SESSION 11: ELECTRIC CIRCUITS

Key Concepts

- Resistance and Ohm’s laws
- Ohmic and non-ohmic conductors
- Series and parallel connection
- Energy in an electric circuit

X-planation

1. CONDUCTORS AND INSULATORS

An electrostatic force will cause for charges to move. If charges can move through a substance, it is called a conductor. If the charge cannot move through a substance, it is called an insulator or a non-conductor.

Conductors

- Metals are good conductors because their electrons are loosely bonded and can move easily.
- If a solution conducts electricity, it is called an electrolyte.

Insulators

- Non-metals are very good insulators; their electrons are very tightly bonded and cannot move.

2. CURRENT ELECTRICITY

This is the movement of charges inside a conductor, e.g. the closed circuit. Electrons are the “carriers” of charge in metals and ion carry charge in solutions.

A closed circuit is needed for a current to flow. A circuit needs at least three components: electrical source, conductor and a resistor. Current can only flow in a closed circuit – a circuit in which there are no “gaps.”

3. CURRENT

Electric current is the amount of charge that moves past any point in a conductor each second. Electric current can be calculated by using the following equation:

\[ Q = It \]

1 Coulomb is the amount of charge that moves past a point of a conductor in 1 second when the current in the conductor is 1 ampere.

Electric current is measured with an ammeter that is always connected in series.

The direction of conventional current is always from the positive terminal of the cell through the circuit to the negative terminal of the cell.
4. POTENTIAL DIFFERENCE
A difference in electric potential energy between two points in a circuit is the potential difference across that point.

The potential difference between two points in an electric circuit is the energy transferred (work must be done) when 1 coulomb charge moves from the one point to the other.

Potential difference is measured across the components in the circuit where electrical energy is given to the charges (i.e. over the cells) or where electrical energy is “used” or given off by the charges when they move through components (i.e. bulbs or resistors),

A voltmeter is used to measure potential difference. A voltmeter is always connected in parallel over which it measures the potential difference; it has a high resistance. The one end of the connection registers how much energy the charges have when they enter the cell or resistor, the other registers the energy that the charges have when they leave the component. The voltmeter now gives the reading showing the difference in energy across the component.

5. RESISTANCE
Resistance is caused by collisions in a conductor when a current is flowing through it. A good conductor has a low resistance.

Electric resistance is the resistance that a conductor offers against the flow of charge.

6. RESISTANCE AND OHM’S LAW
   - **Ohm’s Law** states that the current between any two points in a conductor is directly proportional to the potential difference between these points provided that the temperature of the conductor remains constant.

   Equation: \[ R = \frac{V}{I} \]
   Units: current – amperes (A), voltage – volts (V) and resistance – ohms (Ω)

   - The resistance of the conductor depends on
     - The type of material used
     - The length of the conductor – the longer the conductor, the greater the resistance
     - The thickness of the conductor – the thicker the conductor, the smaller the resistance
     - The temperature of the conductor – the higher the temperature, the greater the resistance
7. OHMIC AND NON-OHMIC CONDUCTORS

- There is a mention of constant temperature when we talk about Ohm's Law. This is because the resistance of some conductors changes as their temperature changes. These types of conductors are called non-ohmic conductors because they do not obey Ohm's Law. As can be expected, the conductors that obey Ohm's Law are called ohmic conductors. A light bulb is a common example of a non-ohmic conductor. Nichrome wire is an ohmic conductor.

- In a light bulb, the resistance of the filament wire will increase dramatically as it warms from room temperature to operating temperature. If we increase the supply voltage in a real lamp circuit, the resulting increase in current causes the filament to increase in temperature which increases its resistance. This effectively limits the increase in current. In this case, voltage and current do not obey Ohm's Law.

- The phenomenon of resistance changing with variations in temperature is one shared by almost all metals of which most wires are made. For most applications, these changes in resistance are small enough to be ignored. In the application of metal lamp filaments, which increase a lot in temperature (up to about 1000°C, and starting from room temperature), the change is quite large.

- In general non-ohmic conductors have plots of voltage against current that are curved, indicating that the resistance is not constant over all values of voltage and current.
# 8. SERIES AND PARALLEL CONNECTION

<table>
<thead>
<tr>
<th>Components</th>
<th>Connection</th>
<th>Diagram</th>
<th>Effect on Current (A)</th>
<th>Effect on Potential Difference (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cells</td>
<td>Series</td>
<td><img src="image" alt="Series diagram" /></td>
<td>Increases</td>
<td>Increases</td>
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<tr>
<td>Cells</td>
<td>Parallel</td>
<td><img src="image" alt="Parallel diagram" /></td>
<td>Remains the same</td>
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<td>Resistors</td>
<td>Series</td>
<td><img src="image" alt="Series resistor diagram" /></td>
<td>The current in a given series circuit is the same throughout the circuit. The more resistors in series, the greater the resistance, the current decreases.</td>
<td>Resistors in series are potential dividers i.e. $V_T = V_1 + V_2$</td>
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**Resistors in series** are potential dividers, i.e., the potential difference across each resistor is the same, i.e., $V_T = V_1 + V_2$.

**Resistors in parallel** split the current, i.e., the total current is the sum of the currents through each resistor, i.e., $A_T = A_1 + A_2$.

**Series Circuit**: The current is the same throughout the circuit. The more resistors in series, the greater the resistance, the current decreases.

**Parallel Circuit**: The current splits, i.e., the total current is the sum of the currents through each resistor. The total resistance decreases as more resistors are added in parallel.
9. **ENERGY IN AN ELECTRIC CIRCUIT**


**Potential difference in an electric field**

- Potential difference = Work done to move a charge
  Magnitude of the charge moved.
  i.e. \( V = \frac{W}{Q} \),
  Therefore, \( W = Q \cdot V \)

- Quantity of charge: formula for the quantity of charge is \( Q = I \cdot t \)

- Work done by an electric field: \( W = Q \cdot V \)
  But \( Q = I \cdot t \),
  Therefore, \( W = V \cdot I \cdot t \)

- Power: the rate at which work is done
  \[ \text{Power} = \frac{\text{Work}}{\text{Time}} \]
  Units: watt (W)
  If \( P = \frac{W}{t} \) and \( W = V \cdot I \cdot t \)
  \[ P = \frac{V \cdot I \cdot t}{t} \]
  Therefore, \( P = V \cdot I \)

9.2. **Ohm’s Law and Energy**

The formula \( P = V \cdot I \) gives the power at which electric energy is ‘used’ by a device
or at which it is supplied by a source.

In summary

<table>
<thead>
<tr>
<th>Total amount of work</th>
<th>Power</th>
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<tr>
<td>( W = V \cdot I \cdot t )</td>
<td>( P = V \cdot I )</td>
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</table>

But \( V = I \cdot R \) (Ohm’s Law)

| \( W = I^2 \cdot R \cdot t \) | \( P = I^2 \cdot R \) |

Or if \( I = V \div R \)

| \( W = V^2 \div R \cdot t \) | \( P = V^2 \div R \) |
X-ample Questions

Question 1

A battery of emf 24 V, which has no internal resistance, is connected in a circuit, as in the diagram. The resistance of the ammeter is negligible.

1.1 Calculate the total resistance of the circuit. (6)
1.2 Calculate the reading on the ammeter. (3)
1.3 Calculate the reading on the volt meter. (4)
1.4 Calculate the current through the 6 Ω resistor. (3)
1.5 Calculate the amount of electrical energy transferred by the 12 Ω resistor in 5 minutes' time. (4)

Question 2

Three 1.5 V cells are connected in series to form a battery with negligible internal resistance. Four identical bulbs are connected in the circuit. L₁ is connected in series with the battery and an ammeter that reads the current through the battery. L₂ and L₃ are in connected in series in a parallel branch. L₄ is connected in the second parallel branch. A voltmeter, V₁, reads the potential difference across the battery and a second voltmeter, V₂, reads the potential difference across L₄.

2.1 Draw the circuit diagram of the circuit. (5)
2.2 Calculate the reading on the ammeter. (6)
2.3 Calculate the readings on V₁ and V₂ (4)
2.4 Predict what you would observe about the brightness of the bulbs. Explain your answer by doing some calculations. (5)

Question 3

Theo used the following circuit in an investigation to determine the relationship between resistance and current in a circuit. He first connects the bulbs in series then in parallel.
The emf of each cell is 1,5 V and the resistance of the bulbs A and B is 2 Ω and 3 Ω respectively.

3.1 What is the reading on voltmeter 1?  
3.2 What is the reading on $V_2$ & $V_3$ respectively.  
3.3 Calculate the energy transferred to bulb B in 3 seconds.  

Theo now connects the bulbs in parallel.

3.4 Calculate the resistance in the circuit.  
3.5 Calculate the current in the circuit.  
3.6 Write an investigative question for the experiments Theo performed.  
3.7 Write a conclusion for the investigation.  

Question 4

A kettle is marked 240 V; 1 500 W.

4.1 Calculate the resistance of the kettle when operating according to the above specifications.  
4.2 If the kettle takes 3 minutes to boil some water, calculate the amount of electrical energy transferred to the kettle.
X-ercise

Question 1

A 10 Ω resistor and a variable resistor (rheostat) are connected in series and placed across a 12 V source. The rheostat is adjusted until the current in the circuit is 0.5 A.

1.1 At what resistance is the rheostat set? (5)

1.2 What is the potential difference across the 10 Ω resistor? (3)

1.3 What is the potential difference across the rheostat? (3)

Question 2

What is the power dissipated by a circuit that passes a current of 1.6A when a voltage of 6V is connected across it? (3)

Question 3

An electric lamp uses energy at the rate of 100W when connected to a 12V supply. Calculate:

3.1. The current in the lamp. (3)
3.2. The resistance of the lamp. (3)