Electricity and New Energy

DC Power Circuits

Courseware Sample

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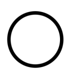
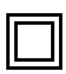
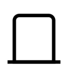
Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger. Consult the relevant user documentation.
	Caution, lifting hazard
	Caution, belt drive entanglement hazard
	Caution, chain drive entanglement hazard
	Caution, gear entanglement hazard
	Caution, hand crushing hazard
	Notice, non-ionizing radiation
	Consult the relevant user documentation.
	Direct current

Safety and Common Symbols

Symbol	Description
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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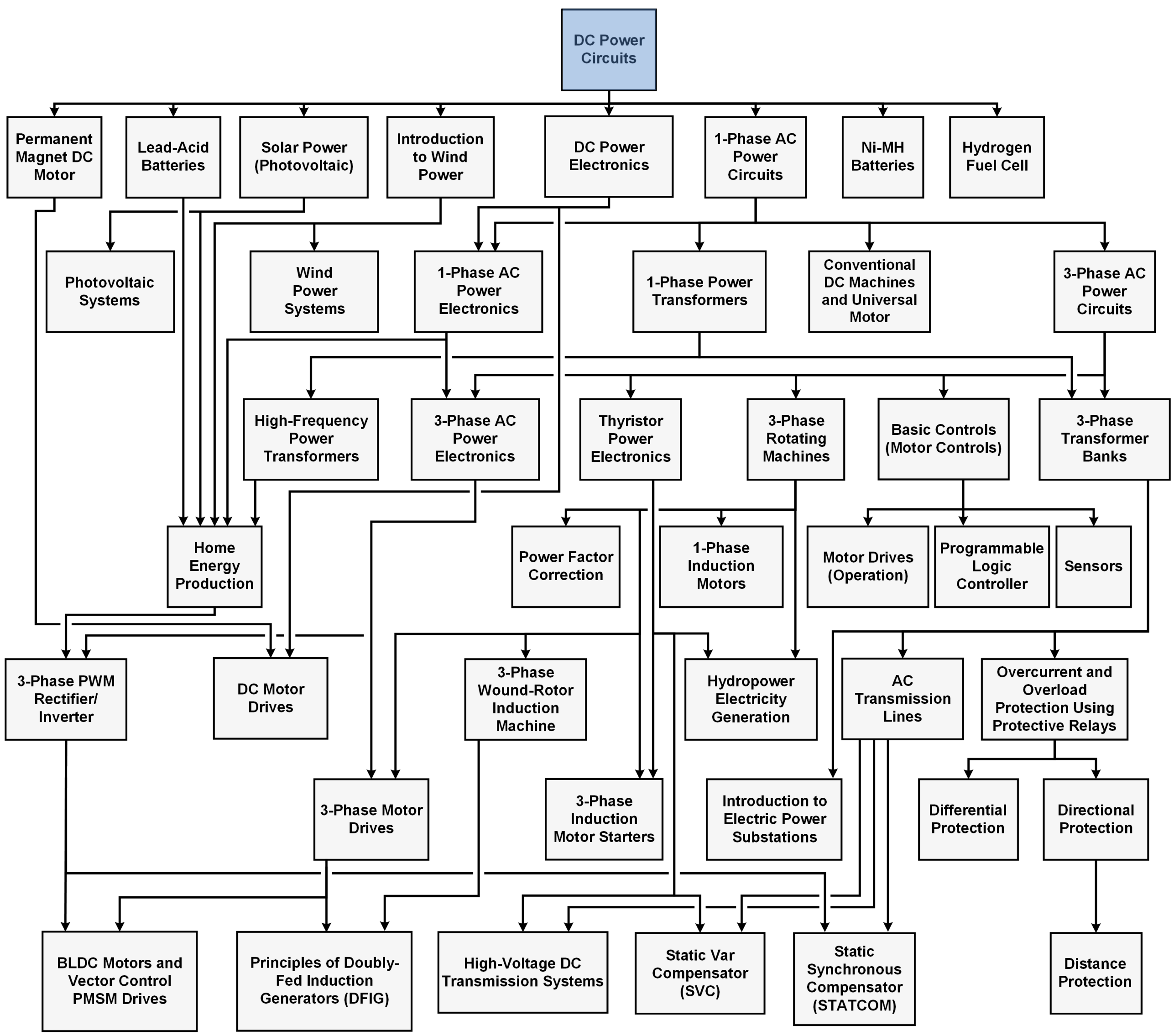
Preface

The production of energy using renewable natural resources such as wind, sunlight, rain, tides, geothermal heat, etc., has gained much importance in recent years as it is an effective means of reducing greenhouse gas (GHG) emissions. The need for innovative technologies to make the grid smarter has recently emerged as a major trend, as the increase in electrical power demand observed worldwide makes it harder for the actual grid in many countries to keep up with demand. Furthermore, electric vehicles (from bicycles to cars) are developed and marketed with more and more success in many countries all over the world.

To answer the increasingly diversified needs for training in the wide field of electrical energy, the Electric Power Technology Training Program was developed as a modular study program for technical institutes, colleges, and universities. The program is shown below as a flow chart, with each box in the flow chart representing a course.



The Electric Power Technology Training Program.

Preface

The program starts with a variety of courses providing in-depth coverage of basic topics related to the field of electrical energy such as ac and dc power circuits, power transformers, rotating machines, ac power transmission lines, and power electronics. The program then builds on the knowledge gained by the student through these basic courses to provide training in more advanced subjects such as home energy production from renewable resources (wind and sunlight), large-scale electricity production from hydropower, large-scale electricity production from wind power (doubly-fed induction generator [DFIG], synchronous generator, and asynchronous generator technologies), smart-grid technologies (SVC, STATCOM, HVDC transmission, etc.), storage of electrical energy in batteries, and drive systems for small electric vehicles and cars.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

About the course DC Power Circuits

The DC *Power Circuits course* teaches the basic concepts of electricity. Students are introduced to the fundamental laws of electricity. They learn how to calculate voltage, current, resistance, and power in direct-current (dc) circuits. Students analyze simple dc circuits, and learn how to determine their equivalent resistance for various combinations of series and parallel resistors. Finally, students use the acquired knowledge to simplify complex circuits. They verify their calculations by performing circuit measurements.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Equipment installation

In order for students to be able to perform the exercises in the Student Manual, the Electric Power Technology Training Equipment must have been properly installed, according to the instructions given in the user guide Electric Power Technology Training Equipment.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

Exercise 1

Voltage, Current, and Ohm's Law

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to measure voltages and currents in electrical circuits. You will be able to demonstrate Ohm's law, through the measurement of current and voltage.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Electromotive force and voltage
- Batteries
- A simple dc circuit
- Ohm's law
- Types of electrical current
- Measuring resistance, voltage, and current
- The Resistive Load module
- Safety rules

DISCUSSION

Electromotive force and voltage

Electric components such as wires and lamps are made of conducting material, and so allow electrons to pass through them.

To produce a flow of electrons, the electric components must be connected to a source of electromotive force that pushes the electrons through the components.

- In electrical dc circuits, the source of electromotive force is a dc power source or a battery. The source produces a **voltage**, or potential difference, i.e. an electromotive force between two points called. The magnitude of the voltage is measured in **volts** (**V**).
- There is always an opposition to the flow of electrons through an electric component. This opposition to electron flow is called **resistance**. Resistance is measured in **ohms**. Ohms are symbolized by the Greek letter **omega** (**Ω**).
- The result of electrons flowing through electric components is called **current**. The magnitude of the current is measured in **amperes** (**A**). One ampere is equal to the motion of 6.24×10^{18} electrons past a given cross section in 1 second.

Batteries

Around 1745, Ewald Georg von Kleist and Pieter van Musschenbroek invented a device used to store electric charges, called the **Leyden jar**. They combined several Leyden jars in parallel to increase the maximum stored charge.

In 1749, Benjamin Franklin introduced the term **battery** for an arrangement of multiple Leyden jars. A battery is a device with two or more electrochemical cells that converts chemical energy into electrical energy. It has a positive terminal (cathode) and a negative terminal (anode).

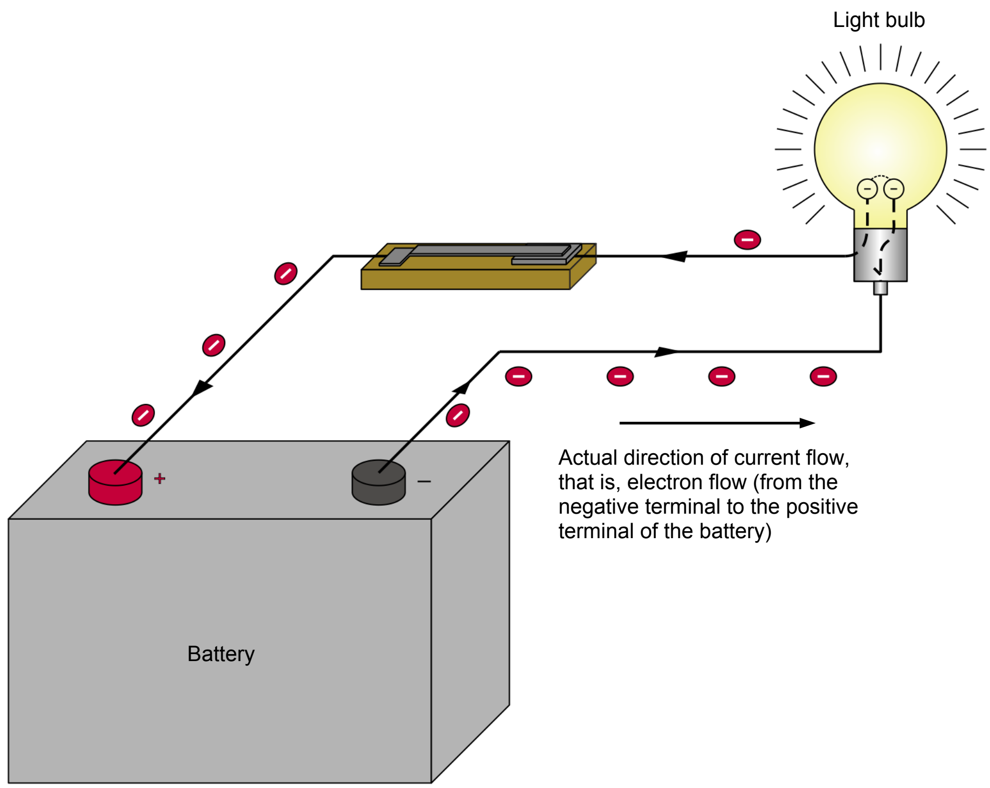
Then, in 1799, Alessandro Volta invented the first **voltaic cell**, which led to the development of modern batteries. Nowadays, batteries are made of several electrochemical galvanic cells. During the charging of a battery, the battery cells store chemical energy, which creates a **voltage (potential difference)** between the positive (+) and negative (–) terminals of the battery.

A simple dc circuit

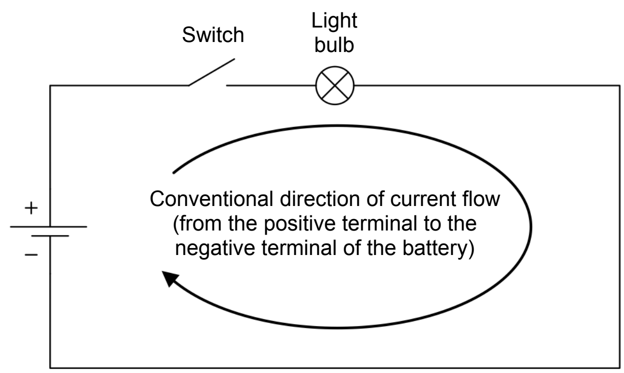
Figure 3 shows a simple dc circuit consisting of a battery, a switch used to start and stop the flow of current in the circuit, conductor wires, and a load (a light bulb). The battery could also be a dc voltage source.

When the switch is closed, the voltage difference between the positive (+) and negative (-) terminals of the battery exerts an electrical pressure that pushes the electrons through the wires, causing the bulb to turn on.

Technically, the direction of current flow, that is, the direction of electron flow, is from the negative terminal to the positive terminal of the battery, as the upper section of Figure 3 shows. When analyzing circuits with schematic diagrams, however, the convention is that the direction of current is from the positive terminal to the negative terminal, as the lower section of Figure 3 shows.



(a) Pictorial diagram



(b) Schematic diagram

Figure 3. Simple electrical dc circuit.

Ohm's law

The relationship between voltage, current, and resistance is called **Ohm's law**. This law is expressed in Equation (1).

$$I = \frac{E}{R} \tag{1}$$

where I is the current flowing through the device, expressed in amperes (A).
E is the voltage, or potential difference across an electric device, in volts (V).
R is the resistance of the electric device, in ohms (Ω).

Ohm's law can be reformulated to permit calculation of the current, voltage, or resistance when the values of the other two variables are known. This is illustrated in Figure 4.

Parameter	Common symbol	Unit of measurement
Current	I	Ampere (A)
Voltage	E	Volt (V)
Resistance	R	Ohm (Ω)

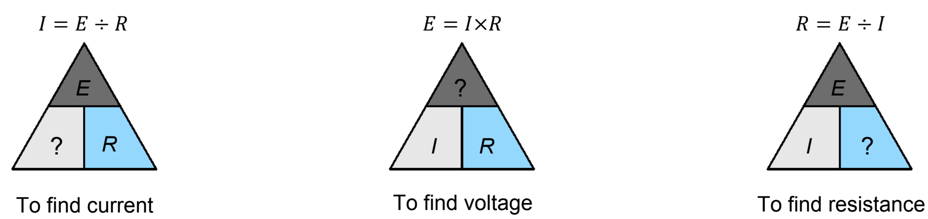


Figure 4. Ohm's law.

The letter "V" can also be used to represent voltage. We can therefore write $I = V/R$, $V = I \times R$, etc.

For example, Ohm's law can be reformulated to find voltage:

$$E = I \times R \tag{2}$$

Equation (2) indicates that the voltage, E, present across an electrical device is equal to the current, I, flowing through the device multiplied by the resistance, R, of the device.

Ohm's law can also be reformulated to find resistance:

$$R = \frac{E}{I} \tag{3}$$

Types of electrical current

The current flow through an electrical circuit may be one of two types: direct current or alternating current.

- **Direct current (dc)** is the type of current produced by batteries and dc sources. This type of current flows in only one direction: from the positive (+) terminal of the battery or power source to the negative (–) terminal (conventional direction).

- **Alternating current (ac)** is the type of current supplied to most houses and factories. This type of current changes direction (polarity) many times each second. Examples of devices that produce ac current are rotating machines such as alternators and ac generators.

Figure 5 shows symbols used to represent dc and ac voltage sources in electrical diagrams. The arrow on a symbol indicates that the source voltage can be varied.

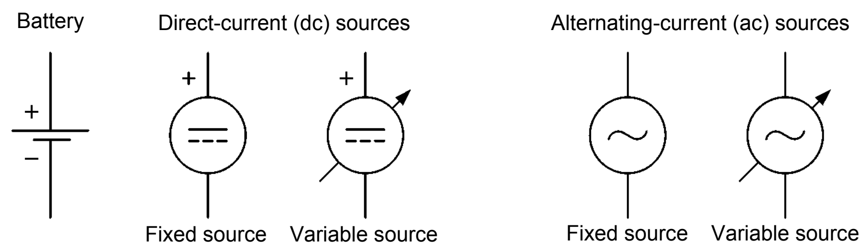


Figure 5. Symbols used to represent dc and ac voltage sources in electrical diagrams.

Measuring resistance, voltage, and current

Resistance is measured with an **ohmmeter**, voltage is measured with a **voltmeter**, and current is measured with an **ammeter**.

The ohmmeter

The ohmmeter is used to measure resistance. The ohmmeter normally contains a voltage source (usually a battery) used to produce a current flow through the component under test. The ohmmeter determines the resistance of the component under test from the magnitude of the current flowing through it.

The ohmmeter is connected across the component of unknown resistance value, as Figure 6 shows. If the component is part of an electrical circuit, **the voltage source must be turned off and the component must be disconnected from the circuit**. This is illustrated in Figure 6.

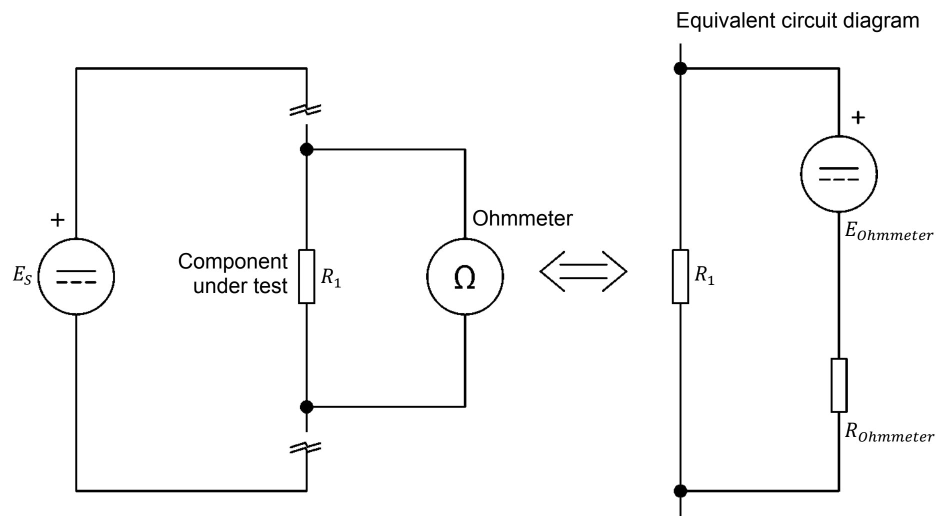


Figure 6. Measuring resistance with an ohmmeter.

Note that a resistor ($R_{Ohmmeter}$) is connected in series with the dc voltage source in the ohmmeter. This resistor prevents too high a current from flowing through the dc voltage source in case the ohmmeter terminals are involuntarily connected together (short-circuited).

The voltmeter

The voltmeter is used to measure voltage. The voltmeter must be connected in parallel with (across) the circuit or component, and the power source must be turned on. As an example, Figure 7 shows a voltmeter connected in parallel with a resistor; the power source is a battery.

Voltmeters have a high internal resistance to minimize the current flow via their terminals. This minimizes their effect on circuit operation.

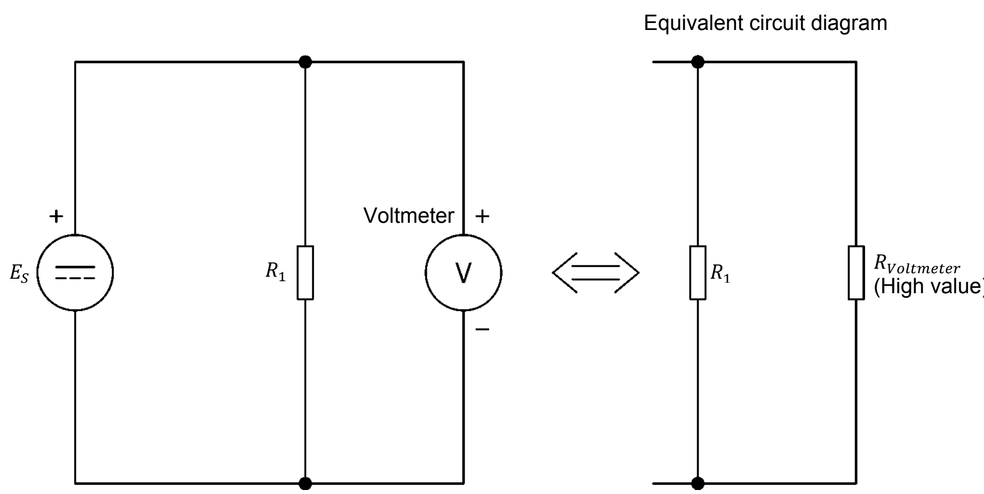


Figure 7. Measuring voltage with a voltmeter.

When used in dc circuits, the voltmeter must be connected according to the conventional direction of current flow for its reading to have the proper polarity. This means that the positive terminal (red probe) of the voltmeter must be connected to the positive side of the component under test, and the negative terminal (black probe) of the voltmeter to the negative side of this component.

The positive side of a component is the side that is nearest to the positive terminal of the power source. The voltage on the positive side of a component is always higher than the voltage on its negative side.

The ammeter

The ammeter is used to measure current. As Figure 8 shows, the ammeter must be connected in series with the components in the circuit. Ammeters have a low internal resistance to minimize the addition of extra resistance to the circuit. As for the voltmeter, polarities must be observed when connecting an ammeter in a dc circuit.

Series means that all the source current will flow through the ammeter and the rest of the circuit when the power source is turned on.

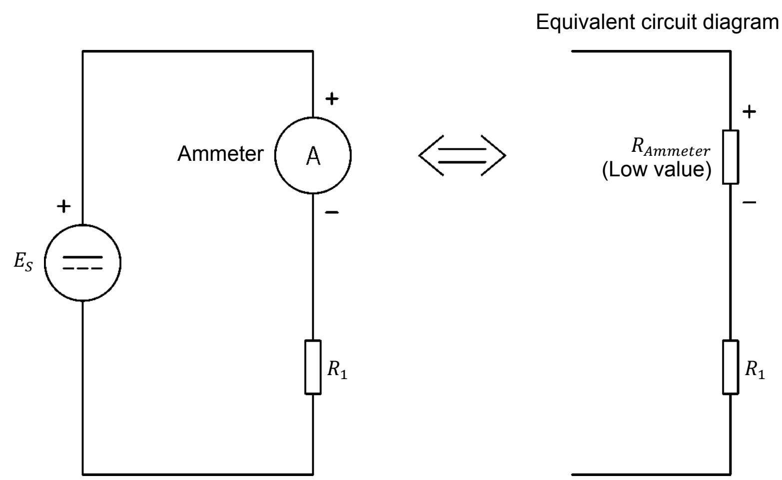


Figure 8. Measuring current with an ammeter.

Multimeters

Multimeters combine an ohmmeter, a voltmeter, and an ammeter in a single enclosure. They allow the measurement of several parameters including dc and ac voltages, dc and ac currents, and resistance.

Figure 9 shows a multimeter set to measure resistance (ohmmeter). The probes of the multimeter are connected to the V/Ω (volt/ohm) terminal and the COMMON (COM) terminal of the multimeter. The selector switch on the multimeter is set to resistance (Ω).

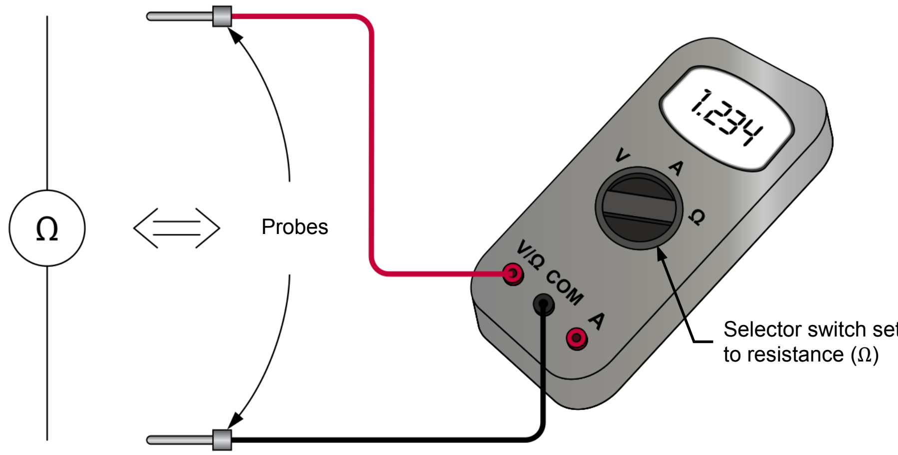


Figure 9. The multimeter is used as an ohmmeter.

Figure 10 shows a multimeter set to measure voltage (voltmeter). The probe (usually red) connected to the V/Ω (volt/ohm) terminal of the multimeter is the positive (+) terminal of the voltmeter. The probe (usually black) connected to the COMMON (COM) terminal of the multimeter is the negative (–) terminal of the voltmeter. The selector switch on the multimeter is set to voltage (E or V).

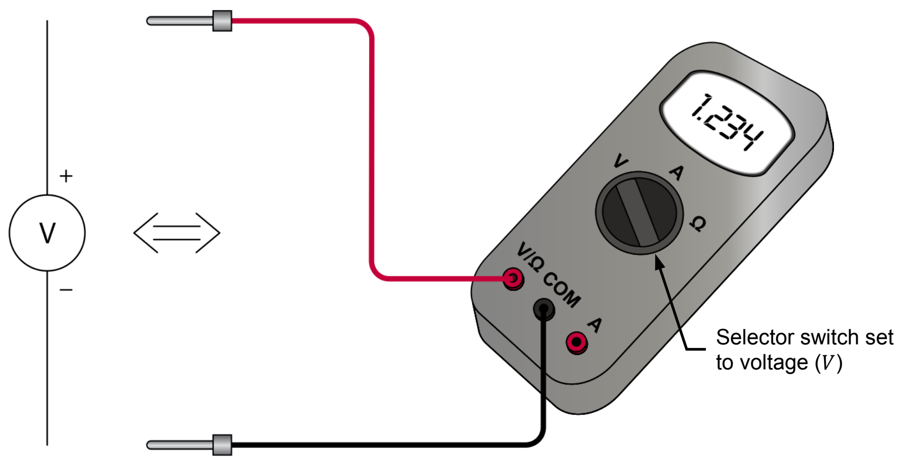


Figure 10. The multimeter is used as a dc voltmeter.

Figure 11 shows a multimeter set to measure current (ammeter). The probe (usually red) connected to the I (current) terminal of the multimeter is the positive (+) terminal of the ammeter. The probe (usually black) connected to the COMMON (COM) terminal of the multimeter is the negative (–) terminal of the ammeter. The selector switch on the multimeter is set to current (I).

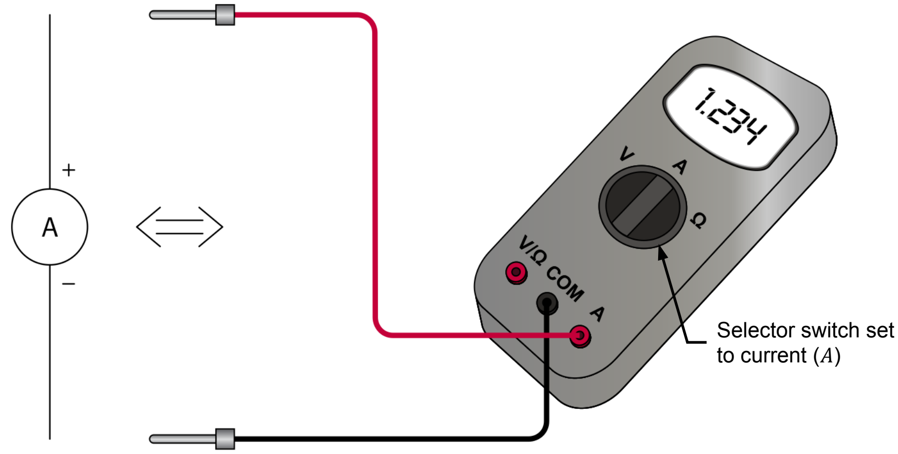


Figure 11. The multimeter is used as a dc ammeter.

The Resistive Load module

Figure 12 shows the Resistive Load module. This module consists of three identical sections. Each section has three resistors of different values which can be connected to electrical circuits through a pair of terminals.

To insert a particular resistor in an electrical circuit, the terminals of the section in which this resistor is located are connected to the circuit, and the toggle switch associated with this resistor is set to the **I** (on) position.

In Figure 12, for example, the toggle switch associated with the resistor at the extreme left of the module front panel is set to the **I** (on) position, while the toggle switches associated with all other resistors are set to the O (off) position. This allows this particular resistor to be inserted in a circuit, using the corresponding section terminals (red terminals).

Several combinations of switch positions are possible, allowing you to place different resistance values in a circuit, as you will see in the next exercise. Appendix C of this manual lists combinations of switch positions required to obtain various resistance values.

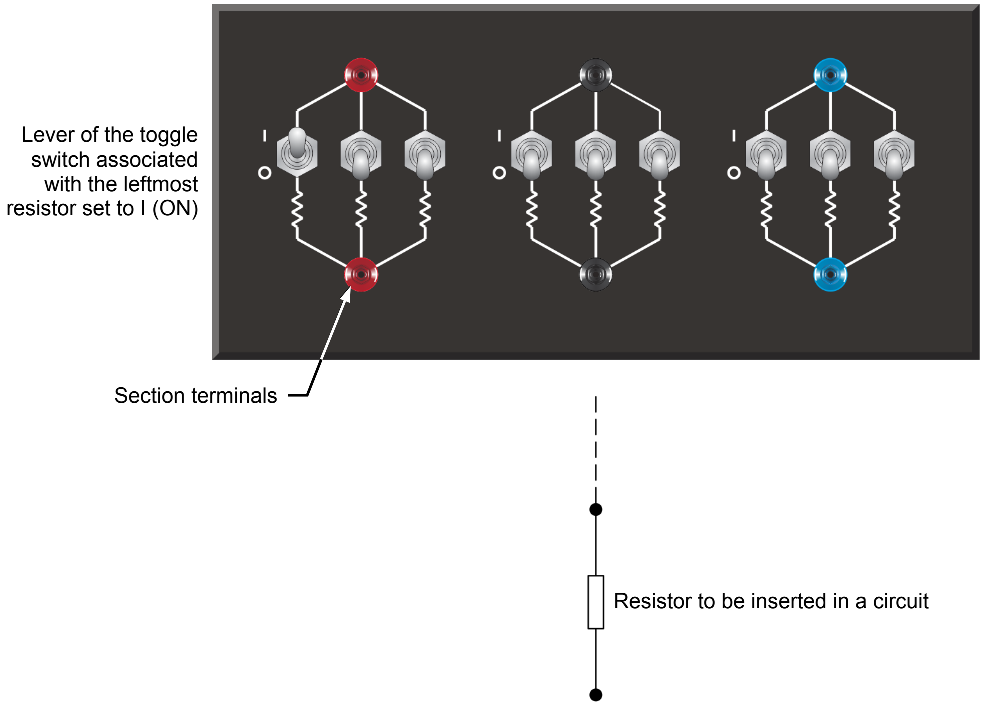


Figure 12. The Resistive Load module.

Safety rules

Observe the following safety rules when using electrical equipment:

1. Always make sure that the electrical power supply is disabled when connecting or disconnecting leads or components.

2. Never leave any electrical lead unconnected. Touching the unconnected end of a lead while the electrical power supply is enabled could give you an electric shock. A short circuit could also occur if the unconnected end of a lead touches a conducting surface.

3. Make sure that the power switch on the electrical power supply is set to the off position before connecting the power supply line cord.

4. When connecting an electrical circuit, make sure that the contact terminals are free of dirt, oil, and water. Dirt and oil are insulators and impair the connection between two components. Water is a conductor and might make a connection where it is not wanted.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Setup and connections
- Plotting the source current as a function of the source voltage on a graph
- Demonstrating Ohm's law by performing voltage, current, and resistance measurements

⚠ WARNING

High voltages are present in this laboratory exercise. Do not make or modify any banana jack connections with the power on unless otherwise specified.

PROCEDURE

Setup and connections

In this section, you will connect a simple electrical circuit. You will set the multimeters to measure dc current (ammeter mode) and dc voltage (voltmeter mode). You will set the switches of the resistive load module to insert a specific resistance value into the circuit.

1. Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required to perform this exercise.

   Install the equipment required in the Workstation.

2. Make sure that the main power switch on the Four-Quadrant Dynamometer/Power Supply is set to the O (off) position then connect the *Power Input* to an ac power wall outlet.

3. Set up the circuit shown in Figure 13. The upper part of the figure shows the electrical diagram of the circuit to connect. The bottom part of the figure shows the detailed circuit connections.

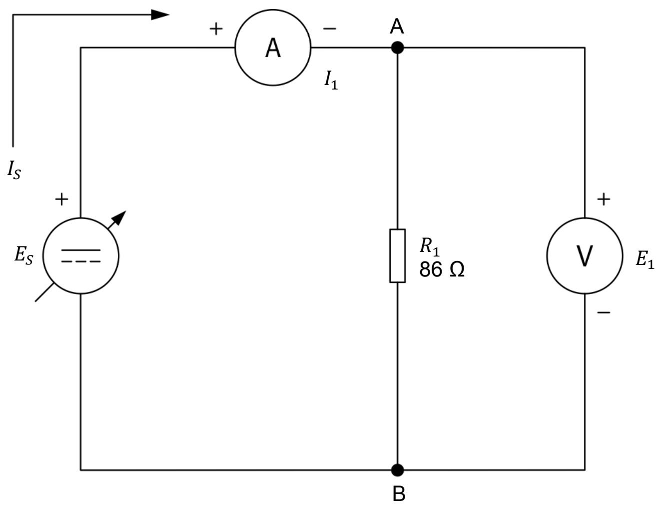
   The Resistive Load module is used to insert a resistor (R_1) in the circuit. To obtain the resistance value indicated next to R_1 in the electrical diagram, make the necessary connections and switch settings on the Resistive Load module. Terminals A and B in Figure 13 correspond to the terminals of the resistor sections of the module that are used to implement R_1.

   – Set multimeter 1 to measure dc current and connect it in series with resistor R_1. Be careful to observe the terminal polarity.

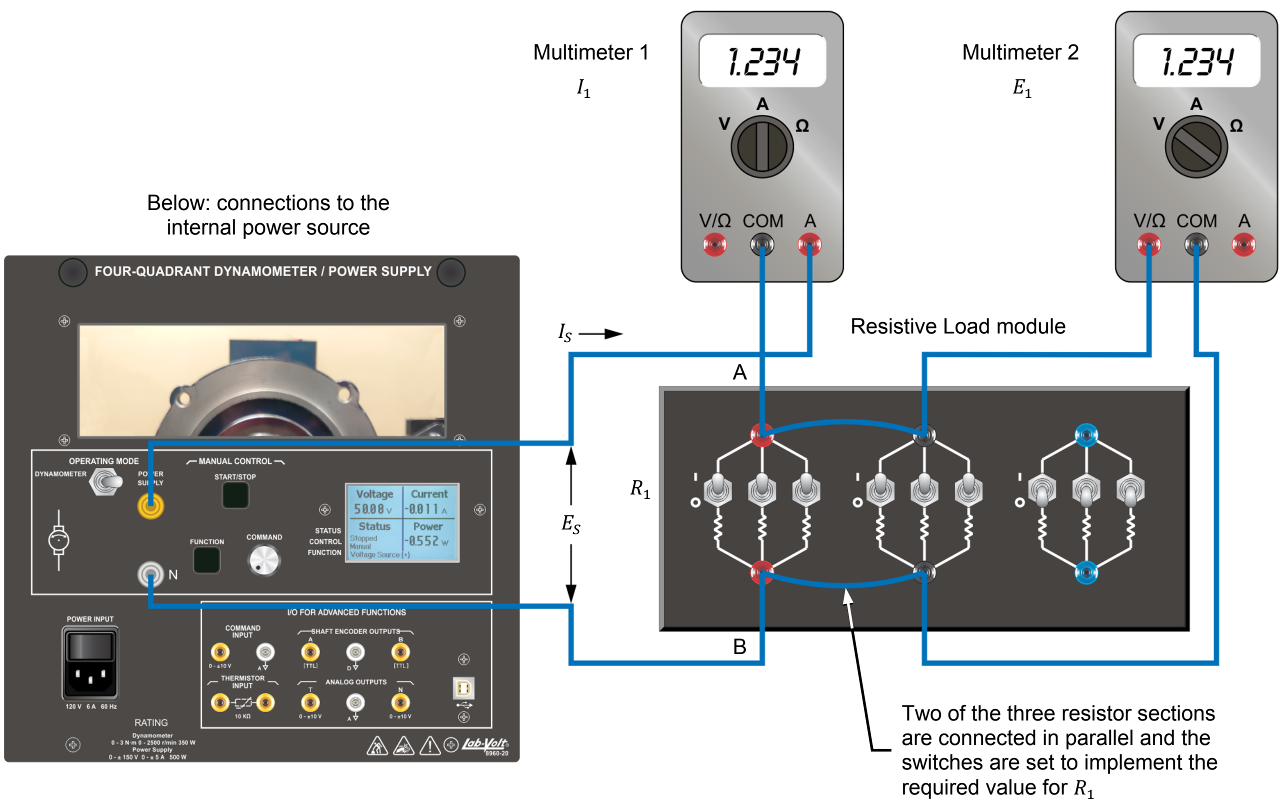
   – Set multimeter 2 to measure dc voltage and connect it across (in parallel with) the resistor. Be careful to observe the terminal polarity.

   Appendix C of this manual lists the switch settings to perform on the Resistive Load module in order to insert various resistance values into the circuit. For example, to insert a resistance value equivalent to 86 Ω into the circuit, two resistor sections of the Resistive Load module must be connected in parallel, and the levers of the toggle switches associated with resistors R_1, R_2, R_3, R_4, R_5, and R_6 in these sections must be set to the I (on) position. The concept of equivalent resistance will be studied in detail in the next exercise.

4. Turn the Four-Quadrant Dynamometer/Power Supply on by setting the *Power Input* switch to the I (on) position.



(a) Electrical diagram



(b) Connection diagram

Figure 13. Setup for voltage and current measurement.

5. Make the following settings on the Four-Quadrant Dynamometer/Power Supply:

– Set the *Operating Mode* switch to *Power Supply*. This connects the internal power source of the module to the *Power Supply* terminals on the front panel.

– Select the *Voltage Source (+)* mode of operation of the power source using the *Function* push button. The mode of operation selected is indicated on the module display. Selecting this mode makes the internal power source operate as a positive voltage source. When the Four-Quadrant Dynamometer/Power Supply operates as a positive voltage source, the voltage at the yellow terminal is positive with respect to the voltage at the white terminal (neutral terminal N).

– Set the voltage of the positive voltage source to 50.0 V by using the *Command* knob. This voltage is indicated on the module display. Notice that the displayed voltage is blinking. This occurs because the output of the internal power source is disabled. The output of the internal power source can be enabled by depressing the *Start/Stop* push button. This will be done in the next section of the Procedure.

Plotting the source current as a function of the source voltage on a graph

In this section, you will increase the voltage of the positive voltage source by steps. For each new setting, you will record the voltage indicated by the voltmeter and the current indicated by the ammeter. This will allow you to plot the source current as a function of the source voltage on a graph.

6. On the Four-Quadrant Dynamometer/Power Supply, enable the output of the internal power source by depressing the *Start/Stop* push button. The display indicates *Started*, thereby confirming that the internal power source is on.

7. Observe that the voltage indicated by the voltmeter (E_1) is virtually the same as the source voltage indicated on the display of the Four-Quadrant Dynamometer/Power Supply.

Also, observe that the current indicated by the ammeter (I_1) is virtually the same as the source current (I_S) indicated on the display of the Four-Quadrant Dynamometer/Power Supply. Is this your observation?

❑ Yes ❑ No

Yes. The voltage and the current indicated on the voltmeter and the ammeter are virtually the same as those indicated on the display of the Four-Quadrant Dynamometer/Power Supply.

8. Set the source voltage to 0 V by setting the *Command* knob of the source to the fully counterclockwise position.

9. Fill in Table 1. To do this, increase the voltage of the positive voltage source by steps from 0 to 50 V. Seven or eight steps will be enough. For each setting, record the source voltage and the source current in the table.

Table 1. Measured voltages and currents.

Voltage E_S (V)	Current I_S (A)
0	0
50	

Measured voltages and currents.

Voltage E_S (V)	Current I_S (A)
0	0.00
7	0.08
14	0.16
21	0.24
28	0.33
35	0.41
42	0.49
50	0.58

10. From the results recorded in Table 1, plot in Figure 14 the source current, I_S, as a function of the source voltage, E_S.

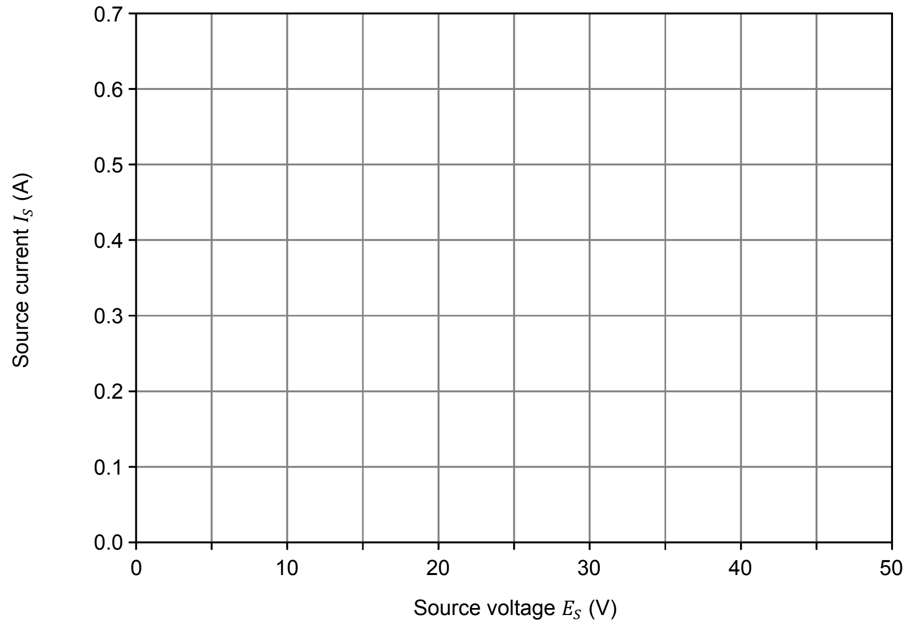
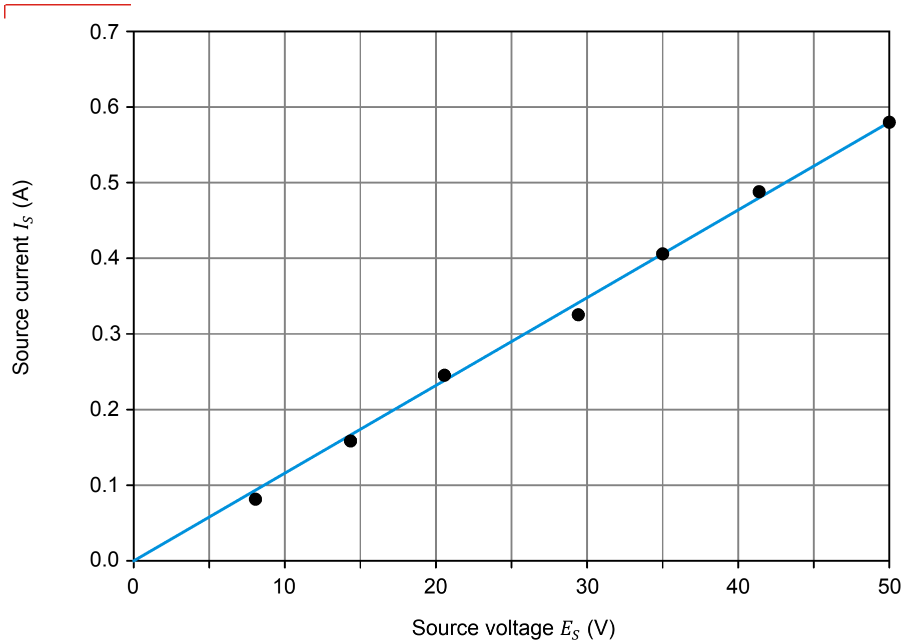


Figure 14. Source current I_S as a function of the source voltage E_S.



Source current I_S as a function of the source voltage E_S.

According to the obtained curve, does the source current vary linearly in direct proportion to the source voltage (the current doubles, triples, etc. when the voltage doubles, triples)?

❑ Yes ❑ No

Yes. The source current I_S varies linearly in direct proportion to the source voltage E_S (the current doubles, triples, etc. when the voltage doubles, triples).

11. Calculate the ratio E_S / I_S for several voltage/current values. Is the ratio approximately equal to the resistance R_1 of the resistor used in the circuit?

Yes. The ratio E_S / I_S is approximately equal to the value of the resistor used in the circuit (86 Ω).

12. Calculate the ratio E_S / R_1 for a source voltage E_S of 50 V. Is this ratio equal to the current I_S recorded in Table 1 for this voltage?

$$\frac{E_S}{R_1} = I_S = \_\_\_\_\_\_\_ \text{ A}$$

❑ Yes ❑ No

$$I_S = \frac{50\text{ V}}{86\ \Omega} = 0.581\text{ A}$$

Yes. The ratio E_S / R_1 is approximately equal to the current I_S recorded in the table for a voltage of 50 V.

Demonstrating Ohm's law by performing voltage, current, and resistance measurements

In this section, you will demonstrate Ohm's law, through the measurement of the circuit voltage, current, and resistance.

13. On the Resistive Load module, modify the position of the switches for the value of R_1 to be 100 Ω. (Refer to Appendix C to find the switch setting to perform on the Resistive Load module).

Then, readjust the voltage of the positive voltage source until the source current I_S is equal to 0.4 A. Record the source voltage E_S below.

$$E_S = \_\_\_\_\_\_\_ \text{V}$$

The source voltage E_S should be approximately equal to 40 V.

Is the source voltage E_S equal to the product $I_S \cdot R_1$?

❑ Yes ❑ No

Yes. 40 V = 0.4 A · 100 Ω

14. Adjust the source voltage E_S to 30 V.

15. Calculate the equivalent resistance $R_{Eq.}$ required to allow a current I_S of 0.25 A to flow in the circuit, with a source voltage E_S of 30 V.

$$R_{Eq.} = \frac{E_S}{I_S} = \_\_\_\_\_\_\_ \Omega$$

$$R_{Eq.} = \frac{30\ \text{V}}{0.25\ \text{A}} = 120\ \Omega$$

16. On the Resistive Load module, modify the position of the switches for the value of the circuit resistance to allow a current I_S equal to 0.25 A approximately.

17. Turn off the Four-Quadrant Dynamometer/Power Supply by setting the *Power Input* switch to the O (off) position.

Measure the equivalent resistance used to allow a current I_S of 0.25 A in the previous step, using the steps below.

CAUTION

When measuring the resistance of a component, make sure that the voltage source is turned off and that the component is disconnected from the circuit to prevent damage to the ohmmeter.

- Disconnect the circuit except the leads interconnecting the resistor sections that you used on the resistive load module. Take care not to change the position of the toggle switch levers on this module. Return the other leads to their storage location.
- Set a multimeter to measure resistance (ohmmeter mode).
- Connect the ohmmeter to the terminals of one of the resistor sections that you used on the resistive load module in order to measure its equivalent resistance. Record the ohmmeter reading below.

$R_{Eq.} = \_\_\_\_\_\_\_\ \Omega$

$R_{Eq.} = 120\ \Omega$

Is the measured resistance approximately equal to the equivalent resistance you calculated in step 15?

❑ Yes ❑ No

Yes, the measured resistance is approximately equal to the equivalent resistance calculated above.

18. Remove all circuit connections. The, return all equipment to its storage location.

CONCLUSION

In this exercise, you performed voltage, current, and resistance measurements to demonstrate Ohm's law. You verified that Ohm's law permits calculation of the circuit current, voltage, or resistance when the values of any two of these three variables are known.

REVIEW QUESTIONS

1. Will a voltmeter having an internal resistance of 100 000 Ω have less effect on circuit operation than a voltmeter having an internal resistance of 1 000 000 Ω? Why?

No. The higher the internal resistance of a voltmeter, the lower its effect on circuit operation. Therefore, the risk that a voltmeter of 100 000 Ω will affect circuit operation is higher than with a voltmeter of 1 000 000 Ω.

2. An ammeter has an internal resistance equal to the equivalent resistance of the circuit in which the current must be measured. What will happen to the circuit current when the ammeter is inserted into the circuit? Explain.

The circuit current will decrease by half. This occurs because the ammeter is connected in series with the circuit. With an internal resistor equal to the equivalent resistance of the circuit, the ammeter will increase the circuit resistance by two, thereby decreasing the circuit current by half.

3. What does "potential difference" (voltage) mean when speaking of a battery or dc power source? How is this potential difference (voltage) used in electrical circuits?

Potential difference (voltage) is a difference in voltage between the positive (+) and negative (-) terminals of a battery or dc power source. When the battery or dc power source is connected to an electrical circuit, this potential difference (voltage) creates an electrical pressure that pushes electrons through the circuit components and make the current flow.

4. What is the resistance of a circuit in which a dc current of 0.25 A flows when a dc voltage of 50 V is applied to the circuit?

The resistance of the circuit is calculated below:

$$R = \frac{E}{I} = \frac{50\ \text{V}}{0.25\ \text{A}} = 200\ \Omega$$

5. What is the dc voltage required across a resistor of 15 Ω to make a dc current of 3 A flow through it?

The dc voltage required across the resistor is calculated below:

$$E = IR = 3\ \text{A} \cdot 15\ \Omega = 45\ \text{V}$$

Bibliography

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