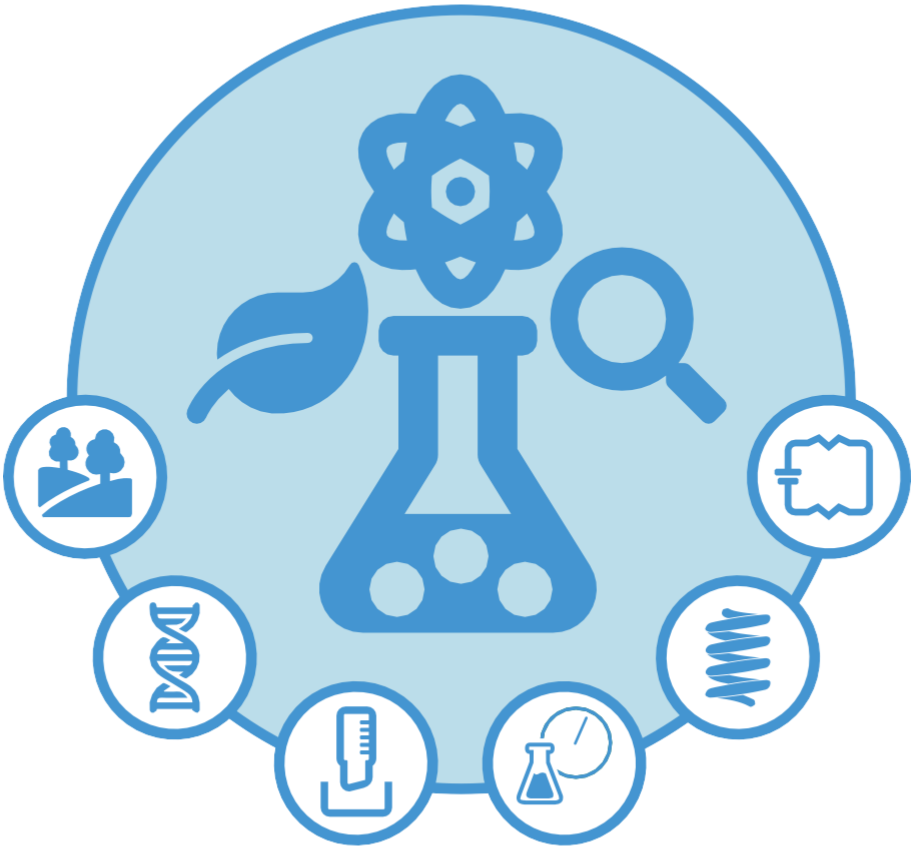
EXEMPLAR LESSON

OpenSTEM Africa

EXPLORING RESISTANCE IN ELECTRICAL CIRCUITS



Acknowledgements

Ministry of Education

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For information on OpenSTEM Africa see: www.open.edu/openlearncreate/OpenSTEM_Africa

OPITO for their generous support, which has made OpenSTEM Africa and the development of the Virtual Laboratory and these materials possible.

Contents

Exemplar lessons for the OpenSTEM Africa Virtual Laboratory applications

All the exemplar lessons are examples of lessons which could be used both individually and by whole classes of Senior High School (SHS) students in the elective sciences of Biology, Chemistry and Physics. Each of the lessons is linked specifically to one of the applications in the OpenSTEM Africa Virtual Laboratory. The exemplar lesson is created to give, both to SHS students and to SHS teachers, a clear example of the ways in which the applications can be used in the learning and teaching of practical science. There is a focus throughout the lesson on the student's development of the practical and experimental skills which, along with knowledge and understanding, are integral to the profile of learning, teaching and assessment in SHS sciences.

The 'you' in this lesson is 'you', the Senior High School student. Remember that you can repeat the experiments and activities in this lesson as often as you have time for in class. This freedom to repeat experiments and activities is also important if you are accessing the lesson outside the classroom, for example for homework. Every application in the OpenSTEM Africa Virtual Laboratory contains real data – the experiments are real experiments. This means you might make mistakes the first or second or third time you try an experiment or an activity – and that is exactly what often happens in the real world in the sciences. So, it is helpful for you as a student to share in some of the real-world trial and error of science as you develop your skills as a scientist.

The exemplar lesson also contains a set of teaching notes at the end of this document for 'you' the SHS science teacher, to suggest how you might want to set up this particular lesson with one of your classes. Hopefully it will also generate ideas for other lessons on the same topic, or other lessons which use the same OpenSTEM Africa Virtual Laboratory application.

Exploring resistance in electrical circuits

Lesson objectives

By the end of the lesson, you will be able to:

- Describe the unit of resistance
- Apply Ohm's law to determine current, voltage and resistance in an electrical circuit
- Describe how resistors in series affect current flowing in an electrical circuit
- Describe how resistors in parallel affect current flowing in an electrical circuit
- Explain how the length and diameter of a nichrome wire determine its resistance

The following practical and experimental skills will be developed:

- Observations
- Plotting
- Analysing
- Interpretation
- Reporting

Background

Resistors are found in most electrical circuits and their role is to resist the flow of electrical current. Like the wires found in an electrical circuit, resistors are able to conduct current, but they do so less effectively. The resistors shown in Figure 1 are made from a mixture of powdered carbon, which is a conductor of electricity, and non-conducting powder. It is the amount of carbon that determines how well a resistor can conduct electricity and therefore the value of its resistance.

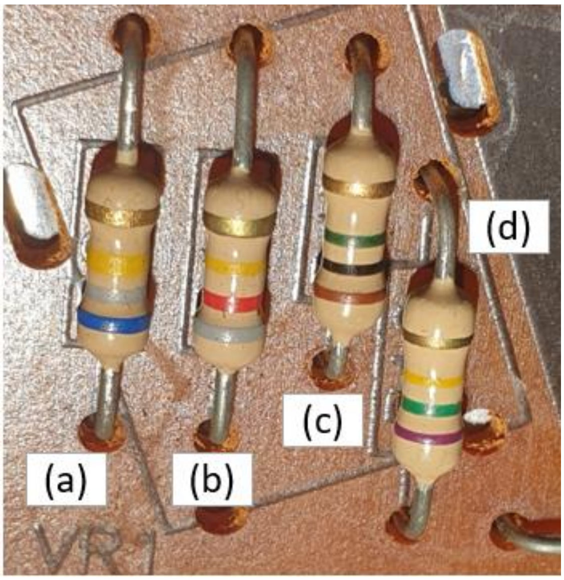


Figure 1. Four resistors in a circuit board (labelled (a) to (d)) of a smoke alarm (note that each has a different colour coding in the form of four colour bands – you will learn more about this coding system later in this lesson).

Activity 1: Resistors
Note down the colour bands for each of the resistors (a) to (d), for example, (a) has blue/grey/yellow bands that are close together and a gold band set apart. You will use this information to identify the resistance values for each of these resistors later in this lesson.

Figure 2 is a representation of a simple electrical circuit consisting of a single resistor and a battery. There is also a voltmeter to measure the voltage across the resistor and an ammeter to measure the current flowing in the circuit (you will notice that the ammeter is 'in line' and forms part of the circuit whereas the voltmeter is external to the circuit).

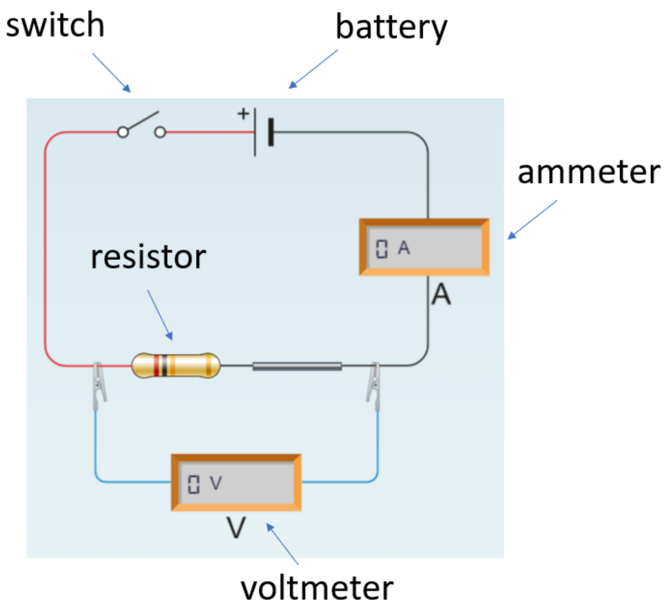


Figure 2. A simple electrical circuit with a single resistor.

The resistance of an electrical circuit is calculated as the number of **volts (V)** of battery power needed to allow a current of 1 **ampere (A)** to flow around the circuit. A low resistance circuit might need only 2 volts per ampere such that a 1 V battery would produce a current of 0.5 A.

The unit of resistance is therefore V per A – however, today we call this unit an **ohm (Ω)** after George Ohm, a 19th century physicist who was an early investigator of how current flows in electrical circuits.

$$\text{ohm} = \text{volts/ampere}$$

The current (I) flowing in an electrical circuit is defined by **Ohm's law** where the unit for current (I) is A, the unit for voltage is V and resistance (R) is Ω:

$$I = V/R$$

Ohm's law can be rearranged so that if you know two of the values it is possible to calculate the third. So, if you know the voltage across a resistor and the current flowing in the circuit, it is possible to measure the resistance of the resistor.

$$R = V/I$$

(Note the above equation is identical to the one defining the units of an ohm).

How would you rearrange Ohm's law to calculate the voltage in an electrical cirecuit if both the resistance and current are known?
Go to Appendix 3 for the answer.

Now consider a circuit similar to that shown in Figure 2 where the voltage across the resistor is 5 V and the current is 4 A. What is the resistance of the resistor?
Go to Appendix 3 for the answer.

In this lesson you will explore how the arrangement of resistors in an electrical circuit affects the current flowing in that circuit. You will examine this by looking at the way resistors work when arranged in **series** (Figure 3(a)) and arranged in **parallel** (Figure 3(b)).

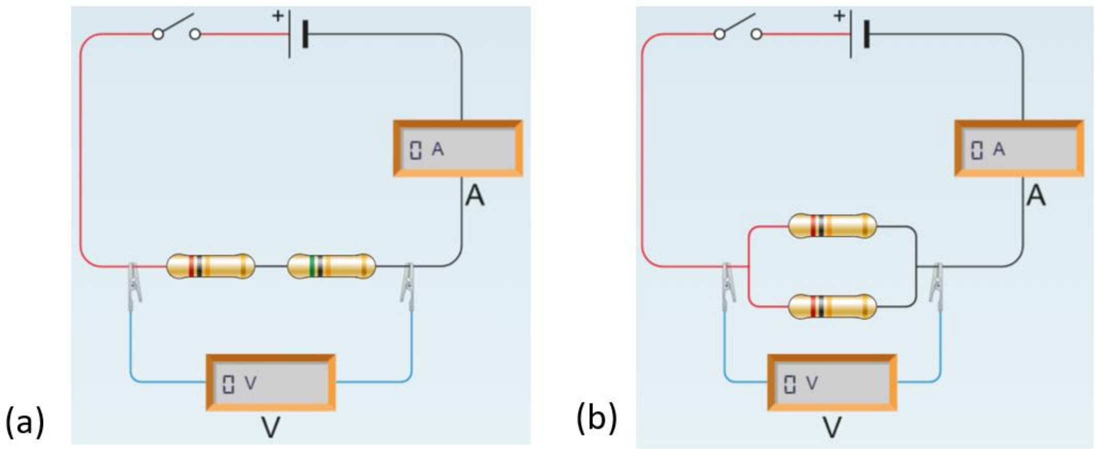


Figure 3. (a) Resistors in series (in line). (b) Resistors in parallel (side by side).

You may have noticed that the resistors shown in Figure 1 each have four colour bands. This is a coding system used to indicate the resistance and the quality of the resistor. Figure 4 shows the four-colour band table commonly used for carbon resistors.

The first three bands of the four-band colour coding system indicate the resistance value and the final band, set slightly apart, is the tolerance – a measure by how much a resistor may deviate from the stated resistance (the lower the tolerance rating, the closer the resistor will be in terms of the stated resistance value). The example resistor shown in Figure 4 has red/black/gold bands for its resistance value. The red gives the number '2', the black a '0' and the gold a multiplier of 'x0.1'. The resistance is read as:

$$20 \times 0.1 = 2\ \Omega.$$

The fourth and final band is gold, and this gives a tolerance value of ±5% – meaning that the resistor will have a resistance that is 2 ±5% Ω (a range of 1.9 to 2.1 Ω).

2 Ω

colour	first band	second band	multiplier	tolerance
black	0	0	x1Ω	
brown	1	1	x10Ω	±1%
red	2	2	x100Ω	±2%
orange	3	3	x1000Ω	±3%
yellow	4	4	x10000Ω	±4%
green	5	5	x100000Ω	±0.5%
blue	6	6	x1000000Ω	±0.25%
violet	7	7	x10000000Ω	±0.1%
grey	8	8	x100000000Ω	±0.05%
white	9	9	x1000000000Ω	
gold			x0.1Ω	±5%
silver			X0.01Ω	±10%

Figure 4. The four-band colour coding system used to indicate the resistance and tolerance (quality) of carbon resistors. This coding system is used because resistors are too small for numbers and tolerance values to be printed on them. The example resistor shown is a 2Ω resistor.

Resistors (re-visited)

Use the four-band colour code chart shown in Figure 4 to work out the resistance and tolerance for each of the resistors shown in Figure 1.

Go to Appendix 3 for the answers.

Wire also has a resistance, and this is determined by the length of the wire, its cross-sectional area and the material it is made from. You may have wondered why lightning conductor rods attached to tall buildings are made of copper – this is because it is a better conductor than iron.

In the practical activity associated with this lesson you will explore how the length and diameter of a **nichrome** wire affects resistance. Nichrome wire is made from mainly nickel and chrome and has a high resistance rating – as a result it tends to heat up when high currents are passed through and consequently is used as the heating element in toasters and hairdryers.

Practical activity

This practical activity consists of three tasks. The first is to explore how resistors in series work to control current flowing in an electrical circuit, the second is to explore how resistors in parallel work to control current flow and the third is to examine how the resistance of nichrome wires is determined by length and diameter.

Task 1

Your first task is to investigate resistors in series.

Before you enter the experiment, read these instructions thoroughly. When you are ready, enter the experiment using the first option 'Resistors in series'. You are provided with a range of resistors with known resistances, 4 resistors (a) to (d) with unknown resistances and a piece of bare wire (Figure 5).

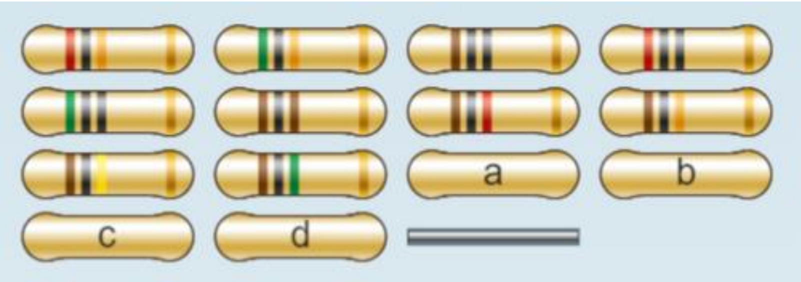


Figure 5. Resistors and a piece of bare wire located in the Electrical Circuits application.

You can find the stated resistance value for each resistor by placing the cursor over a resistor or by using the four-band colour code. Note that some stated values are expressed as kiloohms (1 kΩ = 1000 Ω) and megaohms (1 MΩ = 1000000 Ω). Before we explore how resistors work in series, we will examine each resistor to check that the stated value is correct.

In your laboratory notebook make a table with the following headings (Table 1).

Voltage (V)	Current (A)	Stated resistance (Ω)	Measured resistance (Ω)

Table 1 Laboratory notebook headings for examining a single resistor.

- Now choose a battery (you have a choice of either a 1.5 V or 9 V battery).
- Select a resistor with a stated resistance and place it into one of the two slots.
- To complete the circuit, you will need to place the bare wire into the second unfilled slot.
- Now close the switch and record the voltage across the resistor and the current flowing in the circuit (the switch will open automatically after a few seconds).
- Repeat this procedure for five other resistors with stated resistances.

To check the stated resistance values against the measured values you will now use Ohms' law to calculate the measured resistance for each of your resistors.

$$R = V/I$$

Note: the ammeter provides the current in amperes (A), but it uses metric notation, such that 0.1 A is represented as 100 milliamperes (mA), 0.0001 A is represented as 100 microamperes (µA).

Based on your observations, how well do the measured resistance values compare with the stated values?
Go to Appendix 3 for the answer.

Now that you are familiar with using the application and Ohm's law to calculate resistance, repeat the above process using the resistors with unknown values (resistors (a) to (d)) to calculate their measured resistance values and discuss your findings with your classmates.

Your next step is to look at how resistors work in series to control current flow. Copy Table 2 into your laboratory notebook.

Voltage (V)	**Current (A)**	**Stated resistance for resistor 1 (Ω)**	**Stated resistance for resistor 2 (Ω)**	**Measured resistance (Ω)**

Table 2 Laboratory notebook table headings for examining resistors in series.

- Once again choose a battery (you have a choice of either a 1.5 V or 9 V battery).
- Select a resistor with a stated resistance and place it into one of the two slots.
- To complete the circuit, place a second resistor into the second unfilled slot.
- Now close the switch and record the voltage across the resistors and the current flowing in the circuit (the switch will open automatically after a few seconds).
- Repeat this procedure for five other pairings of resistors with stated resistances.

Now use Ohm's law to calculate the measured resistance in the circuit for each of your resistor pairings and discuss your findings with your classmates.

Task 2

Your second task is to investigate resistors in parallel.

Before you enter the experiment, read these instructions thoroughly. When you are ready, enter the experiment using the second option 'Resistors in parallel'. Once again, copy the following table headings into your laboratory notebook (Table 3).

Voltage (V)	**Current (A)**	**Stated resistance for resistor 1 (Ω)**	**Stated resistance for resistor 2 (Ω)**	**Measured resistance (Ω)**

Table 3 Laboratory notebook table headings for examining resistors in parallel.

- Once again choose a battery (you have a choice of either a 1.5 V or 9 V battery).

- Select a resistor with a stated resistance and place it into one of the two slots.
- Select another resistor and place it into the second slot.
- Now close the switch and record the voltage across the resistors and the current flowing in the circuit (the switch will open automatically after a few seconds).
- Repeat this procedure for five other pairings of resistors with stated resistances.

Now use Ohm's law to calculate the measured resistance in the circuit for each of your resistor pairings and discuss your findings with your classmates.

Task 3

Your third task is to investigate the resistance in a wire.

Before you enter the experiment, read these instructions thoroughly. When you are ready, enter the experiment using the third option 'Resistance in a wire'. This experimental set-up is different to those you used in Tasks 1 and 2 (see Figure 6). Here you are given the choice of three 1 m lengths of nichrome wire of varying thickness.

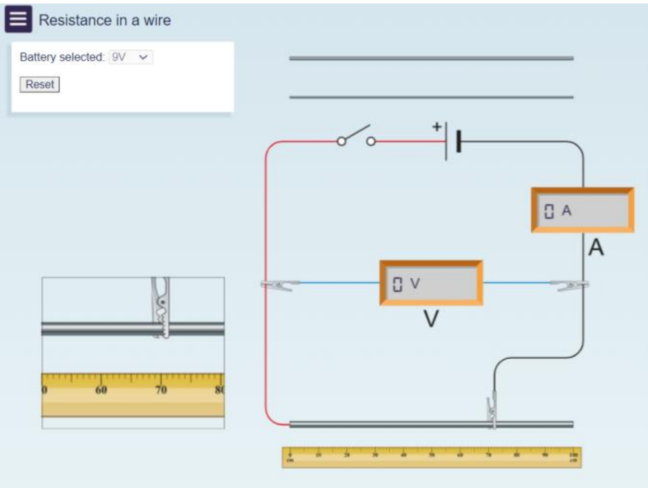


Figure 6 The experimental set-up for measuring the resistances of nichrome wires. In this illustrated example, the thick wire has been placed into the circuit and the crocodile clip has been used to close the circuit at 70 cm.

Copy Table 4 into your laboratory notebook.

Chosen wire	Length (cm)	Voltage (V)	Current (A)	Measured resistance (Ω)

Table 4 Laboratory notebook table headings for examining resistance in a nichrome wire.

In Tasks 1 and 2 the voltage across the resistor was stable, however in this task the voltage will vary depending on the load on the battery – the current flowing in the circuit.

- Select a nichrome wire and drag it into the slot at the bottom of the electrical circuit.
- Use the crocodile clip to close the circuit, starting at 90 to 100 cm – use the zoom view to accurately record the length you've selected.
- Turn on the switch and record both the voltage and current.
- Now move the crocodile clip 10 to 15 cm further down the length of the wire, turn on the switch and record the voltage and current readings.
- Repeat this process several more times – beware, at shorter lengths the nichrome wires will start to heat up and your recordings will be compromised.

Once you have recorded your observations, use Ohm's law to calculate the measured resistances for each length of the wire and repeat the process until you have examined all three wires.

Now that you have data for each wire. Plot resistance against length for each wire on the same graph and fit a best fit line to each data set.

Discuss your findings with your classmates.

Resistance

Go to the OpenSTEM Africa Virtual Laboratory.

Click on on the icon to access the Electrical circuits application homepage.

Watch the introductory video before entering the experiment.

Interpreting your observations

Read this section once you have completed the experimental tasks.

Task 1 – resistors in series explained

In this task you first examined each resistor individually – for example, you may have noted that when the 1 MΩ resistor was placed in the circuit with a 9 V battery, the recorded current was approximately 9 µA when the circuit was turned on (though this will vary slightly depending on the tolerance of the selected resistor). The second part of this task was to examine the effect of resitors in series on current follow. Let's continue with the 1 MΩ resistor selection – you may have noted that two 1 MΩ resistors in series only allowed approximately 4.5 µA to flow in the system.

How much current would flow in an electrical circuit with a 9 V battery and a single 2 MΩ resistor? (Remember that 1 MΩ is 1 million ohms.)
Go to Appendix 3 for the answer.

Resistors in series combine together, for example, if you had a circuit with a 2 Ω resistor and a 8 Ω resistor in series, their combined series resistance is 2 Ω + 8 Ω = 10 Ω.

$$R = R_1 + R_2$$

Task 2 – resistors in parallel explained

Resistors in parallel behave differently to those in series. For this worked example, we will use 5 Ω resistors in an electrical circuit with a 9 V battery. A single 5 Ω resistor will produce a current of approximately 1.8 A and two 5 Ω resistors in series will produce a current of approximately 900 mA. Whereas two 5 Ω resistors in parallel produce a current of 3.6 A.

Let's summarise:

One 5 Ω resistor gives a current of **1.8 A**

Two 5 Ω resistors in *series* gives a current of **900 mA**

Two 5 Ω resistors in *parallel* gives a current of **3.6 A**

You might have been surprised to learn that two resistors in parallel allow more current to flow than a single resistor. One way to visualise this is to think of a bucket of water with a hole in its base – water will leak out of the hole. What would happen if instead of one hole, the bucket now has two holes of the same size? More water would leak out of the bucket!

When resistors are in parallel, the combined resistance in parallel is calculated using the following equation:

$$1/R = 1/R_1 + 1/R_2$$

Therefore, the resistance of a circuit with two 5 Ω resistors in parallel is calculated as:

$$1/R = 1/5 + 1/5 = 2/5$$

To find R we must turn 1/R over:

$$R = 5/2 = 2.5\ \Omega$$

And we can check this by applying Ohm's law R = V/I

$$9\ V/3.6\ A = 2.5\ \Omega.$$

Task 3 – nichrome wires and resistance explained

In this task, you observed how the resistance of three different wires changed as a function of length and then plotted your measurements on a graph and discussed your findings with your classmates.

You should have noticed the following:

- Resistance is proportional to the length of the wire
- Wires with a larger cross-sectional area have a lower resistance.

And these observations are captured by the following equation which is used to calculate the resistance of a wire:

$$R = \rho l/A$$

Where the symbol ρ (the Greek letter rho) is a constant that depends on the material the wire is made from (also called the resistivity of the material), l is the length and A the cross-sectional area.

Summary

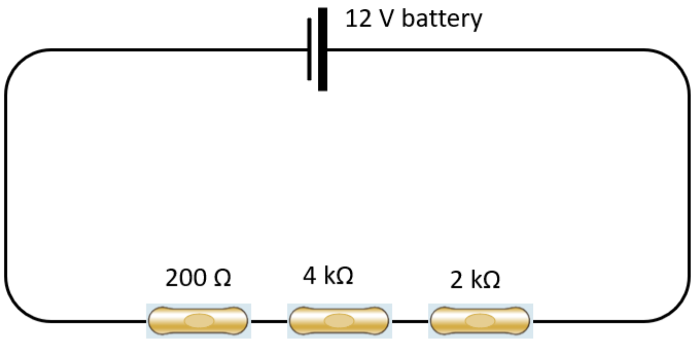
You have used the Electrical circuits application to explore how resistors work in series and parallel and may have been surprised to discover that resistors of the same value actually allow more current to flow when arranged in parallel than as a single resistor in an electrical circuit. You also explored the relationship between length and thickness on the resistive properties of nichrome wire.

Quiz

Answer the questions, then search for the answers in Appendix 4.

Question 1

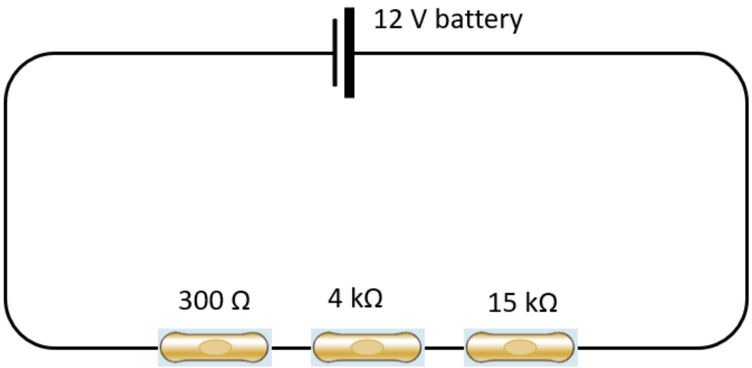
What is the resistance for this circuit?



a) 6.2 kΩ
b) 6 MΩ
c) 620 Ω

Question 2

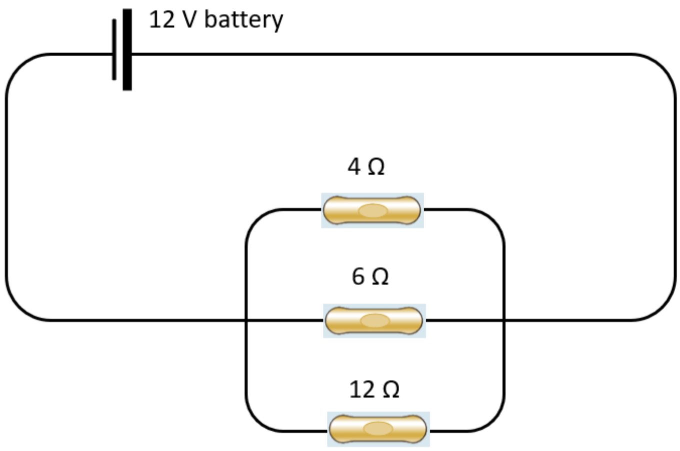
How much current is flowing through this circuit?



a) 622 A
b) 622 mA
c) 62.2 mA

Question 3

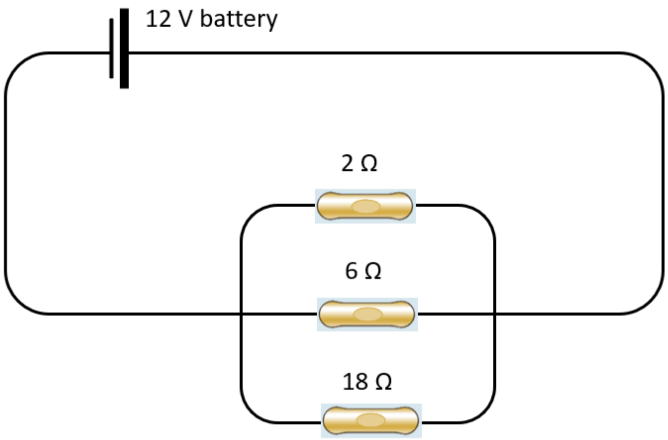
What is the resistance for this circuit?



a) 2 Ω
b) 12 Ω
c) 22 Ω

Question 4

How much current is flowing through this circuit?



a) 8.7 A
b) 8.7 mA
c) 87 A

Appendix 1: Teacher notes – organisation of the lesson

Teaching for electrical circuits and the lesson: Physics SHS3, Section 2, Unit 1 Deformation of solids.

This lesson, using electrical circuits links directly to SHS and the teaching and learning activities associated with it.

Ideas for organising this exemplar lesson link directly to activities and teaching examples in the OpenSTEM Africa CPD units on *Using ICT to support learning*, and *Approaches to active notetaking*.

A full list of the OpenSTEM Africa CPD units can be found at: https://www.open.edu/openlearncreate/CPD_units

Overview

If possible, this lesson should take place in the ICT Lab in your school if this can be arranged through your Head of Science and the Head of ICT. If the lesson takes place in the ICT Lab, it may be possible for each student to work individually at a computer; otherwise divide the class so that students are in small groups at a computer.

If it is not possible to use the ICT Lab for this lesson, then try to set up this lesson in your classroom. You may be lucky enough in your school to have a set of 'empty' tablets or mobile phones which students can use. Or you may be able to bring into the classroom a laptop connected to the internet or to your school intranet – and perhaps connected to a projector to make it possible for the whole class to view at once. If access to ICT is a real challenge in your school but you want your students to view an experiment, you might be able demonstrate it to small groups of your students at a time, using your own mobile phone

Whatever way(s) you set up the class, it would still be helpful to the students to be able to work in pairs or small groups for at least some of the lesson. Do remember as well that students need desk space to be able to write in their notebooks and to draw tables and diagrams.

Steps in organising the lesson

Step 1: This could take place in the classroom in the lesson **preceding** the one where you and your class access the OpenSTEM Africa Virtual Laboratory Electrical circuits application. Have students work in pairs to pre-read the Background section of the exemplar lesson. They need to jointly carry out the activities to identify the resistors and to calculate the value of resistance for each of the resistors. They can also ask each other the questions in the Background section and check each other's responses. While they are doing so, you may want to walk round the class and check their laboratory notebooks, as accurate note-taking and filling in the tables is important for this exemplar lesson.

Step 2: This could also take place in the classroom in the lesson **preceding** the one where you and your class access the OpenSTEM Africa Virtual Laboratory Electrical circuits application. Check students' understanding by asking them the questions in the Background section. Have each person in the pair read through the preparation for the three practical activity experiments and, if it is helpful to do so, give the class a set time to make simple diagrams of the electrical circuits. Have each student create the tables for the Practical Activity experiments with the headings specified, in their own laboratory notebook in preparation for their data collection.

Step 3: Once the students have access to the OpenSTEM Africa Virtual Laboratory, give them time to watch the introductory video and to complete the practical activity tasks in the lesson.

Step 4 Make sure that each pair has access to/can see the computer screen to begin the actual experiments. Ensure that each pair knows how to carry out the experiments – or if you are using a laptop/projector, that you draw on the expertise of the class as you go through each step of the electrical circuits experiments – e.g. ask them what the next step is.

Step 5: Have the class follow the instructions for each of the electrical circuits experiments. Make sure, if working in a pair on a PC, that each student in the pair gets to follow all the steps; if working in a group on a PC,have the group leader ensure that everyone in the group is involved.

Step 5: What they write in their tables will be agreed between the pair or within the group but allow enough time for everyone in the class to fill in their own set of tables. Have them check each other's writing.

Step 6: Ten minutes before the end of the lesson, tell the students to complete the quiz.

Appendix 2: Teacher notes – outputs of the lesson

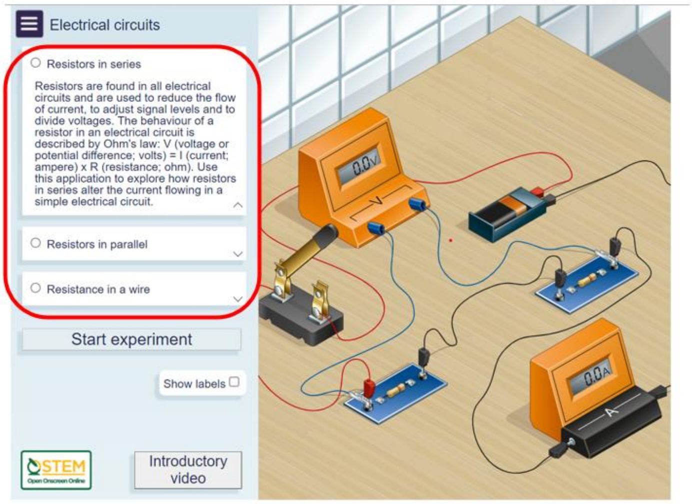
Syllabus section addressed by this lesson

Teaching Syllabus for Physics (SHS 1–3)

SHS2 Mechanics Section 5 Electricity and magnetism

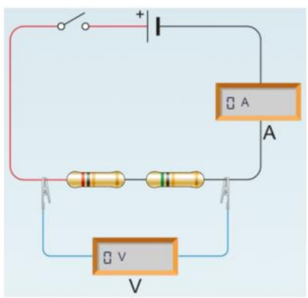
Unit 1 Direct current analysis

The Electrical circuits application is split into three sections, and each is accessed via the application homepage.

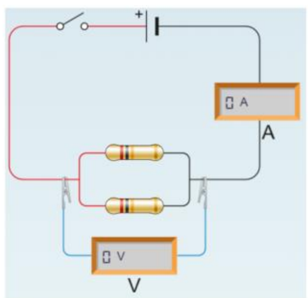


The first and second sections look at the behaviour of carbon resistors in an electrical circuit.

First section – resistors in series

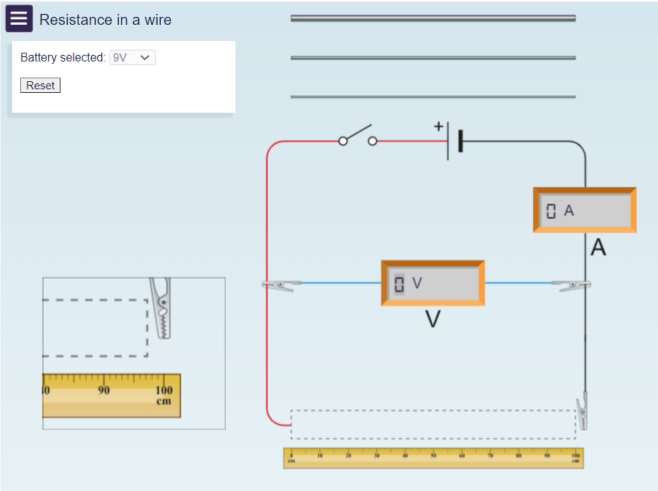


Second section – resistors in parallel



The resistors used have a tolerance of ±5% and each resistor has a resistance that conforms to this standard. The application is designed so that within this range each student will have a selection of resistors that will vary – much as it would in a physical laboratory. Students will have a choice of using a 9 V or 1.5 V battery – because the focus is on the behaviour of resistors (in series and parallel), we have opted to maintain a stable voltage across the resistors. Given the straightforward nature of these two sections and the background and guidance provided to students in the lesson, we have not provided further details here.

The final section explores resistance in three 1 m lengths of nichrome wire with varying cross-sectional areas.



The battery used in this section is rated at 9 V, but the voltage recorded in the circuit will vary according to the current load. The wires will also heat-up at shorter lengths, as they might in a laboratory setting. The thick wire has a diameter which is twice that of the medium wire, and the thin wire has a diameter which half that of the medium wire.

Appendix 3: In-text question answers

How would you rearrange Ohm's law to calculate the voltage in an electrical cirecuit if both the resistance and current are known?

Answer:
$V = IR$

Now consider a circuit similar to that shown in Figure 2 where the voltage across the resistor is 5 V and the current is 4 A. What is the resistance of the resistor?

Answer:
Using Ohm's law $R=V/I$, then 5 V/4 A give a resistance value of 1.25 Ω.

Resistors (re-visited)

Use the four-band colour code chart shown in Figure 4 to work out the resistance and tolerance for each of the resistors shown in Figure 1.

Answers:
Resistor (a), blue/grey/yellow and gold.
68 x10000 = 680000 ±5% Ω (approx. 680kΩ)

Resistor (b), grey/red/yellow and gold.
82 x10000 = 820000 ±5% Ω (approx. 820kΩ)

Resistor (c), brown/black/green and gold.
10 x100000 = 1000000 ±5% Ω (approx. 1000kΩ)

Resistor (d), violet/green/yellow and gold.
75 x10000 = 750000 ±5% Ω (approx. 750kΩ)

Based on your observations, how well do the measured resistance values compare with the stated values?

Answer:
The resistors have a gold band tolerance rating which means your measured values should fall within a range that is ±5% of the stated resistance.

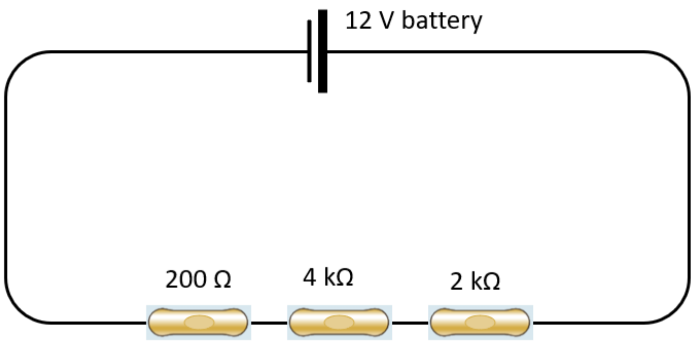
How much current would flow in an electrical circuit with a 9 V battery and a single 2 MΩ resistor? (Remember that 1 MΩ is 1 million ohms.)
Answer: Using Ohm's law I =V/R, the current flowing through circuit will be 4.5 μA. So two 1 MΩ resistors in series behave in the same way as a single 2 MΩ resistor.

Appendix 4: Quiz answers

Correct answers are **highlighted in green**.

Question 1

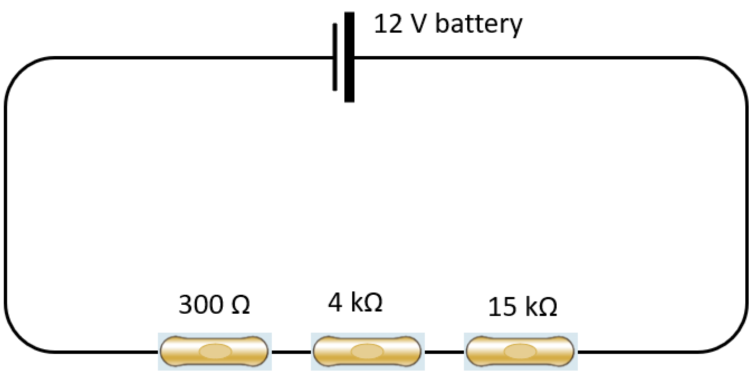
What is the resistance for this circuit?



a) 6.2 kΩ
b) 6 MΩ
c) 620 Ω

Question 2

How much current is flowing through this circuit?

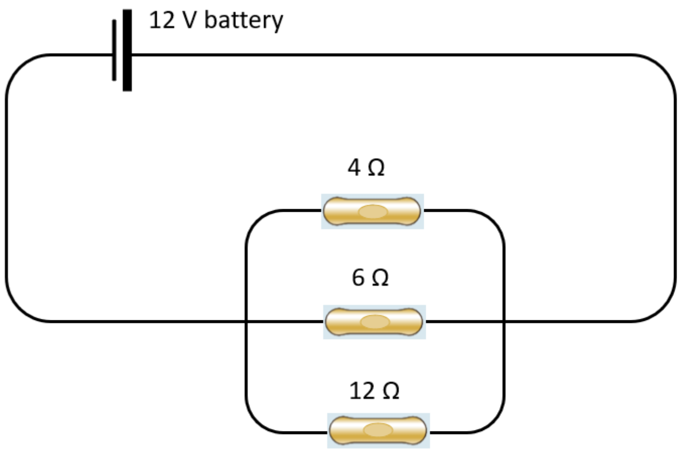


a) 622 A
b) 622 mA (correct:)
c) 62.2 mA

Feedback

I = 12 V/19300 Ω = 622 mA

Question 3



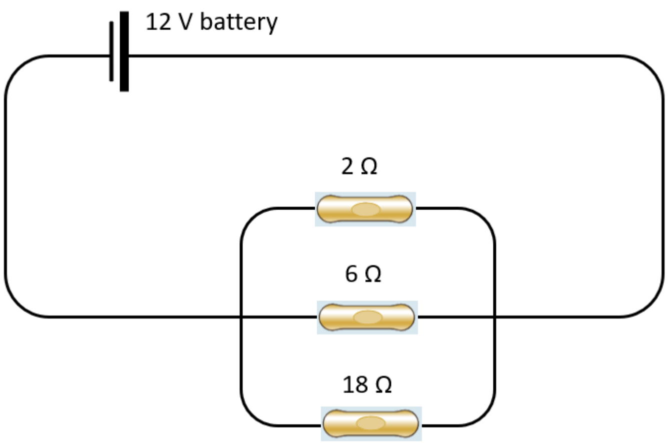
What is the resistance for this circuit?

- **a)** **2 Ω**
- b) 12 Ω
- c) 22 Ω

Feedback

1/R = ¼ + 1/6 + 1/12 = 3/12 + 2/12 + 1/12 = 6/12 = ½, so R = 2/1 = 2)

Question 4



How much current is flowing through this circuit?

- **a)** **8.7 A**
- b) 8.7 mA
- c) 87 A

Feedback

The resistance in the circuit is approximately 1.38 Ω. Applying Ohm's law: I = 12 V/1.38 Ω = 8.7 A.

ACKNOWLEDGEMENTS

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