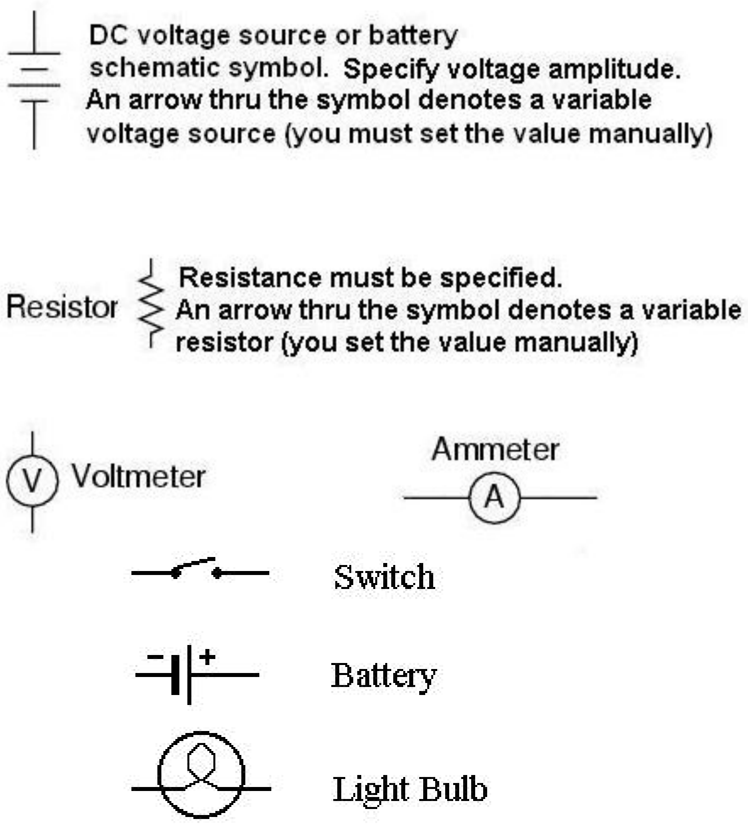
- There are 2 basic ways to wire a circuit. Keep in mind that a resistor could be ANYTHING (bulb, toaster, ceramic material...etc) Series – One after another
- Parallel – between a set of junctions and parallel to each other





Schematic Symbols

Before you begin to understand circuits you need to be able to draw what they look like using a set of standard symbols understood anywhere in the world



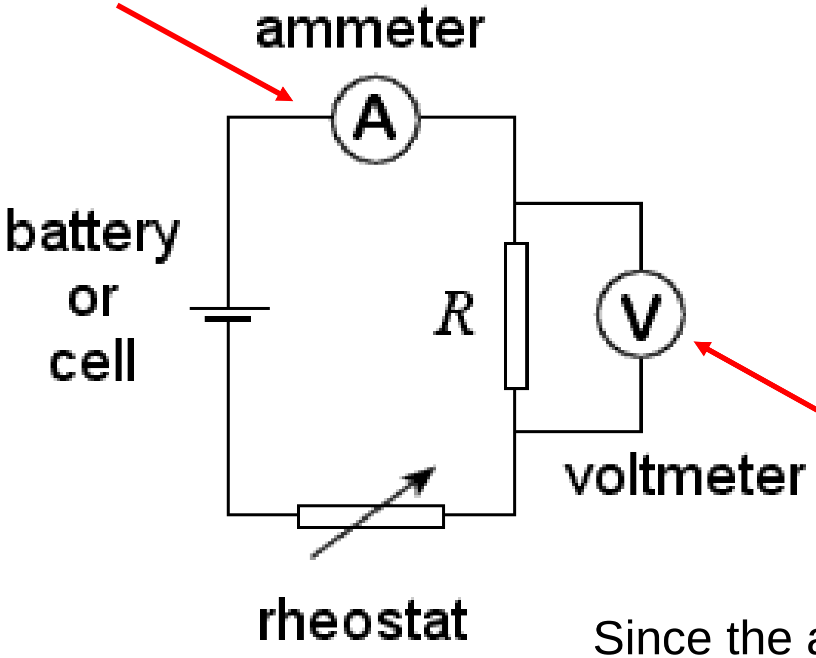
For the battery symbol, the LONG line is considered to be the POSITIVE terminal and the SHORT line , NEGATIVE.

The VOLTMETER and AMMETER are special devices you place IN or AROUND the circuit to measure the VOLTAGE and CURRENT.

The Voltmeter and Ammeter

The voltmeter and ammeter cannot be just placed anywhere in the circuit. They must be used according to their DEFINITION.

Current goes THROUGH the ammeter

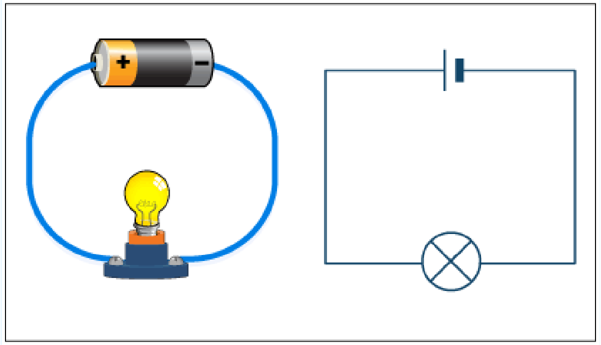


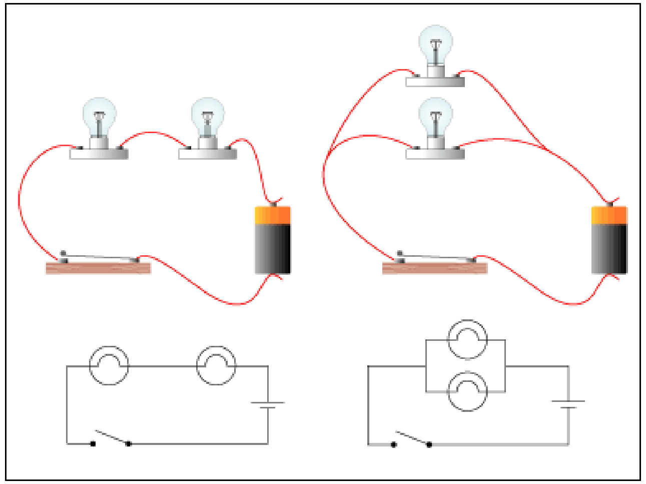
Since a voltmeter measures voltage or POTENTIAL DIFFERENCE it must be placed **ACROSS** the device you want to measure. That way you can measure the CHANGE on either side of the device.

Voltmeter is drawn ACROSS the resistor

Since the ammeter measures the current or FLOW it must be placed in such a way as the charges go **THROUGH** the device.

Simple Circuit

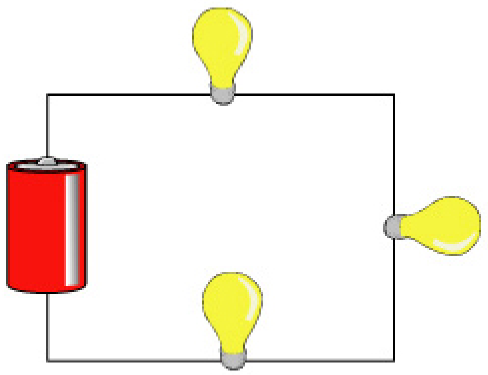




When you are drawing a circuit it may be a wise thing to start by drawing the battery first, then follow along the loop (closed) starting with positive and drawing what you see.

Series Circuit

In in series circuit, the resistors are wired one after another. Since they are all part of the SAME LOOP they each experience the SAME AMOUNT of current. In figure, however, you see that they all exist BETWEEN the terminals of the battery, meaning they SHARE the potential (voltage).



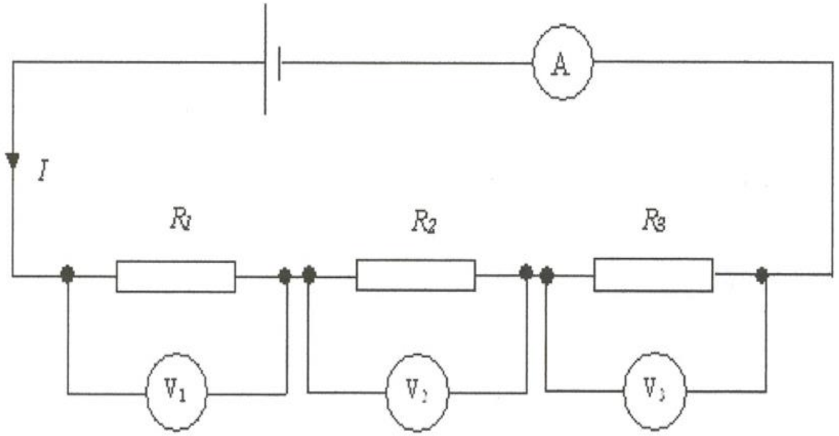
$$I_{(series)Total} = I_1 = I_2 = I_3$$

$$V_{(series)Total} = V_1 + V_2 + V_3$$

Series Circuit

As the current goes through the circuit, the charges must USE ENERGY to get through the resistor. So each individual resistor will get its own individual potential voltage). We call this VOLTAGE DROP.

$$I_{(series)Total} = I_1 = I_2 = I_3$$
$$V_{(series)Total} = V_1 = V_2 = V_3$$



Note: They may use the terms "effective" or "equivalent" to mean TOTAL!

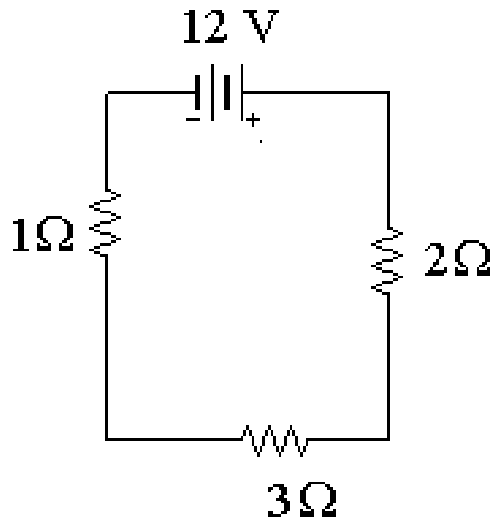
$V_{(series)Total} = V_1 = V_2 = V_3$; $\Delta V = IR$

$(I_T R_T)_{series} = I_1 R_1 + I_2 R_2 + I_3 R_1$, So since $I_1 = I_2 = I_3 = I$

$(I_T R_T)_{series} = I(R_1 + R_2 + R_1)$, $(R_T)_{series} = R_1 + R_2 + R_1$,

$\boldsymbol{R_s = \sum R_i},$

Example



A series circuit is shown to the left.

a) What is the total resistance? $R(series) = 1 + 2 + 3 = 6W$

b) What is the total current? $\Delta V = IR \quad 12 = I(6) \quad I = 2A$

c) What is the current through EACH resistor?

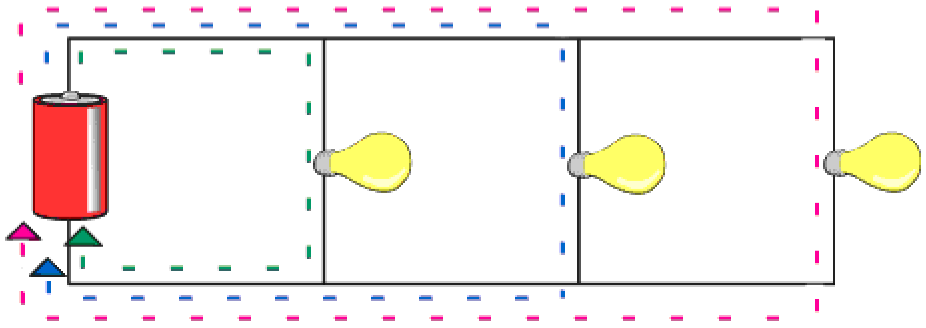
They EACH get 2 amps!

d) What is the voltage drop across each resistor?(Apply Ohm's law to each resistor separately) $V_{1W} = (2)(1) = 2\ V$; $V_{3W} = (2)(3) = 6V$; $V_{2W} = (2)(2) = 4V$

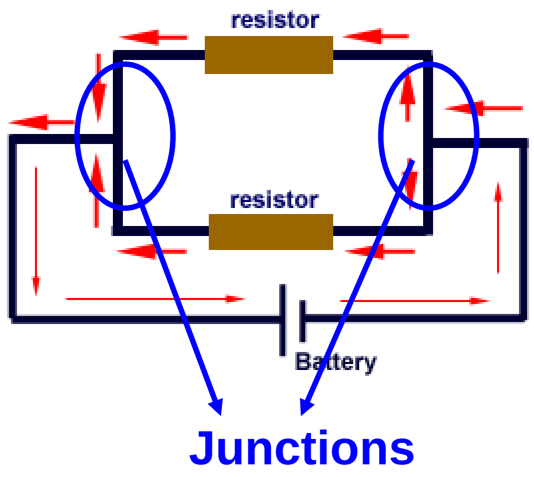
e) Notice that the individual VOLTAGE DROPS add up to the TOTAL!!

Parallel Circuit

In a parallel circuit, we have multiple loops. So the current splits up among the loops with the individual loop currents **adding** to the total current



It is important to understand that parallel circuits will all have some position where the current splits and comes back together. We call these **JUNCTIONS**.



The current going IN to a junction will always equal the current going OUT of a junction.

$$I_{(parallel)Total} = I_1 + I_2 + I_3$$

Regarding Junctions :

$$I_{IN} = I_{OUT}$$

Parallel Circuit

Notice that the JUNCTIONS both touch the POSTIVE and NEGATIVE terminals of the battery. That means you have the SAME potential difference down EACH individual branch of the parallel circuit. This means that the individual voltages drops are equal.

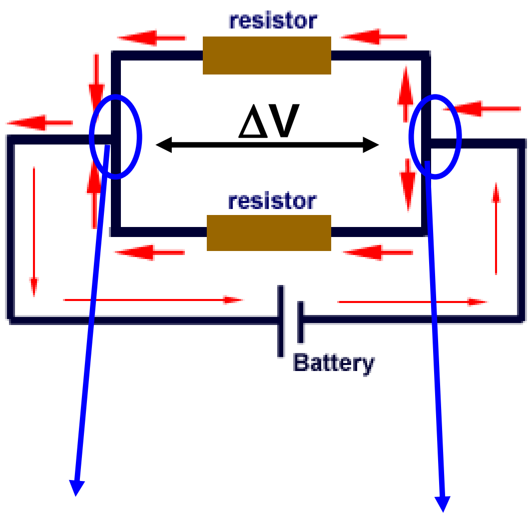
$$V_{(parallel)Total} = V_1 = V_2 = V_3$$

$$I_{(parallel)Total} = I_1 + I_2 + I_3; \ \Delta V = IR$$

$$\left(\frac{V_T}{R_T}\right)_{Parallel} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

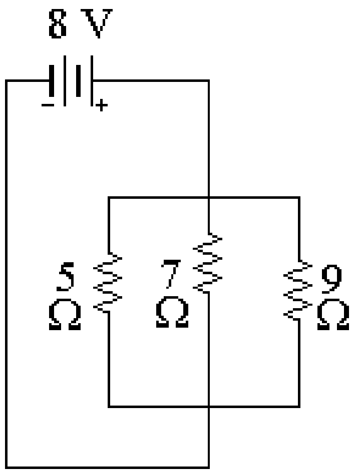
$$\frac{1}{R_P} = \sum \frac{1}{R_i}$$



This junction touches the **POSITIVE** terminal

This junction touches the **NEGATIVE** terminal

Example



To the left is an example of a parallel circuit.

a) What is the total resistance?

$$\frac{1}{R_P} = \frac{1}{5} + \frac{1}{7} + \frac{1}{9}$$

$$\frac{1}{R_p} = 0.454 \rightarrow R_P = \frac{1}{0.454} =$$ **2.20 Ω**

b) What is the total current? $\Delta V = IR$

$$8 = I(R) =$$ **3.64 A**

c) What is the voltage across EACH resistor?

8 V each!

d) What is the current through each resistor?
(Apply Ohm's law to each resistor separately)

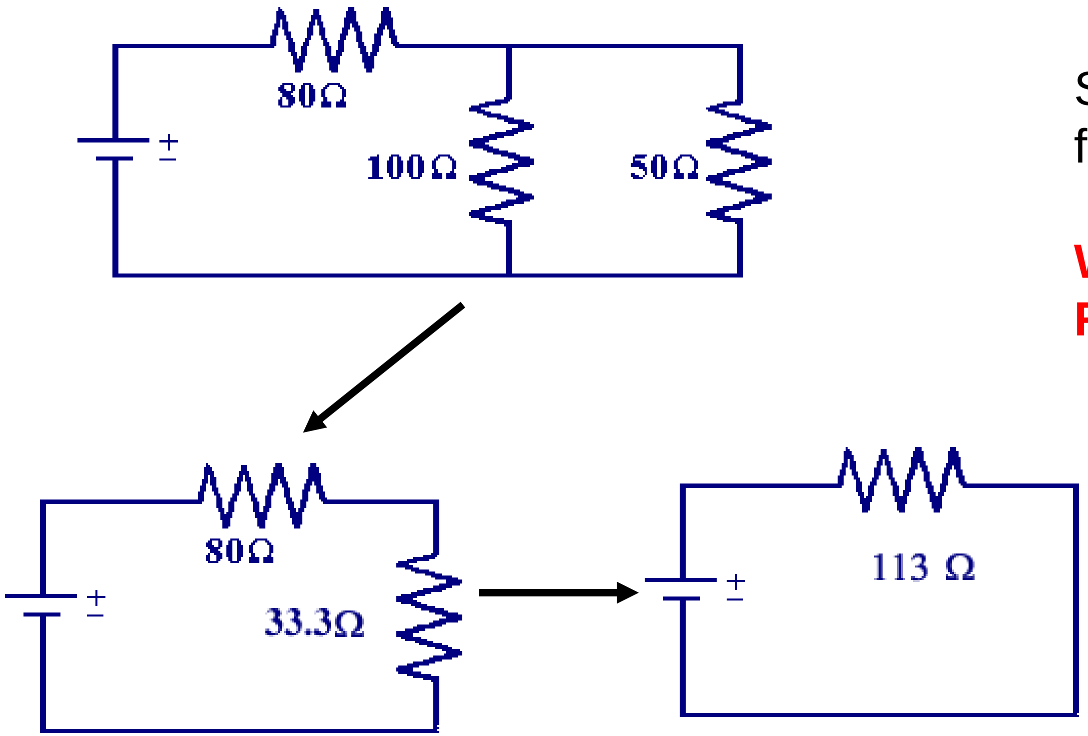
$$\Delta V = IR$$

$$I_{5\Omega} = \frac{8}{5} =$$ **1.6 A** $$I_{7\Omega} = \frac{8}{7} =$$ **1.14 A** $$I_{9\Omega} = \frac{8}{9} =$$ **0.90 A**

Notice that the individual currents ADD to the total.

Compound (Complex) Circuits

Many times you will have series and parallel in the SAME circuit.



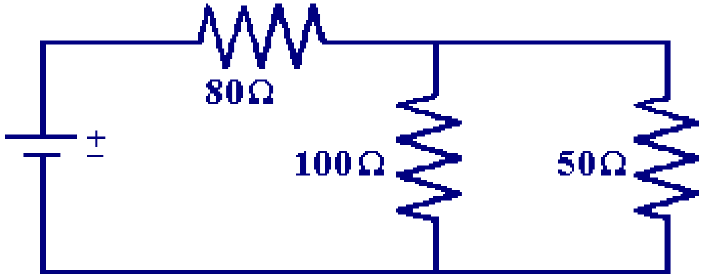
Solve this type of circuit from the inside out.

WHAT IS THE TOTAL RESISTANCE?

$$\frac{1}{R_P} = \frac{1}{100} + \frac{1}{50}; \quad R_P = 33.3\Omega$$

$$R_s = 80 + 33.3 = 113.3\Omega$$

Compound (Complex) Circuits



$$\frac{1}{R_P} = \frac{1}{100} + \frac{1}{50}; \quad R_P = 33.3\Omega$$

$$R_s = 80 + 33.3 = 113.3\Omega$$

Suppose the potential difference (voltage) is equal to **120V**. What is the total current?

$$\Delta V_T = I_T R_T$$

$$120 = I_T (113.3)$$

$$I_T = \textbf{1.06 A}$$

What is the VOLTAGE DROP across the 80Ω resistor?

$$\Delta V_{80\Omega} = I_{80\Omega} R_{80\Omega}$$

$$V_{80\Omega} = (1.06)(80)$$

$$V_{80\Omega} = \textbf{84.8 V}$$

Compound (Complex) Circuits

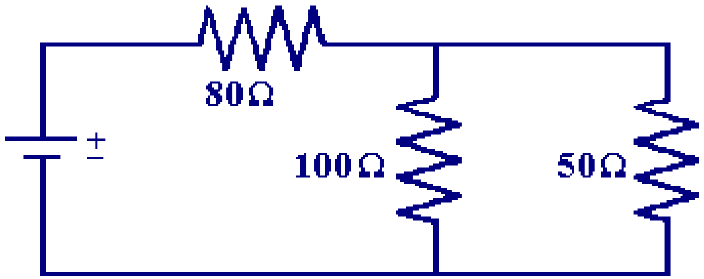
$$R_T = 113.3\Omega$$

$$V_T = 120V$$

$$I_T = 1.06A$$

$$V_{80\Omega} = 84.8V$$

$$I_{80\Omega} = 1.06A$$



What is the VOLTAGE DROP across the 100Ω and 50Ω resistor?

$$V_{T(parallel)} = V_2 = V_3$$

$$V_{T(series)} = V_1 + V_{2\&3}$$

$$120 = 84.8 + V_{2\&3}$$

$V_{2\&3} =$ **35.2 V Each!**

What is the current across the 100Ω and 50Ω resistor?

$$I_{T(parallel)} = I_2 + I_3$$

$$I_{T(series)} = I_1 = I_{2\&3}$$

$I_{100\Omega} = \frac{35.2}{100} =$ **0.352 A**

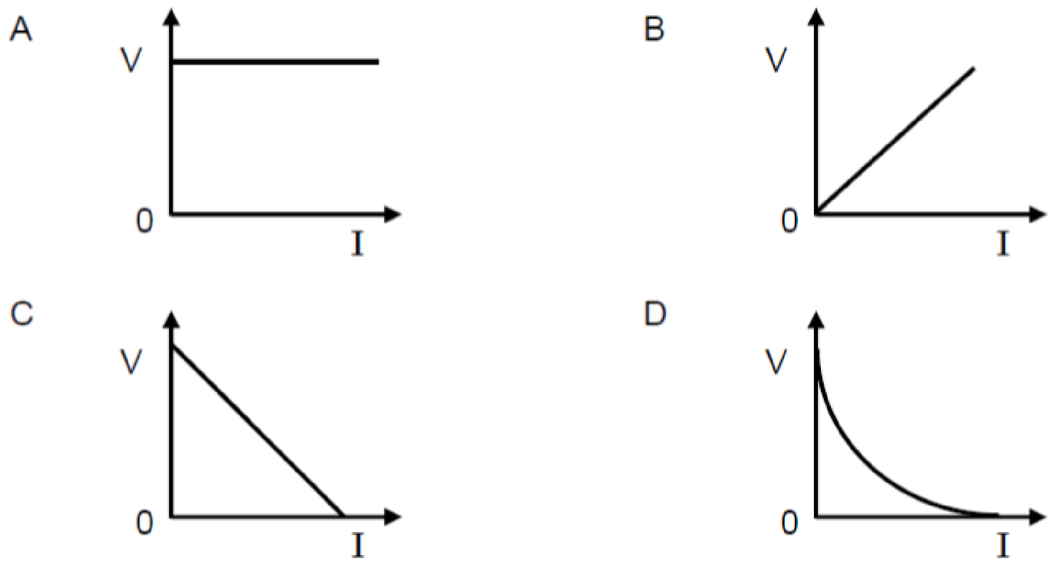
$I_{50\Omega} = \frac{35.2}{50} =$ **0.704 A**

Add to 1.06A

Multiple choice

1.8 Which ONE of the graphs below best represents the relationship between potential difference (V) and current (I) for an ohmic conductor? ($\boldsymbol{V = IR}$)

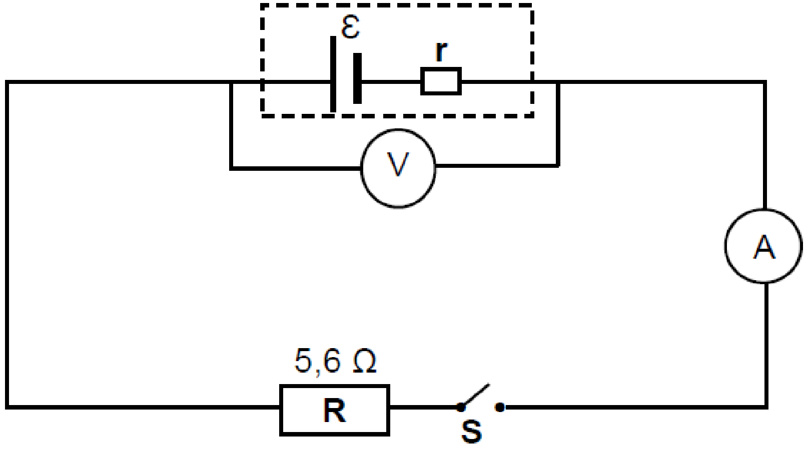
this is a straight line equation B



Sample exam questions:

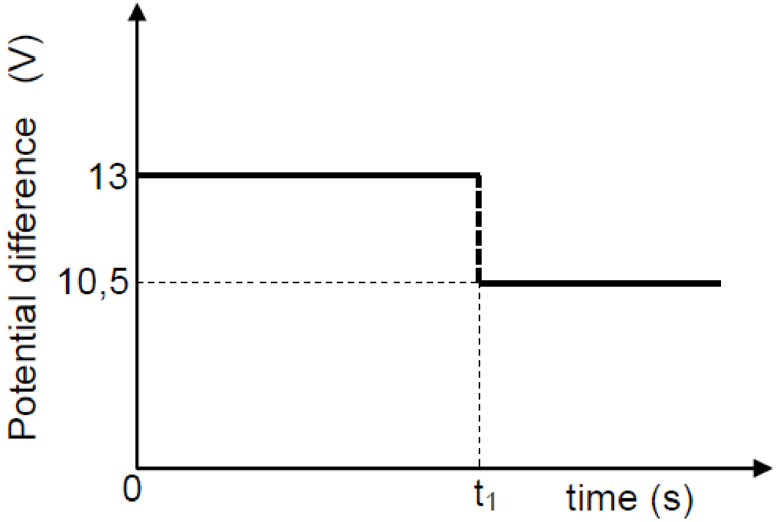
QUESTION 8

In the circuit diagram below, resistor R, with a resistance of 5,6 Ω, is connected, together with a switch, an ammeter and a high-resistance voltmeter, to a battery with an unknown internal resistance, r.



The resistance of the connecting wires and the ammeter may be ignored.

The graph below shows the potential difference across the terminals of the battery as a function of time.



At time t1, switch S is closed.

Give data:

$R = 5{,}6\ \Omega$,

Internal resistor r, ammeter and wire resistance are negligible

$\varepsilon(emf) = 13{,}0\ V$ (from graph – open circuit voltage of battery)

External circuit voltage

$V_{external} = 10{,}5\ V$,

8.1 Define the term emf of a battery. (2)

(Maximum) energy provided (work done) ε by a battery per coulomb / unit charge passing through it.

Electromotive force (EMF) is equal to the terminal potential difference when no current flows.

EMF and terminal potential difference (*V*) are both measured in volts, however they are not the same thing.

EMF (ϵ) is the amount of energy (*E*) provided by the battery to each coulomb of charge (*Q*) passing through.

The emf of a battery is essentially constant because it only depends on the chemical reaction (that converts chemical energy into electrical energy) going on inside the battery. Therefore, we can see that the voltage across the terminals of the battery is dependent on the current drawn by the load. The higher the current, the lower the voltage across the terminals, because the emf is constant. By the same reasoning, the voltage only equals the emf when the current is very small.

8.2 Write down the value of the emf of the battery. (1)

$\varepsilon(emf) = 13{,}0\ V$ (from graph – open circuit voltage of battery)

8.3 When switch S is CLOSED, calculate the:

8.3.1 Current through resistor R (3)

$$I = \frac{V_{external}}{R} = \frac{10{,}5\ V}{5{,}6\ \Omega} = 1{,}88\ A$$

8.3.2 Power dissipated in resistor R (3)

$$P = I^2 R = IV = \frac{V^2}{R} = 19{,}75\ W$$

8.3.3 Internal resistance, r, of the battery (3)

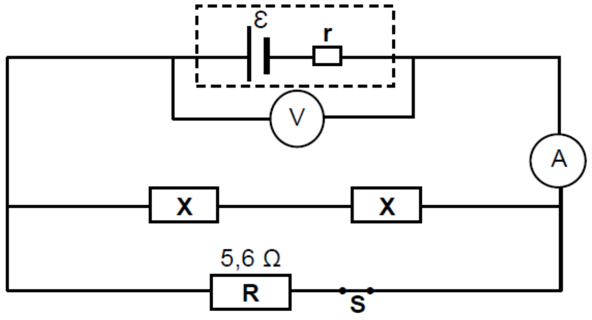
$V_{int} = Ir$, and from

$\varepsilon = V_{int} + V_{ext}$, therefore $V_{int} = \varepsilon - V_{ext} = 13{,}0\ V - 10{,}5\ V = 2{,}5\ V$

$Ir = 1{,}88\, r = 2{,}5\ V,$

$r = \frac{2{,}5}{1{,}88}\ \Omega = 1{,}33\ \Omega,$

8.4 Two IDENTICAL resistors, each with resistance X, are now connected in the same circuit with switch S closed, as shown below. The ammeter reading now increases to 4 A.



8.4.1 How would the voltmeter reading change? Choose from INCREASES, DECREASES or REMAINS THE SAME.

Give a reason for the answer by referring to Internal resistance.

Solution:

We want to know how is V_{ext} affected with increase of current flowing in the circuit.

$V_{ext} = \varepsilon - V_{int} = \varepsilon - Ir$, so since ε and r are relatively constant, increasing I will increase internal voltage and hence decrease the external voltage. So the voltmeter reading will DECREASE (2)

8.4.2 Calculate resistance X. (5)

The two resistors are in series with a total of 2X but in parallel with R.

Equivalent resistance $R_{eq} = \frac{2XR}{2X+R} = \frac{V_{ext}}{4\ A} = \frac{(\varepsilon - V_{int})}{4\ A} = \frac{(\varepsilon - Ir\ )}{4\ A} = \frac{(13{,}0-5{,}32)}{4} = 1{,}92\ \Omega$

$$R_{eq}2X + RR_{eq} = 2XR,\ R_{eq}2X - 2XR = -RR_{eq}$$

$$X = -\frac{RR_{eq}}{2(R_{eq}-R)} = \frac{-5{,}6\times1{,}92}{2(1{,}92-5{,}6)} = \frac{10{,}752}{7{,}36} = 1{,}46\ \Omega$$

Electrodynamics : (electrical machines (generators, motors), alternating current)

David Tinarwo

QUESTION 9: ELECTRODYNAMICS

Common Errors and Misconceptions

(a) Many candidates had difficulty in explaining that for an emf to be induced, there must be a change in the magnetic flux linked to the coil.

(b) Many candidates still omit the subscripts rms and ave in the equations $P_{ave} = I_{rms}^2 R$ and $P_{ave} = \frac{V_{rms}^2}{R}$

(c) Candidates could not differentiate between a DC and an AC source.

- The root mean square is defined as the square root of the mean square. $RMS = \sqrt{\frac{1}{n}\sum_i^n x_i^2}$
- RMS = root mean square
- N = number of measurements
- x_i = each value

So what can we do to improve the understanding of our students of the application of ELECTRODYNAMICS laws?

Suggestions for Improvement

(a) Emphasize the use of subscripts in the formulae when rms calculations are done.

(b) Teachers should show learners the workings of an AC and DC generator using demonstration models of generators or also by allowing learners to build small generators that work.

(c) The Grade 11 work on electromagnetic induction must be revised in Grade 12 when motors and generators are discussed.

(d) Emphasis should be placed on the use of subscripts in the formulae when rms calculations are done.

(e) The differences and similarities between V_{rms} and V_{max}, I_{rms} and I_{max}, P_{ave} and P_{max} must be explained clearly and sufficient application on the type of questions must be given to learners.

(f) Khan Academy, PhET and Edukite are also very useful resources for teachers especially for topics that have a lot practical aspects.

PRIOR KNOWLEDGE • •	PRIOR KNOWLEDGE	CURRENT	
GRADE 10	GRADE 11	GRADE 12	
Magnetic field of permanent magnets • Poles of permanent magnets, attraction and repulsion, magnetic field lines	Magnetic field associated with current carrying wires • Faraday’s law	• Electrical machines (generators, motors) • Alternating current	

Electrical machines - generators and motors

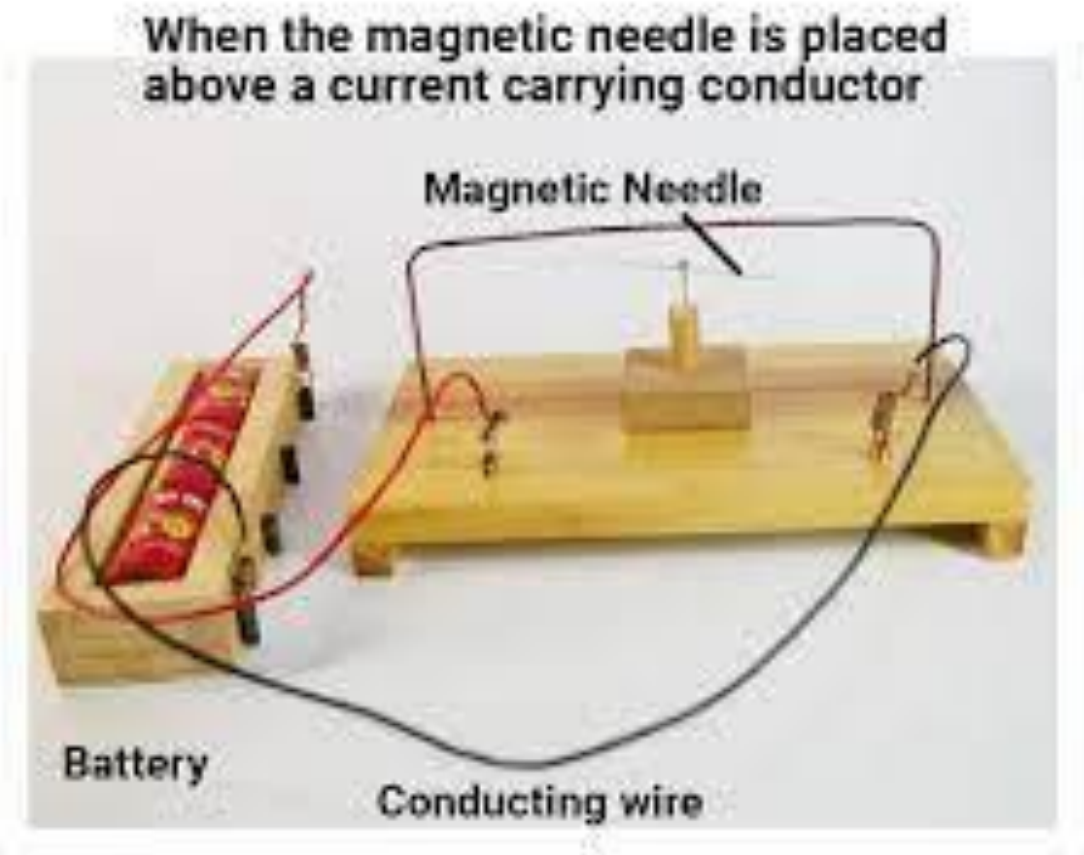
Start by revisiting

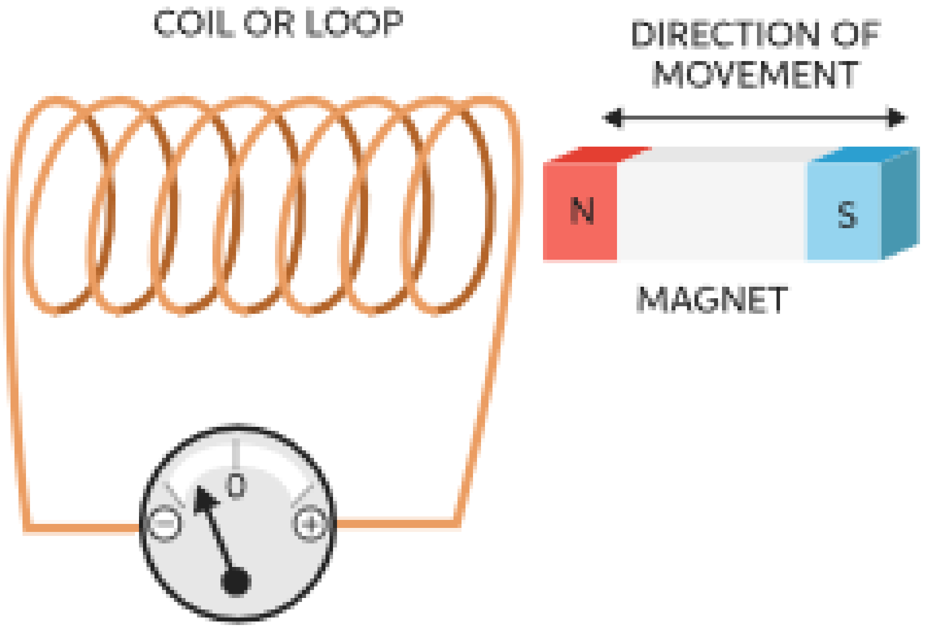
- Oersted law
- Definition of Faraday's Law.
- Using Faraday's Law for explanations.
- Definition of Lorentz Force.
- Explains what happens when a current carrying coil is placed in a magnetic field.
- Definition of a generator
- State the difference between generators and motors.
- Explaining the principle of an AC and DC generator using words and pictures.
- Explaining the difference between AC and DC generators.
- Explaining the principle of an electric motor using word and pictures.
- Examples of AC and DC generators and the use of motors.

Hans Christian Oersted (1777 - 1851), In 1820 discovered that electricity and magnetism were related

- a decade after Oersted's discovery, **Michael Faraday** demonstrated essentially the opposite of what Oersted had found–that a changing magnetic field induces an electric current.

- French physicist **André Ampère** developed a mathematical law to describe the magnetic forces between current carrying wires.
- Following Faraday's work, **James Clerk Maxwell** developed Maxwell's equations, formally unifying electricity and magnetism.


When the magnetic needle is placed above a current carrying conductor
Magnetic Needle
Battery
Conducting wire

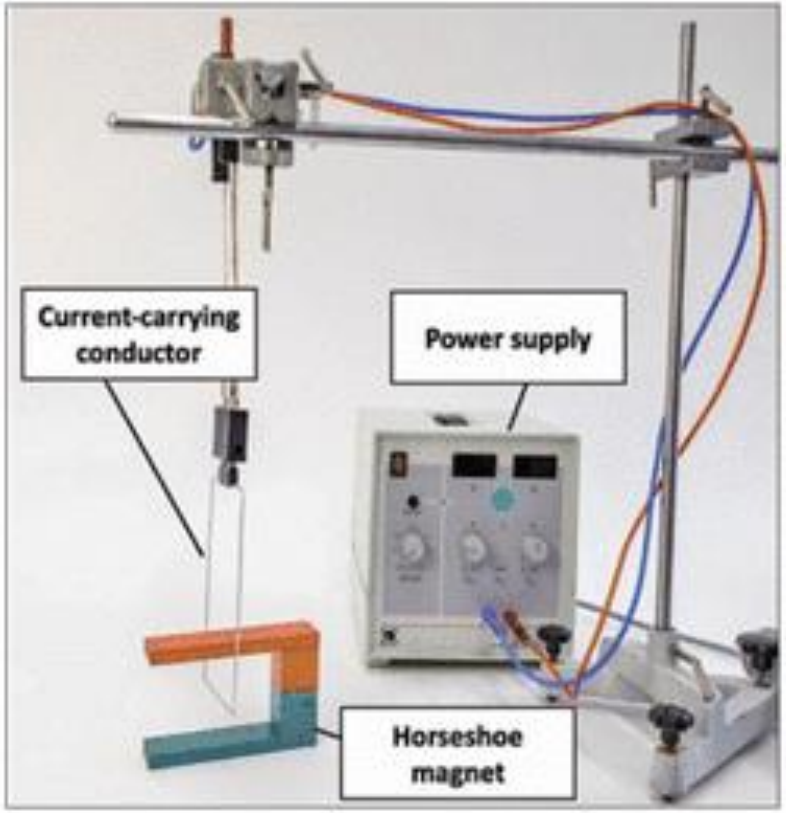

COIL OR LOOP
DIRECTION OF MOVEMENT
N
S
MAGNET
0

Lorentz experimental set-up and procedure

In the experiment a current – carrying conductor is freely suspended in the magnetic field of a horseshoe magnet.

A power supply generates a current of 10 A in the conductor swing

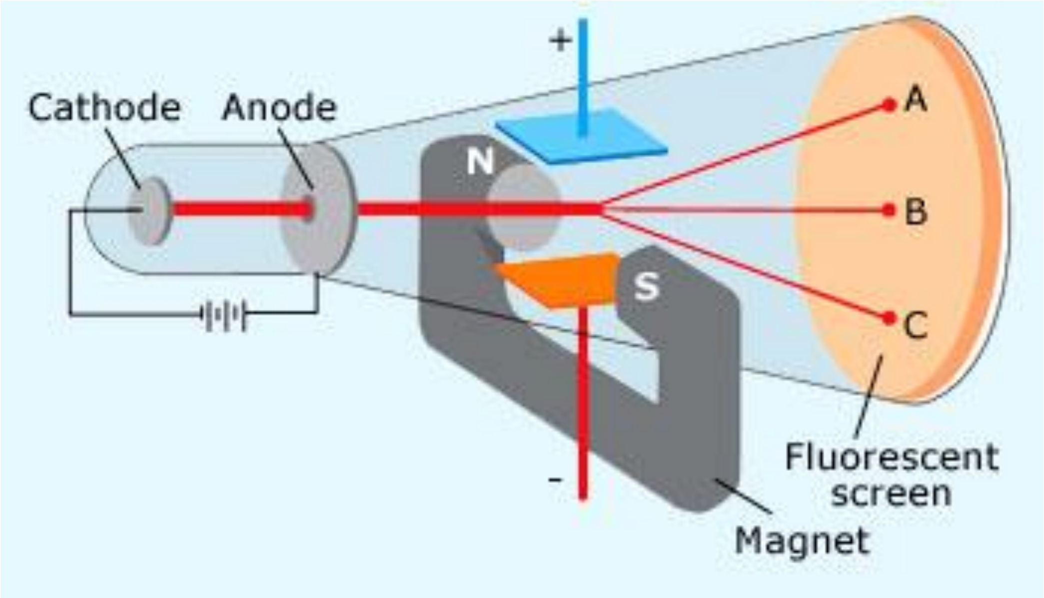
The force is generalized by the Lorentz law: $\vec{F}_L = Q\vec{E} + Q\vec{v} \times \vec{B}$

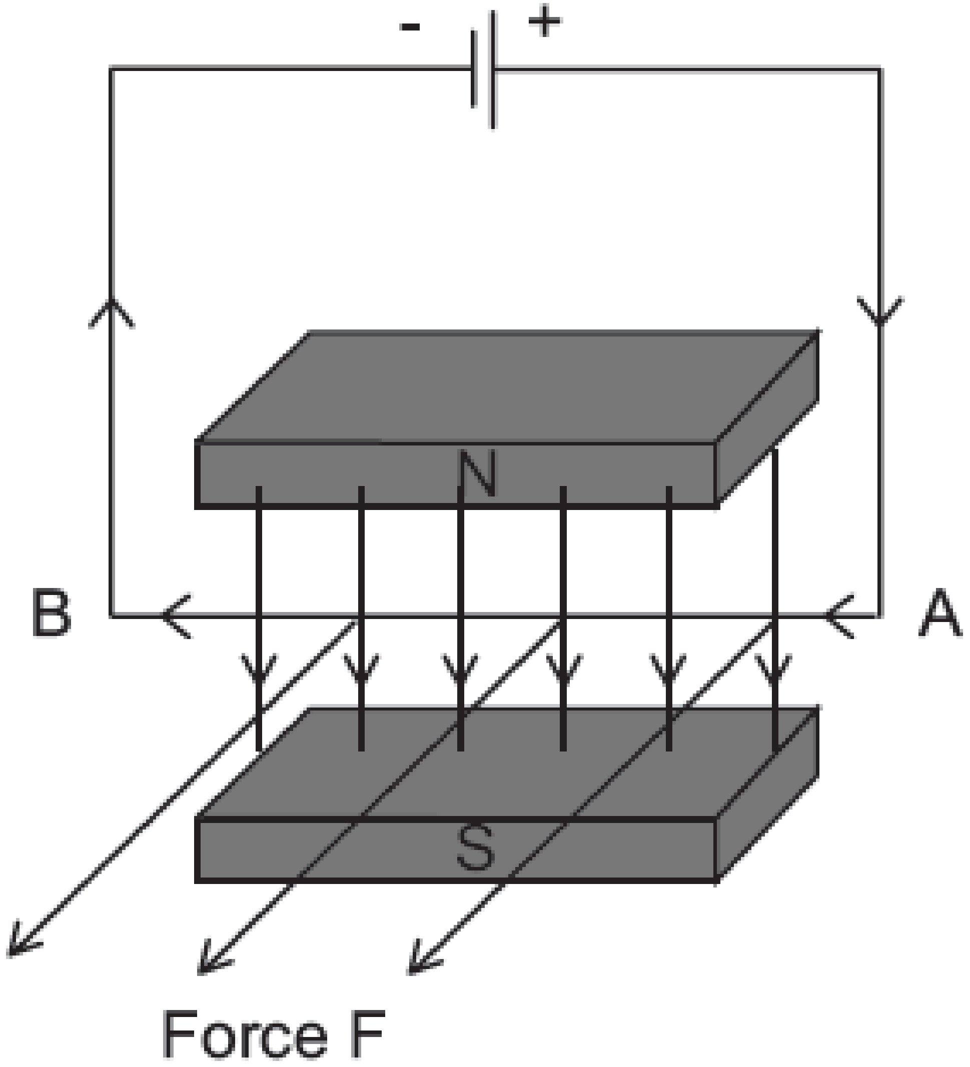


Applications of the Lorentz law/force

- **Discovery of Electrons**
  Cathode rays are a type of radiation emitted by the negative terminal, the cathode, and was discovered by passing electricity through glass tubes from which the air was mostly evacuated. One device used to investigate this phenomenon was a cathode ray tube, the forerunner of the television tube. It is a glass tube from which most of the air has been evacuated. When the two metal plates are connected to a high–voltage source, the negatively charged plate, called the cathode, emits an invisible ray. The cathode ray is drawn to the positively charged plate, called the anode, where it passes through a hole and continues traveling to the other end of the tube. When the ray strikes the specially coated surface, it produces a strong fluorescence, or bright light.

- In some experiments, two electrically charged plates and a magnet were added to the outside of the cathode ray tube. In the presence of magnetic field, the cathode ray strikes point 'B' whereas in the presence of electric field, the cathode ray strikes point 'A' as shown in the figure. In the presence or absence of both electric and magnetic fields such that their magnitudes cancel out each other, the cathode ray strikes point 'C'. According to electromagnetic theory, a moving charged body behaves like a magnet and can interact with electric and magnetic field through which it passes. Because the cathode ray is attracted by the plate bearing positive charges and repelled by the plate bearing negative charges, it must consist of negatively charged particles. These negatively charged particles are called as electrons.




-
+
N
B
A
S
Force F

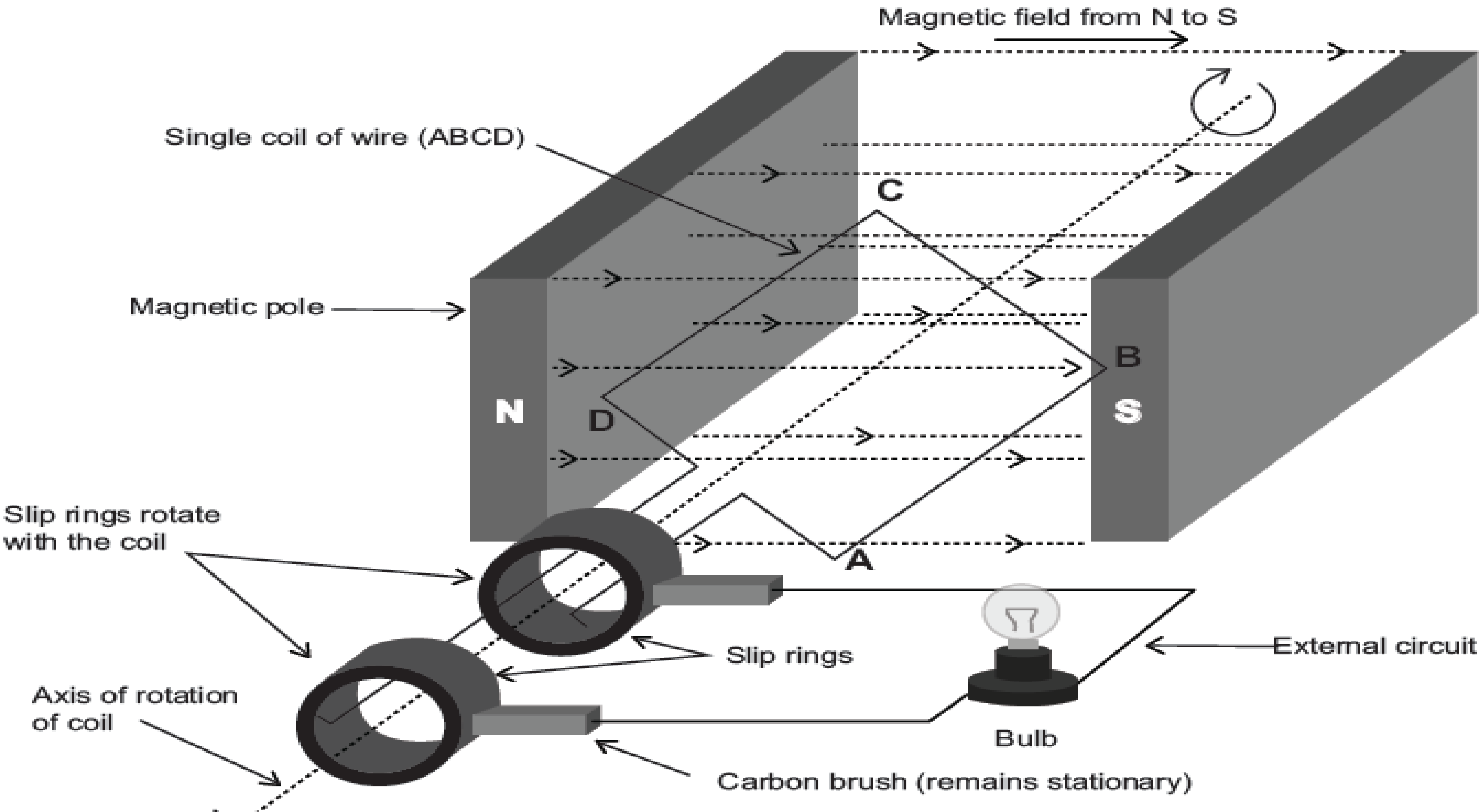
ELECTRIC GENERATORS

INTRODUCTION

- An electric generator converts mechanical energy into electrical energy. Electricity is an essential part of our daily lives. It drives industry and allows our economy to grow and develop.

CONCEPT EXPLANATION AND CLARIFICATION

- a simplified diagram of an AC generator A single coil of wire (ABCD) is placed in the magnetic field.
- Slip rings are connected to each end of the coil of wire.
- Carbon brushes make contact with the slip rings and are connected to the external circuit (bulb).


Magnetic field from N to S
Single coil of wire (ABCD)
C
Magnetic pole
N
D
B
S
A
Slip rings rotate
with the coil
Slip rings
External circuit
Axis of rotation
of coil
Bulb
Carbon brush (remains stationary)

- the coil is rotated (mechanical energy) and the slip rings move with the coil.
- the carbon brushes remain stationary and press against each slip ring, therefore the coil is connected to the external circuit (bulb).
- the coil is now rotated THROUGH THE MAGNETIC FIELD between the permanent magnets.

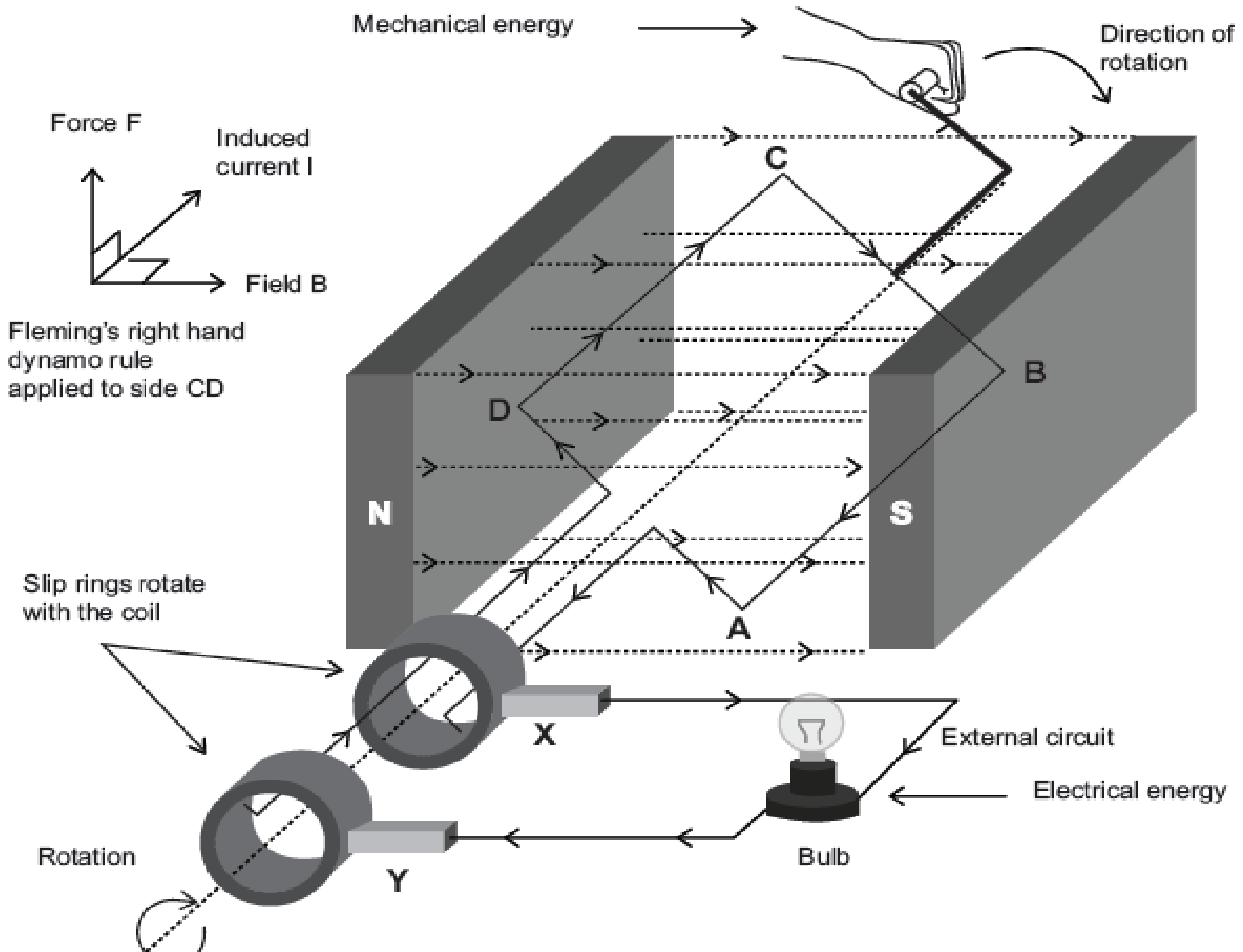
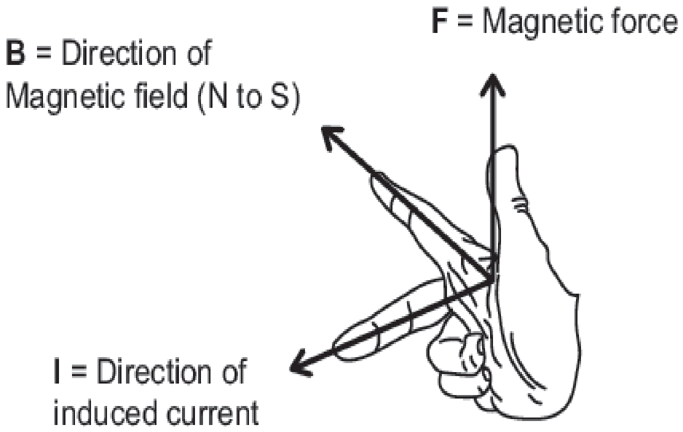


Diagram 2: The coil is rotated clockwise through the magnetic field

Fleming's Right Hand Dynamo Rule:

- Using your RIGHT HAND; hold your thumb, first finger and second finger at right angles to each other as shown below.
- Your THUMB must point in the direction of the MOTION (Force F)
- Your FIRST FINGER shows the direction of the magnetic field (B), North to South.
- Your SECOND FINGER will then show the direction of the INDUCED CURRENT (Current I).
- REFER TO DIAGRAM 2(generator)
- AGAIN. Side CD of the coil is FORCED UPWARDS.
- According to Fleming's right hand dynamo rule, the direction of the INDUCED CURRENT is from D to C in the coil. Side AB of the coil is FORCED DOWNWARDS.
- According to Fleming's right hand dynamo rule, the direction of the INDUCED CURRENT is from B to A in the coil.
- The direction of the induced current IN THE COIL is DCBA. The direction of the current in the EXTERNAL CIRCUIT is from X to Y.
- As the coil is rotated through the magnetic field, the MAGNETIC FLUX (φ) passing through the surface area of the coil is CHANGING.
- Draw the following graph on the board (Diagram 4). The graph shows how the magnetic flux changes with time as the coil rotates.



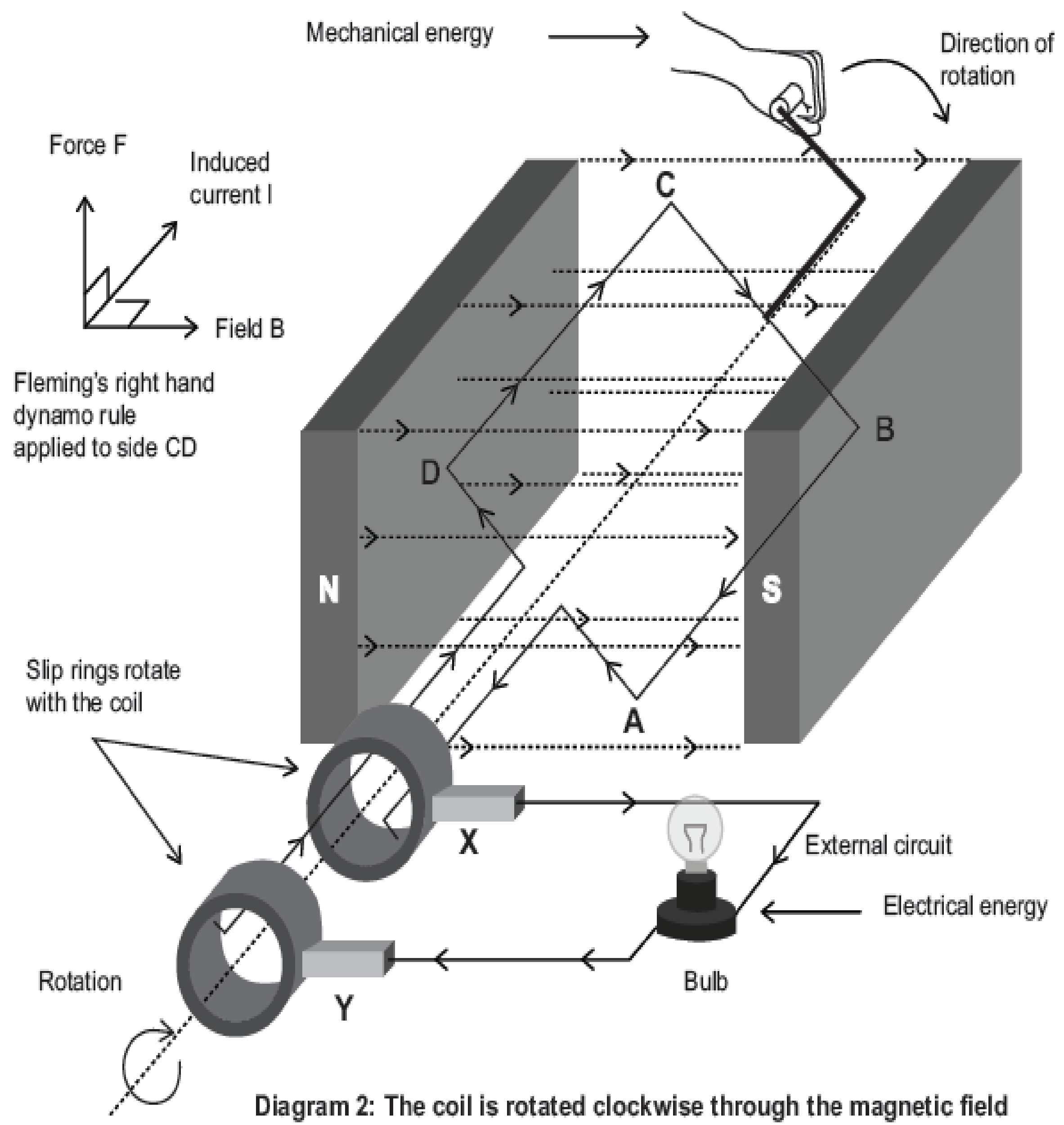


Diagram 2: The coil is rotated clockwise through the magnetic field

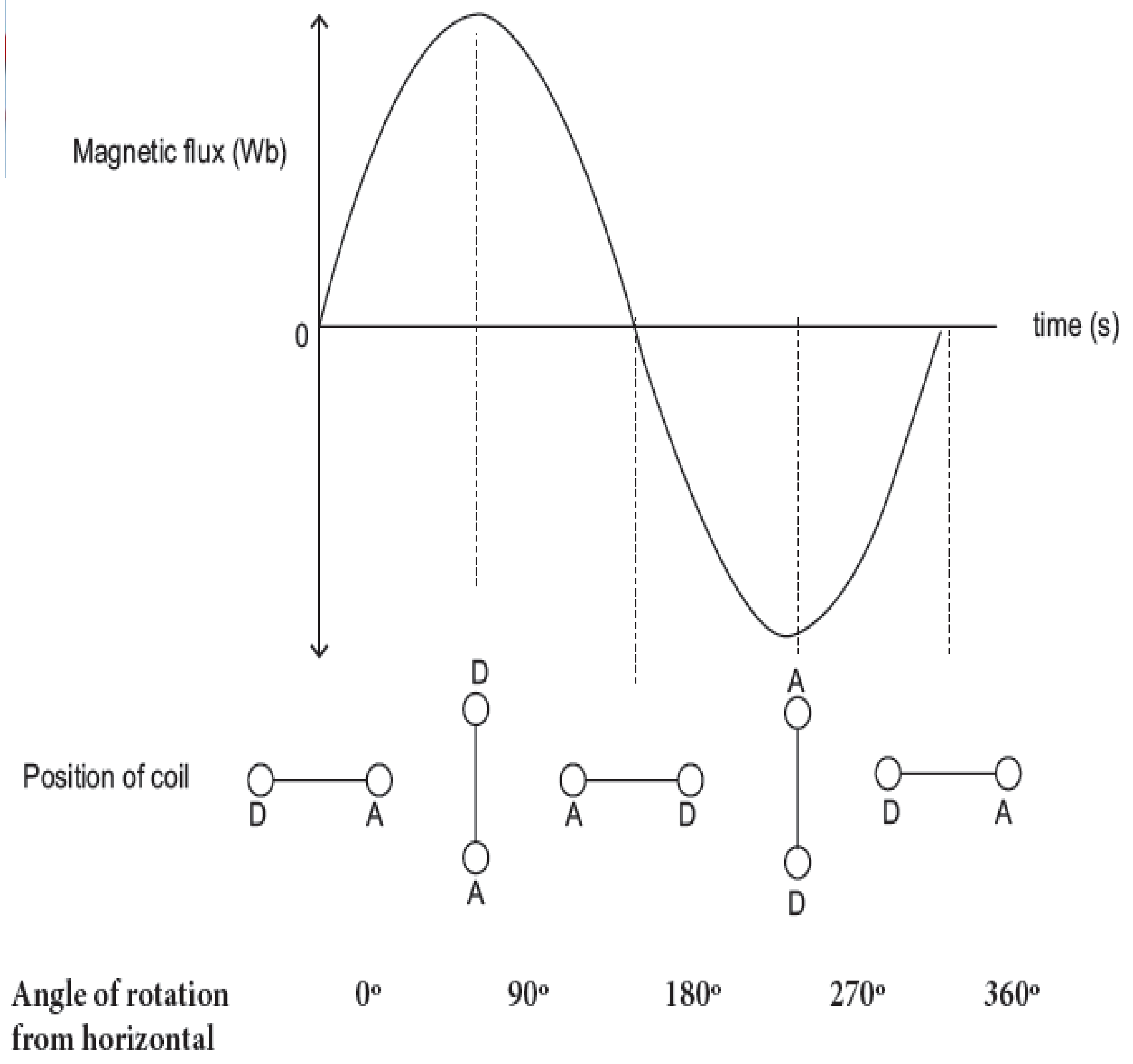


Diagram 4: Graph to show how magnetic flux (ϕ) through the coil changes with the position of the coil

Emphasize the following points to your learners:

a. When the PLANE OF THE COIL is PARALLEL to the MAGNETIC FIELD, MAGNETIC FLUX through the coil is ZERO.

b. When the PLANE OF THE COIL is PERPENDICULAR to the MAGNETIC FIELD, MAGNETIC FLUX through the coil is a MAXIMUM.

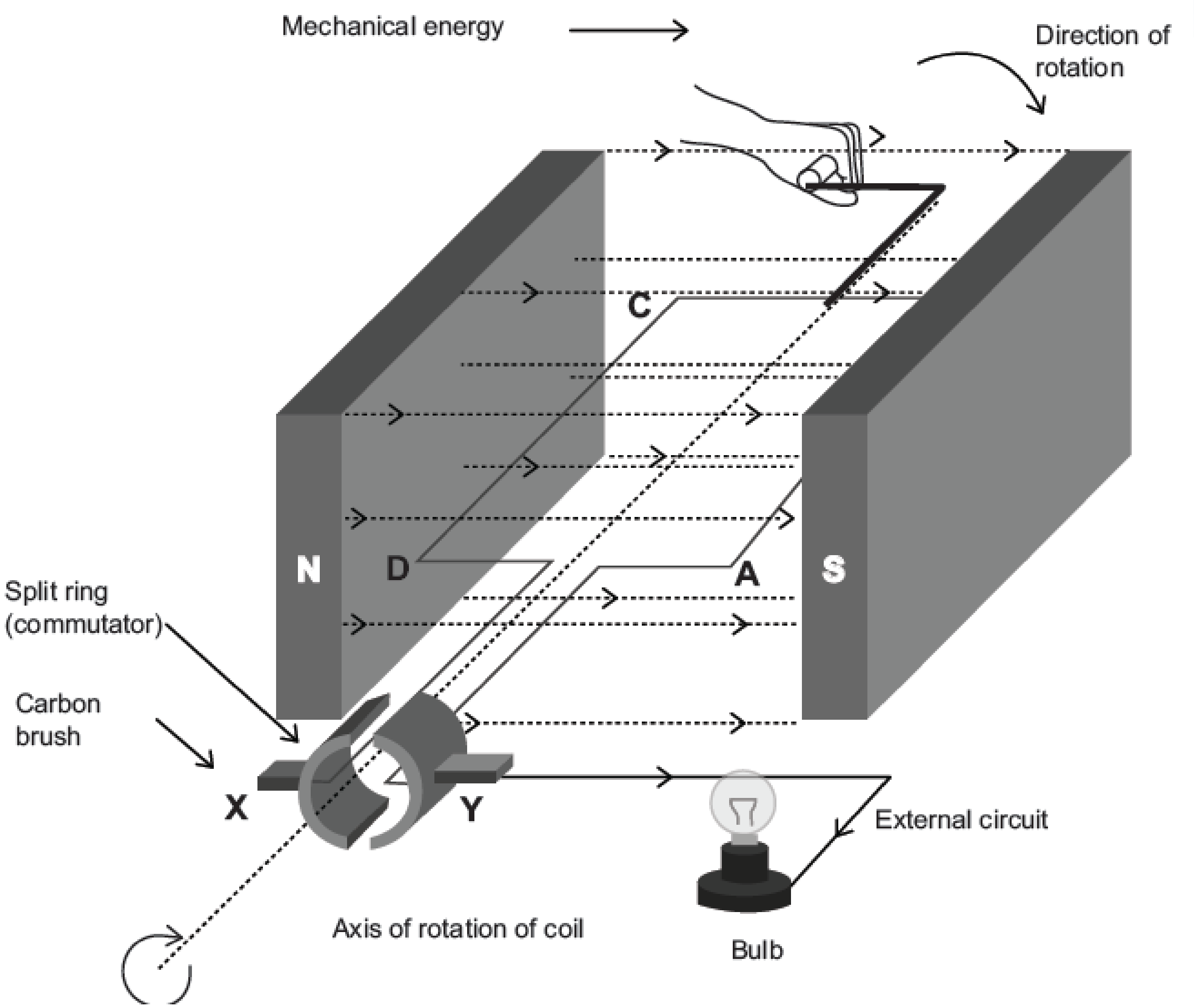
Important to emphasize to the learners is:

a. The GRADIENT (slope) of the magnetic flux (φ) versus time (t) graph is:

$$gradient = \frac{\Delta y}{\Delta x} = \frac{\Delta \varphi}{\Delta t}$$

The GRADIENT of the magnetic flux (φ) versus time (t) graph is equal to THE RATE OF CHANGE OF MAGNETIC FLUX. The gradient (slope) of the graph is a maximum when the coil is parallel to the magnetic field lines. The gradient (slope) of the graph is a zero when the coil is perpendicular to the magnetic field lines.

- Important to emphasize is that in a DC generator, the **slip** rings are replaced by a **Split** ring (commutator).
- A split ring (commutator) is a metal ring that has been split into two halves. There is a gap between the two halves of the ring.
- Important to note again that an alternating current (AC) is induced in the coil as it is rotated through the magnetic field (explained earlier). BUT, the split ring (commutator) ensures that the DIRECTION of the CURRENT in the EXTERNAL CIRCUIT does NOT CHANGE.



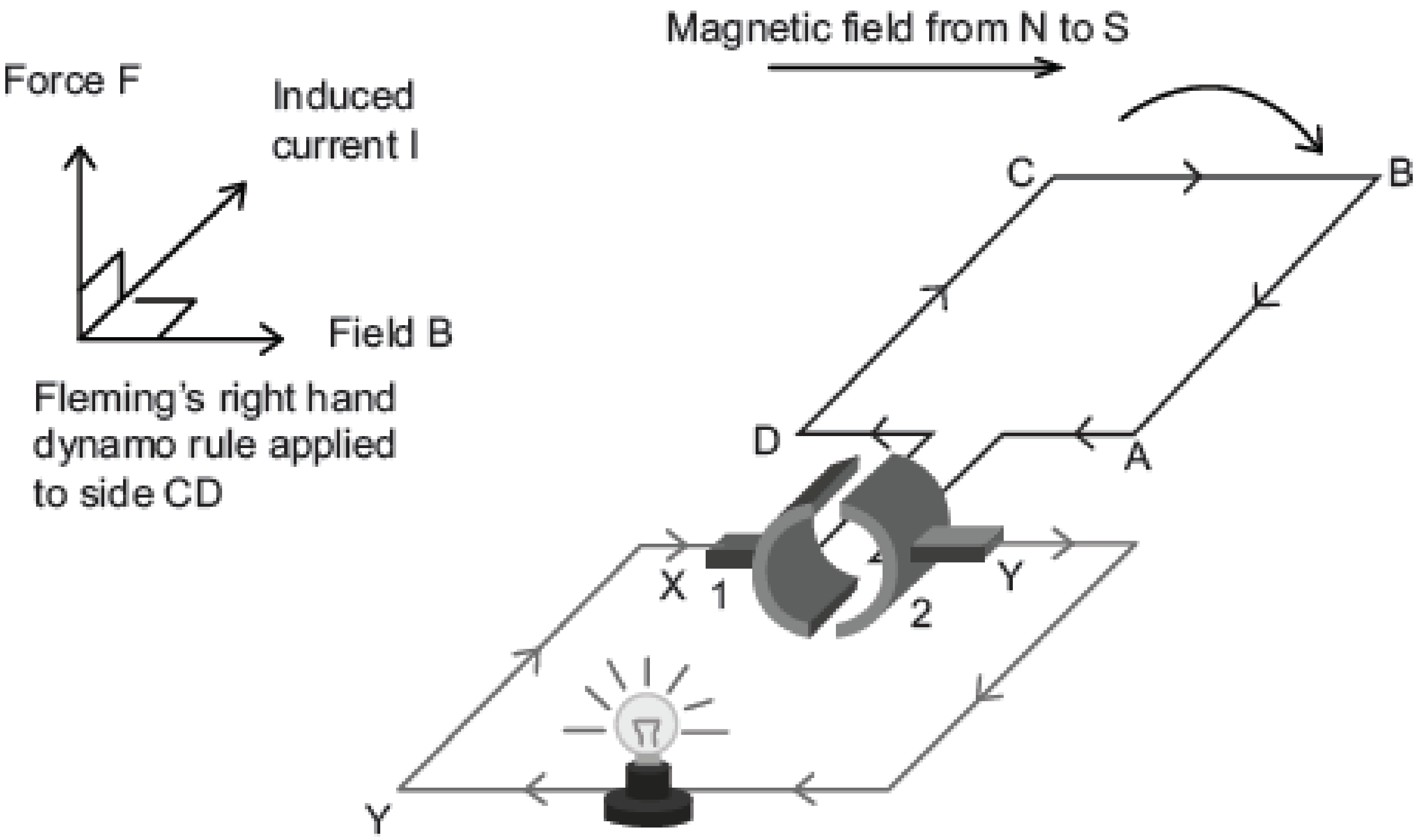


Diagram 9: The direction of the current in the external circuit is from Y to X

A **DC POWER SOURCE** is connected to the carbon brushes as shown below.

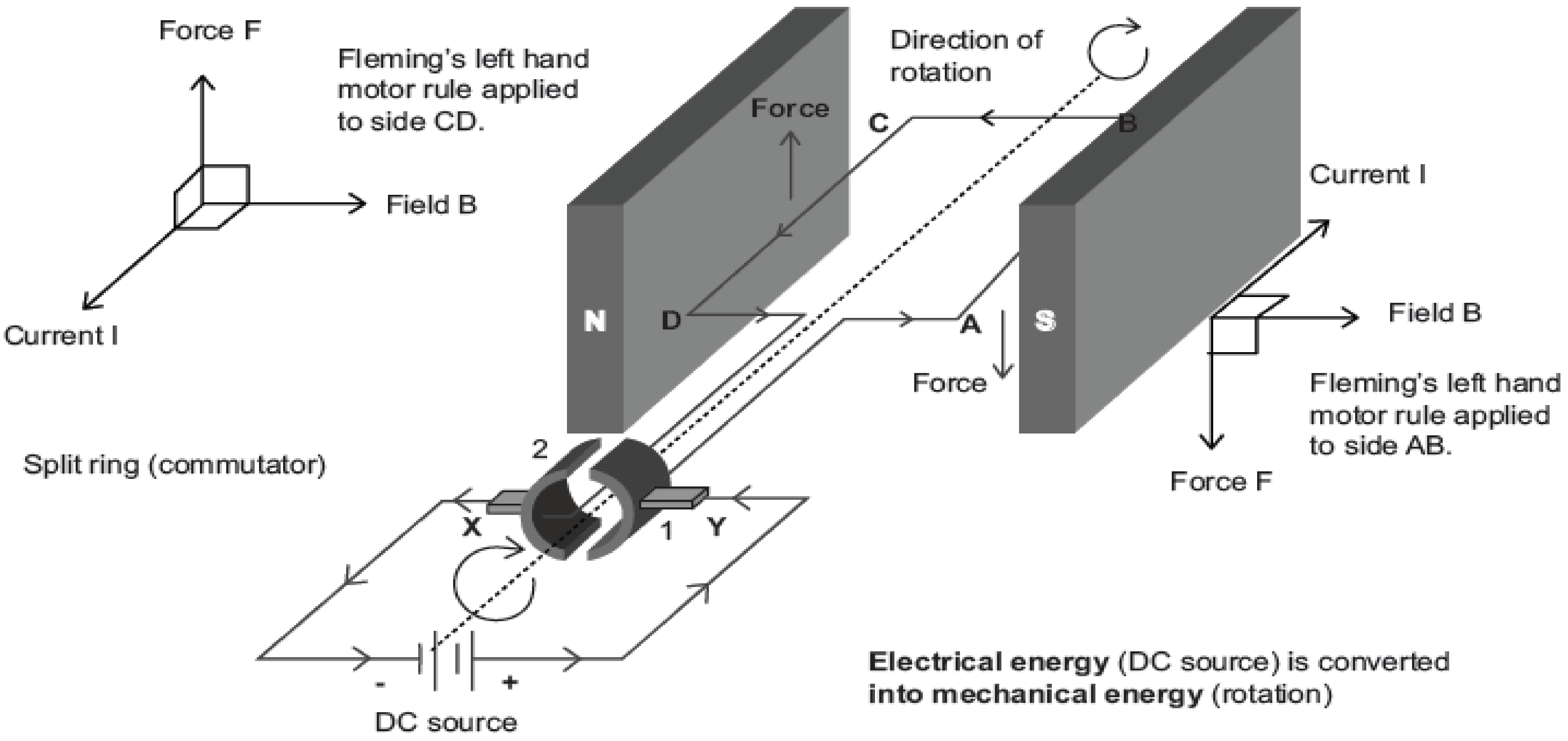


Diagram 3: The parts of a DC electric motor.

QUESTION 9 (Start on a new page.)

9.1 A simplified diagram of an electric generator is shown below. When the coil is rotated with a constant speed, an emf is induced in the coil.

9.1.1 Is this an AC generator or a DC generator? (1)

9.1.2 Briefly explain how an emf is generated in the coil when the coil is rotated by referring to the principle of electromagnetic induction.
(2)

9.1.3 Draw a sketch graph of the output voltage versus time for this generator. Show ONE complete cycle.
(2)

QUESTION 7: ELECTROSTATICS (COULOMB'S LAW and ELECTRIC FIELDS)

Common Errors and Misconceptions

a) Candidates failed to recall that 'like charges repel', hence the repelled sphere should have been positive.

b) Many candidates omitted the force of gravity in their free body diagram.

c) Candidates also confused Coulomb's Law with Newton's Law of Universal Gravitation.

d) Candidates swopped/mixed-up on the formulae **for E and F; F = $k\frac{Q}{r^2}$ and $E = k\frac{Q_1Q_2}{r^2}$.**

e) Many candidates failed to realize that the forces acting on the sphere are in equilibrium and a closed vector diagram would have assisted them in calculating the tension in the string.

f) Candidates did not use the absolute value of the charges when substituting in the formula of Coulomb's Law or the electric field at a point.

So what can we do to improve the understanding of our students of field and force?

Suggestions for Improvement

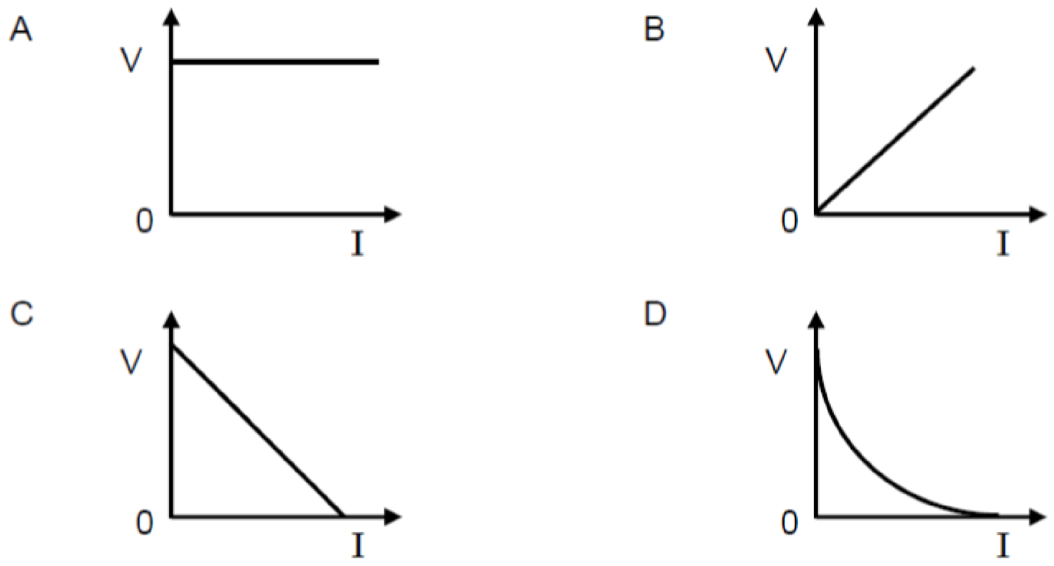
(a) Teachers need to emphasize to learners that calculations of net electrostatic force and electric field are similar in terms of their vector considerations.

(b) Teachers need to clarify the distinction between the two equations i.e. $E = \frac{F}{q}$ and $E = k\frac{Q}{r^2}$. It is important that learners understand which charge 'q' and 'Q' refer to in each of these formulae.

(c) Expose learners to vector diagrams (1D and 2D) and vector triangles when determining the resultant of forces (e.g. electrostatic, gravitational and tension) acting on a body and net electric fields.

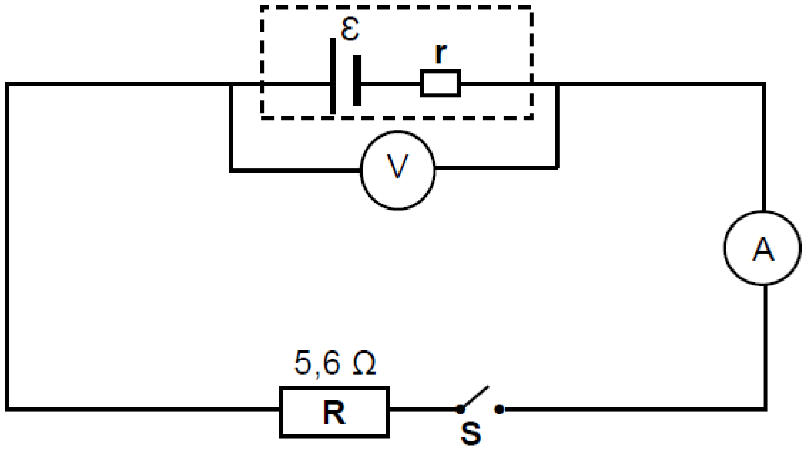
Multiple choice

1.8 Which ONE of the graphs below best represents the relationship between potential difference (V) and current (I) for an ohmic conductor? ($\boldsymbol{V = IR}$)
this is a straight line equation B



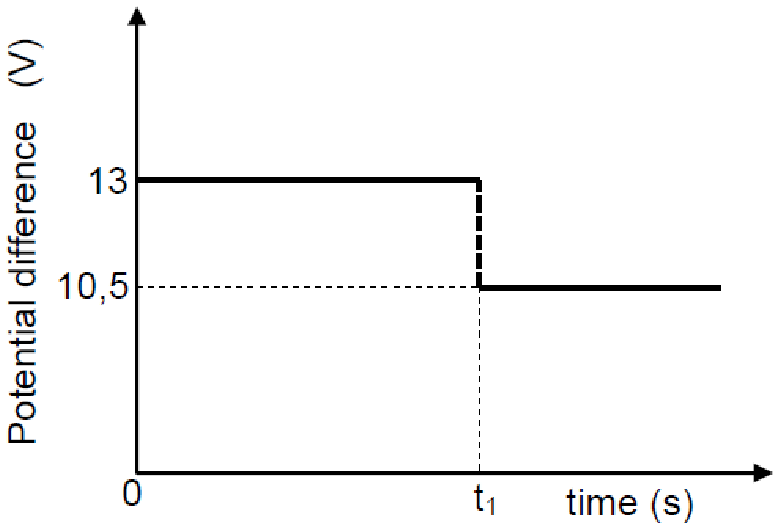
QUESTION 8

In the circuit diagram below, resistor R, with a resistance of 5,6 Ω, is connected, together with a switch, an ammeter and a high-resistance voltmeter, to a battery with an unknown internal resistance, r.



The resistance of the connecting wires and the ammeter may be ignored.

The graph below shows the potential difference across the terminals of the battery as a function of time.



At time t1, switch S is closed.

Give data:

$R = 5{,}6\ \Omega$,

Internal resistor r, ammeter and wire resistance are negligible

$\varepsilon(emf) = 13{,}0\ V$ (from graph – open circuit voltage of battery)

External circuit voltage

$V_{external} = 10{,}5\ V$,

8.1 Define the term emf of a battery. (2)

(Maximum) energy provided (work done) ✓ by a battery per coulomb / unit charge passing through it.

Electromotive force (EMF) is equal to the terminal potential difference when no current flows. EMF and terminal potential difference (*V*) are both measured in volts, however they are not the same thing. EMF (ϵ) is the amount of energy (*E*) provided by the battery to each coulomb of charge (*Q*) passing through. The emf of a battery is essentially constant because it only depends on the chemical reaction (that converts chemical energy into electrical energy) going on inside the battery. Therefore, we can see that the voltage across the terminals of the battery is dependent on the current drawn by the load. The higher the current, the lower the voltage across the terminals, because the emf is constant. By the same reasoning, the voltage only equals the emf when the current is very small.

8.2 Write down the value of the emf of the battery. (1)

$\varepsilon(emf) = 13{,}0\ V$ (from graph – open circuit voltage of battery)

8.3 When switch S is CLOSED, calculate the:

8.3.1 Current through resistor R (3)

$$I = \frac{V_{external}}{R} = \frac{10{,}5\ V}{5{,}6\ \Omega} = 1{,}88\ A$$

8.3.2 Power dissipated in resistor R (3)

$$P = I^2R = IV = \frac{V^2}{R} = 19{,}75\ W$$

8.3.3 Internal resistance, r, of the battery (3)

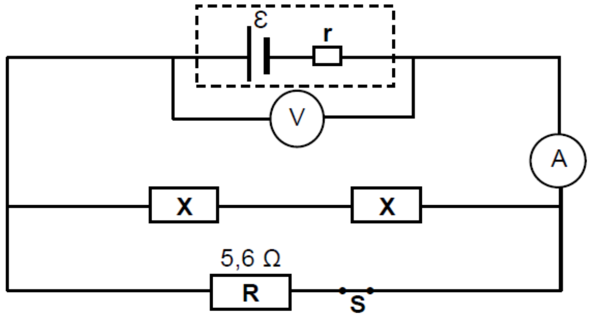
$V_{int} = Ir$, and from

$\varepsilon = V_{int} + V_{ext}$, therefore $V_{int} = \varepsilon - V_{ext} = 13{,}0\ V - 10{,}5\ V = 2{,}5\ V$

$Ir = 1{,}88\ r = 2{,}5\ V,$

$r = \frac{2{,}5}{1{,}88}\ \Omega = 1{,}33\ \Omega,$

8.4 Two IDENTICAL resistors, each with resistance X, are now connected in the same circuit with switch S closed, as shown below. The ammeter reading now increases to 4 A.



8.4.1 How would the voltmeter reading change? Choose from INCREASES, DECREASES or REMAINS THE SAME.

Give a reason for the answer by referring to Internal resistance.

Solution:

We want to know how is V_{ext} affected with increase of current flowing in the circuit.

$V_{ext} = \varepsilon - V_{int} = \varepsilon - Ir$, so since ε and r are relatively constant, increasing I will increase internal voltage and hence decrease the external voltage. So the voltmeter reading will DECREASE (2)

8.4.2 Calculate resistance X. (5)

The two resistors are in series with a total of 2X but in parallel with R.

Equivalent resistance $R_{eq} = \frac{2XR}{2X+R} = \frac{V_{ext}}{4\ A} = \frac{(\varepsilon - V_{int})}{4\ A} = \frac{(\varepsilon - Ir\ )}{4\ A} = \frac{(13{,}0-5{,}32)}{4} =$ 1,92 Ω

$$R_{eq}2X + RR_{eq} = 2XR,\ R_{eq}2X - 2XR = -RR_{eq}$$

$$X = -\frac{RR_{eq}}{2(R_{eq}-R)} = \frac{-5{,}6\times 1{,}92}{2(1{,}92-5{,}6)} = \frac{10{,}752}{7{,}36} = 1{,}46\ \Omega$$

Electrodynamics : (electrical machines (generators, motors), alternating current)

David Tinarwo

QUESTION 9: ELECTRODYNAMICS

Common Errors and Misconceptions

(a) Many candidates had difficulty in explaining that for an emf to be induced, there must be a change in the magnetic flux linked to the coil.

(b) Many candidates still omit the subscripts rms and ave in the equations $P_{ave} = I_{rms}^2 R$ and $P_{ave} = \frac{V_{rms}^2}{R}$

(c) Candidates could not differentiate between a DC and an AC source.

So what can we do to improve the understanding of our students of the application of ELECTRODYNAMICS laws?

Suggestions for Improvement

(a) Emphasize the use of subscripts in the formulae when rms calculations are done.

(b) Teachers should show learners the workings of an AC and DC generator using demonstration models of generators or also by allowing learners to build small generators that work.