
TOPIC 3.1: ELECTRIC CIRCUITS

- S4P-3-1 Describe the origin of conventional current and relate its direction to the electron flow in a conductor.
- S4P-3-2 Describe the historical development of Ohm's Law.
Include: contributions of Gray, Ohm, Joule, and Kirchoff
- S4P-3-3 Investigate the relationships among resistance and resistivity, length, cross-section, and temperature.
Include: $R = \frac{\rho L}{A}$
- S4P-3-4 Demonstrate the ability to construct circuits from schematic diagrams for series, parallel, and combined networks.
Include: correct placement of ammeters and voltmeters
- S4P-3-5 Calculate the total resistance for resistors in series and resistors in parallel.
- S4P-3-6 Calculate the resistance, current, voltage, and power for series, parallel, and combined networks.
Include: $P = IV$, $P = I^2R$, and $P = \frac{V^2}{R}$.
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GENERAL LEARNING OUTCOME CONNECTION

Students will...

Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)

SPECIFIC LEARNING OUTCOME

S4P-3-1: Describe the origin of conventional current and relate its direction to the electron flow in a conductor.



SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

In Senior 1 Science, students studied electrostatics and the particle model of electricity. According to this model, only negative charges move in a conductor.

Notes to the Teacher

Benjamin Franklin advocated a one-fluid model of electricity where the electrical “fluid” would move from a region where there was more of it to a region where there was less fluid. He called the more plentiful region *positive* and the less plentiful area *negative*. According to this theory, electricity moves from positive to negative and is called the **conventional current of electricity**. Years later, the actual flow of electricity was determined to be negative electrons moving from a negative region to a positive region (opposite to Franklin’s theory). This movement was called the **electron flow**.

Certain laws of physics depend on the direction of flow of electricity. Many physics texts continue to use a conventional flow of electricity and a corresponding set of “right-hand rules.” Electricians tend to use the electron flow of electricity and a corresponding set of “left-hand rules.” Each system adequately explains the relation between electricity and magnetism. The teacher may decide to use either right-hand or left-hand rules. This learning outcome merely differentiates between conventional and electron flow of electricity.



SKILLS AND ATTITUDES OUTCOME

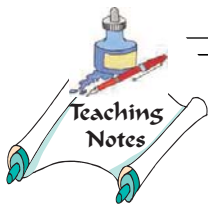
S4P-0-2c: Formulate operational definitions of major variables or concepts.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)

SUGGESTIONS FOR INSTRUCTION




SUGGESTIONS FOR ASSESSMENT

Students complete a compare and contrast frame for conventional and electron current (SYSTH).

SUGGESTED LEARNING RESOURCES

See Appendix 3.1: The Historical Development of Ohm's Law.



GENERAL LEARNING OUTCOME CONNECTION	SPECIFIC LEARNING OUTCOME	SKILLS AND ATTITUDES OUTCOMES 
<p><i>Students will...</i></p> <p>Identify and appreciate contributions made by women and men from many societies and cultural backgrounds toward increasing our understanding of the world and in bringing about technological innovations (GLO A4)</p>	<p>S4P-3-2: Describe the historical development of Ohm’s Law.</p> <p>Include: contributions of Gray, Ohm, Joule, and Kirchoff</p>	<p>S4P-0-1a: Explain the roles of theory, evidence, and models in the development of scientific knowledge.</p> <p>S4P-0-1b: Describe the importance of peer review in the evaluation and acceptance of scientific theories, evidence, and knowledge claims.</p>

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

In Senior 1 Science, students extended the particle model of electricity to electric circuits. In their investigations Ohm’s Law is implied by the inverse relation between current and resistance. That is, students note that as resistance increases, current decreases. Students are also introduced to the concept of voltage; however, this is a very difficult concept and should be revisited.

Notes to the Teacher

The typical treatment of Ohm’s Law involves an experiment to graph voltage and current for a resistance. The slope of the line is given as the resistance and Ohm’s Law is established. This method is really just a circular proof of the law, since the voltmeter is calibrated using Ohm’s Law in the first place. A more accurate (and pedagogically rich) representation is the historical approach that begins with Gray’s demonstration of the conduction of electricity; Ohm’s demonstration that current is inversely proportional to resistance; Joule’s connection of power to current and resistance; and Kirchoff’s synthesis of electrostatics, Ohm’s, and Joule’s work. Since textbooks will not use an historical approach, a complete outline is provided for the teacher in Appendix 3.1. Additionally, the historical approach permits a consideration of the Nature of Science skills outcomes.

Prior Knowledge Activities

Students learn best when they are able to relate new knowledge to what they already know. Use a KWL chart (SYSTH) to activate and assess students’ prior knowledge of electric circuits.

Student Research/Web Quest

Students research the contributions of other scientists to the development of our understanding of voltage, current, and resistance. Some scientists to consider are Volta, Davy, Faraday, and Ampere.

Laboratory Activities

Several experiments are described in the appendix. Ohm’s experiment and Joule’s experiment are integral to the historical approach.

The more traditional experiment of measuring voltage and current can be found in most textbooks. Although not a proof of Ohm’s Law, the activity is useful as students learn to build circuits and use electric meters. It serves as a good follow-up to the historical approach.



SKILLS AND ATTITUDES OUTCOMES

S4P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

S4P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

S4P-0-1e: Differentiate between how scientific theories explain natural phenomena and how scientific laws identify regularities and patterns in nature.

S4P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data-collection methods.

Include: discrepancies in data and sources of error

S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

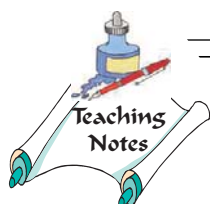
GENERAL LEARNING OUTCOME CONNECTION

Students will...

Describe scientific and technological developments, past and present, and appreciate their impact on individuals, societies, and the environment, both locally and globally (GLO B1)

SUGGESTIONS FOR INSTRUCTION

SUGGESTIONS FOR ASSESSMENT



Empty box for teaching notes.

Laboratory Report

Students complete a formal laboratory report for Ohm’s Law and Joule’s Law.

Demonstration of an Understanding of the Major Explanatory Stories in Science

Students explain their understanding of the particle model of electricity and the relationships among voltage, current, and resistance.

Observation

Observe to determine if students have correctly connected electrical circuits.

SUGGESTED LEARNING RESOURCES

See Appendix 3.1: The Historical Development of Ohm’s Law.



GENERAL LEARNING OUTCOME CONNECTION

Students will...

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SPECIFIC LEARNING OUTCOME

S4P-3-3: Investigate the relationships among resistance and resistivity, length, cross-section, and temperature.

Include: $R = \frac{\rho L}{A}$



SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

The resistance of a material depends on several factors including:

- **Resistivity:** Resistivity, represented by the Greek letter *rho* (ρ), depends upon properties of the material as well as on temperature. It is an indication of how the material resists the movement of charge through it. Resistivity has units of $\Omega \cdot m$. Be careful when consulting tables since the units are not always represented in metres.
- **Length:** A longer conductor offers more resistance than a shorter conductor, since charge must move through more matter. Length is measured in metres.
- **Cross-Sectional Area:** A material with a larger cross-sectional area offers less resistance to charge movement than one with a smaller area. There is more room for charge to move in the wider area. Area must be measured in metres squared to be consistent with resistivity and length.

These factors are combined to determine the resistance of any material, given by the relationship

$$R = \frac{\rho L}{A}$$

Temperature also affects the resistance of materials. Most materials offer more resistance to moving charges at higher temperatures. Most values of resistivity are given at the standard temperature of 20° C.

Laboratory Activity

Students perform a laboratory activity to find the relationship between resistance and length of conductor. At this time, the resistance can easily be found by Ohm's Law

$$\left(R = \frac{V}{I} \right)$$

Students can also perform a lab to find the relationship between resistance and cross-sectional area. Use wires of the same length and different gauges for the measurements.



SKILLS AND ATTITUDES OUTCOMES

S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

S4P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data-collection methods.

Include: discrepancies in data and sources of error

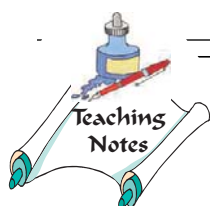
GENERAL LEARNING OUTCOME CONNECTION

Students will...

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SUGGESTIONS FOR INSTRUCTION

SUGGESTIONS FOR ASSESSMENT



A large empty rectangular box for providing suggestions for instruction.

Performance Assessment

Give students three different types of wires (e.g., copper, German silver, nichrome). After appropriate measurements, students calculate resistivity and are required to order them according to their resistivity.

Laboratory Report

Students complete a laboratory report on resistivity.

Pencil-and-Paper Tasks

Students solve problems using the resistivity formula.



GENERAL LEARNING OUTCOME CONNECTION

Students will...

Recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations (GLO C1)

SPECIFIC LEARNING OUTCOME

S4P-3-4: Demonstrate the ability to construct circuits from schematic diagrams for series, parallel, and combined networks.

Include: correct placement of ammeters and voltmeters



SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

In Senior 1 Science, students constructed simple series and parallel circuits with dry cells, switches, bulbs, and meters.

Notes to the Teacher

Series circuits have only one path so all devices are connected end-to-end. The same current passes through each component in the circuit. Ammeters, used to measure current, must always be connected in series. Analogue meters (containing moving needles) must be used very carefully. The meter has an overall low resistance so as not to affect the circuit in which it is placed. An ammeter connected in parallel may draw a large current and be ruined. Also, the meter must be placed with its negative (black) terminal connected to the low-voltage side of the circuit and the positive (red) terminal to the high-voltage side. Finally, a meter should always be set to its highest possible reading when first connected in the circuit. If the needle does not deflect enough to make an accurate measurement, select a lower value in the current range. (Digital multimeters are not as sensitive to incorrect hook-up as are analogue meters.)

Parallel circuits consist of multiple paths called **branches**. They can be recognized by junctions where the current splits or joins. Individual branches may have different values of current but they all have the same potential drop across them. Voltmeters measure voltages or potential differences. Voltmeters contain a high resistance in series with the coil of the meter and they are connected in parallel to the part of the circuit being measured. Therefore, voltmeters draw very little current compared to the original circuit. Proper polarities must also be observed, as well as starting at a high range and working down to a more appropriate level.

Students often have difficulty constructing circuits from schematic diagrams. Take time to allow them to practise circuit construction and the correct placement of meters. It is advisable to have the master power switch off until you have checked all the students' circuits.

Demonstration

Suspend a strip of aluminum foil between the poles of a magnet. Connect the ends of the aluminum strip to a power supply. The current in the foil will establish a magnetic field, which interacts with the magnetic field of the magnet. The foil deflects. An electric meter works on the same principle.



SKILLS AND ATTITUDES OUTCOMES

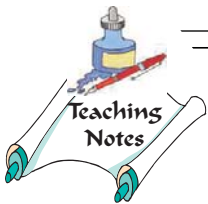
- S4P-0-2d:** Estimate and measure accurately using SI units.
- S4P-0-4a:** Demonstrate work habits that ensure personal safety, the safety of others, and consideration of the environment.

GENERAL LEARNING OUTCOME CONNECTION

Students will...
 Demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information (GLO C4)

SUGGESTIONS FOR INSTRUCTION

SUGGESTIONS FOR ASSESSMENT



Observation

Check for correct placement of meters before the student turns on the power supply.

Science Journal Entries

Students predict the behaviour of a circuit if the meters are placed incorrectly.

Pencil-and-Paper Tasks

Students diagram the correct placement of meters in an electric circuit.



GENERAL LEARNING OUTCOME CONNECTION

Students will...

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SPECIFIC LEARNING OUTCOME

S4P-3-5: Calculate the total resistance for resistors in series and resistors in parallel.



SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

In Senior 1 Science, students visually noted the decrease in brightness of bulbs that were connected in a series arrangement.

Notes to the Teacher

The explanation of series and parallel combinations of resistors can be done conceptually or mathematically.

SERIES RESISTORS

Qualitative Discussion

Resistors placed in series act like longer resistors so the total resistance must be the sum of the individual resistors: $R_T = R_1 + R_2 + R_3 \dots$

The total resistance for a series network is always larger than any of the single resistances.

Mathematical Treatment

In the series circuit above, the resistors are in series so they must have the same current passing through them: $I_1 = I_2 = I_3 = I$. Each resistor gives off energy as heat and has a voltage drop across it. The combined resistance will also draw the same current as all the series resistors.

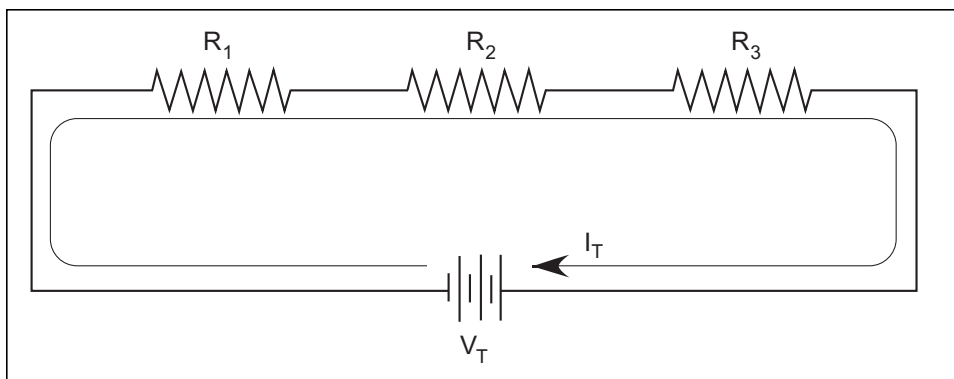
The sum of the individual voltage drops must equal the source voltage. (This is known as Kirchoff's Voltage Law and is really a consequence of the Law of Conservation of Energy.)

$$V_T = V_1 + V_2 + V_3.$$

Since $V_{\text{drop}} = IR$, then

$$IR_T = IR_1 + IR_2 + IR_3.$$

$$\text{So, } R_T = R_1 + R_2 + R_3.$$



Series Resistors



SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)

SUGGESTIONS FOR INSTRUCTION

SUGGESTIONS FOR ASSESSMENT

Example

Find the combined resistance of a series network consisting of 10 Ω , 12 Ω , 18 Ω , and 6 Ω .

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 + R_4 \\ &= 10 \Omega + 12 \Omega + 18 \Omega + 6 \Omega \\ &= 46 \Omega \end{aligned}$$

PARALLEL RESISTORS

Qualitative Discussion

Adding a resistance in parallel is the same as increasing the cross-sectional area through which current can flow. We have already established that resistance is inversely proportional to the cross-sectional area. This suggests an inverse relationship between total resistance and the number of resistors in parallel.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots$$

It is important to note that the equivalent resistance for a parallel network is always less than the smallest branch resistance. This is a useful check when analyzing a circuit.

Pencil-and-Paper Tasks

Students solve problems for various combinations of electric circuits.



GENERAL LEARNING OUTCOME CONNECTION

Students will...

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SPECIFIC LEARNING OUTCOME

S4P-3-5: Calculate the total resistance for resistors in series and resistors in parallel.



SUGGESTIONS FOR INSTRUCTION

Mathematical Discussion

The voltages across resistances in parallel are equal and are the same as the source voltage: $V_1 = V_2 = V_3 = V_T$. The total current that leaves the source is determined by the source voltage and the total resistance of the network. This total current breaks up into separate branch currents but then recombines to produce the total current that returns to the source. (This is Kirchoff's Current Law and relates to conservation of electric charge.) Charge does not disappear, nor is it created when it enters the junction. It is merely rearranged with differing amounts of charge passing through different branches. The amount of current in each branch depends upon the resistance of the branch.

$$I_T = I_1 + I_2 + I_3$$

Since current is found from Ohm's Law, $I = \frac{V}{R}$:

$$\text{so } \frac{V_T}{R_T} = \frac{V_T}{R_1} + \frac{V_T}{R_2} + \frac{V_T}{R_3}$$

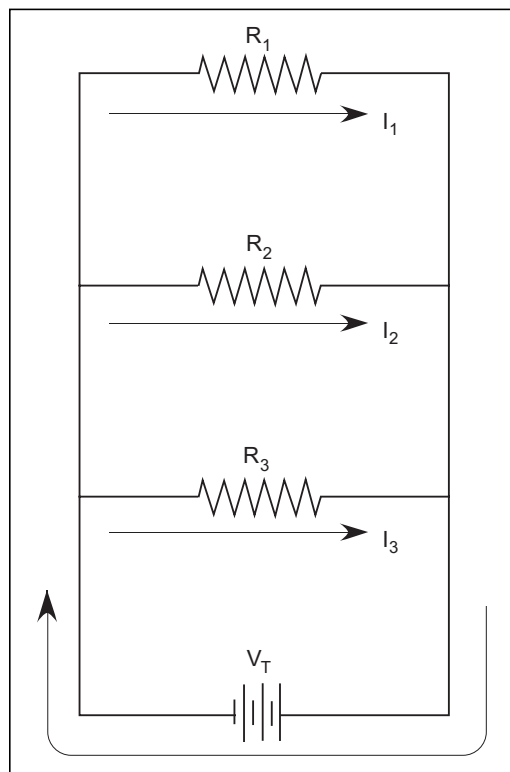
Example

Find the equivalent resistance for 12 and 6 hooked in parallel.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_T} = \frac{1}{12} + \frac{1}{6} = \frac{1}{12} + \frac{2}{12} = \frac{3}{12} = \frac{1}{4}$$

$$\therefore R_T = \frac{4}{1} = 4 \Omega$$



Parallel Resistors



SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

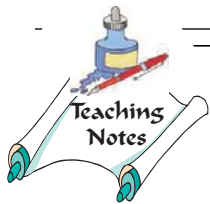
GENERAL LEARNING OUTCOME CONNECTION

Students will...

Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)

SUGGESTIONS FOR INSTRUCTION

SUGGESTIONS FOR ASSESSMENT



GENERAL LEARNING OUTCOME CONNECTION

Students will...

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SPECIFIC LEARNING OUTCOME

S4P-3-6: Calculate the resistance, current, voltage, and power for series, parallel, and combined networks.

Include: $P = IV$, $P = I^2R$, and $P = \frac{V^2}{R}$



SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

In Senior 1 Science, students used Watt's Law, $P = IV$. Power, measured in watts, is the product of current in amperes and electric potential in volts.

Notes to the Teacher

The power law $P = VI$ can be combined with Ohm's Law to produce two other equations, very useful in circuit analysis.

From $I = \frac{V}{R}$ and $P = IV$, $P = I^2R$, and $P = \frac{V^2}{R}$.

Class Activity

Circuit analysis would begin with simple series and simple parallel circuits. An illustrative example of the analysis of a combined network or complex circuit is in Appendix 3.3.



SKILLS AND ATTITUDES OUTCOMES

S4P-0-2d: Estimate and measure accurately using SI units.

S4P-0-2f: Record, organize, and display data using an appropriate format.

Include: labelled diagrams, tables, graphs

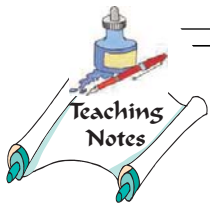
GENERAL LEARNING OUTCOME CONNECTION

Students will...

Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)

SUGGESTIONS FOR INSTRUCTION

SUGGESTIONS FOR ASSESSMENT



Pencil-and-Paper Tasks

Given a complex network, students reduce the network to its equivalent resistance and calculate the voltage, current, and power in each resistance.



NOTES

